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CPS-Referred Mothers' Psychophysiological Responses to Own versus Other Child Predict Sensitivity to Child Distress

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Abstract

Maltreating mothers often struggle to respond sensitively to their children's distress. Examining psychophysiological processing of own child cues may offer insight into neurobiological mechanisms that promote sensitive parenting among high-risk mothers. The current study used event-related potential (ERP) methodology to examine associations between mothers' neural responses to their own child versus other children and observed sensitivity to distress. Participants included 73 mothers: 42 with histories of child protective services (CPS) involvement and 31 low-risk comparison mothers. Maternal sensitivity to child distress was coded from observations of children's blood sample collection. Late positive potential (LPP) ERP responses, which reflect sustained attention to emotionally salient stimuli, were measured when mothers viewed photos of their own child and other children. An own-other LPP difference score (own-other LPP) was computed by regressing the mean amplitude of mothers' LPP to their own child on the mean amplitude of mothers' LPP to other children. CPS-referred mothers and low-risk mothers did not differ in their LPP responses to own child, other children, or the own-other LPP. However, there was a significant interaction between group (CPS-referred vs. low-risk) and own-other LPP in predicting maternal sensitivity. Among the CPS-referred mothers, own-other LPP was significantly correlated with maternal sensitivity, with greater LPP amplitude to own versus other child associated with higher maternal sensitivity. In contrast, among the low-risk group, own-other LPP was not significantly correlated with maternal sensitivity. Findings add to our understanding of the neurobiology of sensitive parenting among high-risk mothers.

Keywords

Event-related potentials; maternal sensitivity; maltreatment

Parenting requires the coordination of multiple processes related to attention, perception, reward, and executive function, with deficits in these processes or their integration posing threats to the provision of optimal care. A growing body of research has sought to characterize the neural correlates of parenting behavior (e.g., Belsky & de Haan, 2011; Bernard, Simons, & Dozier, 2015; Swain, Lorberbaum, Kose, & Strathearn, 2007). Of particular interest are the ways in which differences in brain structure and activity are

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associated with differences in parenting behavior, such as parental sensitivity. Sensitive parenting is characterized by parents' capacities to accurately read and respond to children's cues, interact synchronously with their children, and show delight and warmth in response to their children's behavior (Ainsworth, 1967, 1978; de Wolff & van IJzendoorn, 1997). Insensitive parenting, by contrast, may involve intrusive, harsh, and withdrawn behaviors, and ineffective or delayed responses to children's distress or bids for attention (de Wolff & van IJzendoorn, 1997; Pechtel, Murray, Brumariu, & Lyons-Ruth, 2013). Deficits in sensitive parenting contribute to a number of developmental issues, including disorganized attachment, externalizing behavior, socio-emotional deficits, and physiological dysregulation (Blair et al., 2015; Fearon, Bakermans-Kranenburg, van IJzendoorn, Lapsley, & Roisman, 2010; Sulik et al., 2015; Verhage et al., 2016). Maltreated children are especially at risk for problematic outcomes, with lack of sensitive care likely being a primary contributing factor (Cicchetti & Toth, 2005). Thus, parents who have been reported to child protective services (CPS) for concerns about child maltreatment represent an enriched risk population for examining the neural correlates and developmental consequences of insensitive parenting. Understanding how differences in parental brain activity are associated with insensitive parenting has the potential to illuminate avenues for detection, prevention, and intervention among parents at risk for insensitive parenting.

Functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) studies examining the neurobiology of parenting have yielded consistent information about the brain structure and function typically characterizing parenting. A number of fMRI studies have demonstrated that certain brain areas may be preferentially activated when parents view photos or listen to audio recordings of their own child versus an unfamiliar child. These regions include the orbitofrontal cortex (OFC), prefrontal cortex, substantia nigra, left nucleus accumbens, and thalamus (Atzil, Hendler, & Feldman, 2011; Noriuchi, Kikuchi, & Senoo, 2008; Parsons, Stark, Young, Stein, & Kringelbach, 2013), all of which likely contribute to recognizing, orienting, and responding to child cues, organizing interactions, and perceiving child attributes and interactions as rewarding. Furthermore, longitudinal human imaging research has demonstrated that, during the first few weeks of their infants' lives, mothers may experience increased gray matter volume in areas associated with sensorimotor perception, reward, and motivation, such as the hypothalamus, substantia nigra, and amygdala (Kim et al., 2010). It is likely that both hormonal changes secondary to pregnancy and childbirth as well as parenting experiences during the early postpartum period have an enriching organizational effect on brain areas that support attention, reward sensitivity, and perception. Underscoring the role these neural regions and associated cognitions play in supporting adequate caregiving, animal models have linked insensitive caregiving behavior to altered brain functioning in the mesolimbic dopamine system, medial prefrontal cortex, and thalamus, parietal cortex, and brainstem, which are known to affect reward sensitivity, executive functioning, and somatosensory information processing, respectively (Afonso, Sison, Lovic, & Fleming, 2007; Numan & Insel, 2003; Xerri, Stern, & Merzenich, 1994).

Similarly, in the event-related potentials (ERP) literature, the P300 (a positive deflection occurring approximately 300 ms after the stimulus) and late positive potential (LPP; a prolonged positivity extending from approximately 300 ms to 1000 ms after a stimulus),

both thought to reflect attentional to and evaluation of emotionally salient stimuli are larger and have a faster onset when parents view their own children's faces than when viewing unfamiliar children's faces (Doi & Shinohara, 2012; Grasso, Moser, Dozier, & Simons, 2009; Weisman, Feldman, & Goldstein, 2012). The LPP in particular is thought to be sensitive to the biological and motivational relevance of the stimulus (Hajcak, Jackson, Ferri, & Weinberg, 2016) and may therefore have particular relevance to the study of parent-child neurobiology.

Research also suggests that experiences prior to having children may affect cognitive processes implicated in sensitive caregiving. For example, individuals who experienced early adversity or mental illness prior to having children demonstrate impaired reward sensitivity and executive functioning (Bos, Fox, Zeanah, & Nelson Iii, 2009; Nusslock & Miller, 2015), and are also more likely to engage in insensitive parenting (Berlin, Appleyard, & Dodge, 2011; Lovejoy, Graczyk, O'Hare, & Neuman, 2000) than parents who did not experience adversity or mental illness. Furthermore, fMRI research has demonstrated that mothers who struggle with substance abuse and mothers with PTSD show altered neural activity in response to infant faces, cries, and separation (Landi et al., 2011; Schechter et al., 2012). Taken together, the extant body of research on parenting neurobiology suggests that a core set of cognitive processes and related brain areas recruiting reward, attention, executive function, and sensory perception may have evolved to support effective parenting and enhance infant survival, and that these processes may be disrupted by illness or poverty. Attenuation in indices of reward, sensorimotor perception, and attention in response to own-child stimuli may then represent disruption or dysfunction of evolutionarily advantageous circuitry.

Much of the parental brain research to date, however, has focused on identifying patterns of parental brain activity typical in low-risk, healthy samples. Mothers who are reported to child protective services (CPS) represent a high-risk sample, with elevated sociodemographic risk (e.g., poverty, low education) (Jonson-Reid, Drake, & Zhou, 2013), increased likelihood of having experienced childhood maltreatment themselves (Bartlett, Kotake, Fauth, & Easterbrooks, 2017), and psychopathology (Kohl, Kagotho, & Dixon, 2011; Shanahan, Runyan, Martin, & Kotch, 2017), relative to comparison mothers. Research drawing from high-risk populations, such as CPS-referred mothers, is needed to substantiate theories about underlying mechanisms or risk factors that may account for differences in brain activity between sensitive and insensitive parents.

The Current Study

The current study sought to investigate differences in brain activity in mothers with histories of referral to CPS and a low-risk comparison group with no CPS involvement. Specifically, we examined (1) whether CPS-referred mothers and low-risk mothers differed in their ERP responses, specifically the LPP, when they viewed pictures of their own child versus unfamiliar children; (2) to what extent LPP responses to own versus unfamiliar child was associated with variability in maternal sensitivity to child distress; and (3) whether the association between brain activity and observed maternal sensitivity varied between CPS-referred and low-risk mothers.

Method

Participants

Eighty-six mothers were recruited for the present study: 52 mothers with histories of referral to CPS and 34 mothers recruited from the community without histories of CPS involvement. To the extent possible, low-risk comparison mothers were recruited to be of comparable race and have children of similar age to the CPS-referred sample. Descriptive statistics for demographic data for each group are presented in Table 1 and group differences in demographic and risk variables are reported below. Twelve participants were excluded due to unusable ERP data and one because parental sensitivity could not be coded (due to refusal to participate in distress task), leaving a final sample of 73 participants (CPS-referred: $n = 42$, Low-risk comparison: $n = 31$). This study was approved by the Institutional Review Board at the University of Delaware, Protocol 143902, titled “Specialized Services for Birth Parents.”

Procedure

Participant recruitment—In collaboration with a city-level program intended to divert children from placement into foster care, CPS-referred mothers were invited to participate in an ongoing longitudinal study examining the effectiveness of a parenting intervention for infants. All CPS-referred mothers had been involved with CPS, but no additional information about the specific nature of the allegations was available to researchers. Following consent and baseline visits, CPS-referred mothers and their infants were randomly assigned to participate in one of two 10-session parenting interventions: Attachment and Biobehavioral Catch-up (ABC; (Dozier, Bick, & Bernard, 2011), which aimed to enhance maternal sensitivity, or Developmental Education for Families (DEF), which targeted children’s language and motor development. As part of the longitudinal study, dyads continued to participate in annual follow-up visits after the interventions. CPS-referred mothers were recruited for the current study over the phone when children were between 4 – 6 years old, on average 3.61 years ($SD = 0.73$) following participation in one of the interventions. The targeted sample size for each group was 25 participants. Power analyses indicated that 25 participants in each group (CPS-referred/ABC, CPS-referred/DEF, low-risk) would afford at least 80% power to detect a significant within-subject effect of stimulus condition, based on effect size estimates previously obtained in our laboratory for a similar ERP task and participant sample (e.g, Bick et al., 2013); further, for a linear multiple regression testing moderation (including three predictors [main effect of risk group, main effect of LPP response, and an interaction term] and two covariates), 80% power to detect a medium effect and a large effect was estimated to require 77 and 36 participants, respectively. Given that intervention effectiveness was not the focus of the current study, we collapsed ABC mothers ($n = 25$) and DEF mothers ($n = 27$) into the CPS-referred group ($n = 52$) after examining potential intervention effects on variables of interest. Low-risk comparison mothers were recruited from community day-care centers, local mom’s groups, announcements on a university website, and previous studies.

Home and laboratory visits—Parents were consented to the current study during a home visit, during which they also completed questionnaires about demographic and risk

information. The full home visit was video-recorded, with the camera placed in a location that captured both mother and child, who remained in proximity to one another. During the visit (as part of another study), the researcher collected blood spot samples from the child by pricking his or her finger with a pressure-activated lancet, which served as the context for coding maternal sensitivity. For this procedure, the researcher described the finger prick verbally to the mother and child as she set up the materials (e.g., pressure-activated lancet, blood spot collection paper, gauze, Band-Aids). After cleaning the child's finger with an alcohol pad, the researcher pricked the child's finger with a pressure-activated lancet, waited for blood to form a drop, and then held the child's finger to place five drops of blood on the collection paper. After obtaining the samples, the researcher pressed gauze on the child's finger, then placed a Band-Aid around the child's finger. Once the child was settled (if the child showed distress) and after the researcher cleaned up the materials, children were allowed to select from among a set of prizes. The full finger prick procedure from set-up to clean-up lasted 5 to 10 minutes, during which time mothers were free to talk to and interact with their child, reposition themselves or their child (e.g., moving child to lap), and physically respond to the child however they wished. Mothers received no instructions on how to respond to their child during the finger prick procedure.

During a laboratory visit, parents' EEG activity was recorded while viewing pictures of their own versus other children. Upon entering the laboratory, research staff briefly explained the procedure, positioned the electrode cap on the mother's head, and prepared electrode sites using conductive paste to minimize impedance.

Measures

LPP responses to own versus other children—ERP data were recorded from a 32-channel Ag/AgCl electrode cap with placement of electrodes following the International 10-20 System. Continuous EEG was recorded using Advanced Neuro Technology Acquisition Hardware (ANT; Enschede, The Netherlands) and digitized at a rate of 512 samples per second. Tasks were programmed and administered using Presentation software (Neurobehavioral Systems Inc).

Procedures for the ERP task followed those used previously (Bick, Dozier, Bernard, Grasso, & Simons, 2013). Stimuli included three types of images: own child, familiarized child, and unfamiliar child. A photograph was taken of the mother's child during the home visit. The majority of the children were smiling in photographs, although some had neutral expressions. Photographs were modified using Adobe Photoshop to crop images to show a close-up of the child's face, insert a black background, remove color, and standardize the image size. Stimuli for the familiarized and unfamiliar children's faces were selected from a battery of images by matching on children's gender, race, age, and expression (i.e., smiling or neutral). Prior to completing the task, mothers became familiarized with the image of the child selected as the "familiarized" stimulus by viewing the image repeatedly and answering questions about the child's facial features. Following familiarization training, all mothers correctly identified the child's face to which they were familiarized. For the test trials, mothers passively viewed the picture of their own children, the familiarized child, and an unfamiliar child. Each of the three pictures was presented 25 times in a random order, for a

total of 75 trials. Stimuli were displayed for 2000 ms in the center of the computer screen with an intertrial interval of 1500 ms. Mothers also completed other ERP tasks, the order of which was counterbalanced, which are not reported on in the current study.

ERP data were processed using Advanced Source Analysis (ASA) software. The EEG was bandpass filtered between .1 and 30 Hz. Artifact correction was performed for eye blinks and EEG data with peak-to-peak amplitude exceeding $\pm 75 \mu\text{V}$ were rejected. EEG data were re-referenced to the average mastoid, and average waveforms were calculated from 200 ms before to 1000 ms after the stimulus presentation for each stimulus type. LPP responses for each mother were measured with reference to her average baseline voltage during the 200 ms prior to stimulus presentation, by first subtracting the average baseline activity from the entire average. The LPP for each stimulus type was measured as the average amplitude at the Pz electrode from 300 to 650 ms post-stimulus (Bick et al., 2013).

For regression analyses, an own-other LPP residualized difference score was calculated by regressing the mean amplitude of mothers' LPP to their own child on the mean amplitude of mothers' LPP to other children (i.e., an average of LPP to familiarized and unfamiliar child stimuli). More positive own-other LPP scores reflected larger responses to own child than other child, relative to less positive scores.

Maternal sensitivity—Maternal sensitivity to distress was coded from video-recordings of maternal behavior during the finger prick blood collection. Ratings for maternal sensitivity to distress were made on a scale of 1 to 5 using the Qualitative Ratings of Mother-Child Interaction prepared for the NICHD Study of Early Child Care and based on the Qualitative Scales of the Observational Ratings of the Caregiving Environment (ORCE; NICHD Early Child Care Research Network, 1999, 2003). Videos were coded from when the researcher began setting up for the blood collection and until the child selected a prize (which was always offered after the child was no longer visibly distressed). Coders considered the proportion of distress signals responded to, the latency of response, and the appropriateness of response. Low ratings were made for mothers who were very insensitive (e.g., punitive, intrusive/distracting, dismissing) or unresponsive (e.g., ignoring distress). High ratings were made for mothers who responded quickly and appropriately to the child's distress (e.g., rubbing back, offering verbal comfort, acknowledging child's feelings). Moderate ratings were made when mothers showed a mix of sensitivity to distress, at times providing appropriate and timely responses and at other times failing to do so. Sensitivity to distress scores ranged from 1.0 to 5.0 ($M = 3.13$, $SD = 1.29$). All videos were double-coded with averaged scores used in analyses; inter-rater reliability was good, $ICC = 0.83$, $p < .001$. All coders were blinded to group (i.e. ABC, DEF, or low-risk comparison).

Additionally, child distress was rated on a 1 to 3 scale, with 1 indicating no distress (e.g., child sat expressionless, laughed, or talked in matter-of-fact manner), 2 indicating minimal/some distress (e.g., child flinched, said "ow," fussed slightly, or acted nervous when preparing for the procedure), and 3 indicating clear distress (e.g., overt negative affect, prolonged indication of physical discomfort, verbal expressions of concern, crying). Distress scores ranged from 1 to 3 ($M = 2.12$, $SD = 0.81$), with 79% of children showing some or clear distress. Inter-rater reliability for distress scores was also good, $ICC = 0.90$, $p < .001$.

Even when children did not show distress, mothers could still receive high scores on sensitivity (e.g., by reassuring the child before the procedure, maintaining physical proximity, asking the child if they are okay).

Risk factors—Demographic data were collected using a questionnaire, including mother characteristics (i.e., age, race, income, marital status, education, number of children) and child characteristics (i.e., age, race). Maternal depression was assessed using the depression subscale of the Brief Symptoms Inventory (BSI; Derogatis & Spencer, 1982), which demonstrated good internal consistency ($\alpha = 0.91$). We computed a cumulative sociodemographic risk score, following recommendations of previous studies (e.g., Appleyard, Egeland, van Dulmen, & Sroufe, 2005; Sameroff, Seifer, Zax, & Barocas, 1987). Specifically, the following risk indicators were coded dichotomously and totaled to form a composite risk score ranging from 0 to 6: low income (income-to-needs ratio < 1), ethnic/racial minority group, single parenthood, adolescent mother (at the time of child's birth), low education (less than high school), and elevated maternal depression (t-score > 65). Composite risk scores ranged from 0 to 5 ($M = 2.60$, $SD = 1.50$).

Results

Preliminary Analyses

Group comparisons on demographic and risk variables—Demographic information and descriptive statistics for each group are presented in Table 1. CPS-referred and low-risk mothers differed significantly in the total number of risk factors, $t(71) = -4.59$, $p < .001$, with CPS-referred mothers having on average 1.44 more risk factors than low-risk mothers. Taken apart, mothers in the CPS-referred sample were more likely to be low-income and have less than a high-school education than mothers in the low-risk sample. The groups did not differ on maternal or child age, or dichotomized risk factors including likelihood of being depressed, minority status, single parenthood, or being an adolescent mother. Groups did not differ on child distress during finger prick. CPS-referred mothers who received the ABC intervention did not differ from CPS-referred mothers who received the control/DEF intervention in maternal sensitivity or LPP responses. Composite risk and participation in the ABC intervention were included as covariates in primary analyses. Bivariate correlations for the full sample, CPS-referred group, and low-risk group are presented in Table 2.

Preliminary ERP data—Prior to analyses, the quality of ERP data for each participant was examined. Participants were excluded if they had fewer than 50% usable trials in any of the conditions (due to excessive artifacts). Twelve participants were excluded due to fewer than 50% usable trials during any condition of the task (< 12 trials), including 9 CPS-referred mothers (17.3%) and 2 low-risk mothers (5.9%); one CPS-referred mother was excluded due to researcher error resulting in the file not being recorded. Thus, final analyses included 73 participants. Of a potential of 75 trials (25 trials each for own, unfamiliar, and familiarized infant photos) participants had means of 21.57 ($SD = 3.21$), 21.88 ($SD = 2.49$), and 21.50 ($SD = 2.95$) trials for own, unfamiliar, and familiarized faces respectively,

included in analyses. Descriptive statistics of LPP responses for CPS-referred and low-risk mothers are presented in Table 1.

Primary analyses—First, we examined whether CPS-referred and low-risk mothers differed in their LPP responses to own versus other child using a 2 X 2 mixed model ANOVA, with child type (own vs. other [average of familiarized and unfamiliar]) as the within-subjects factor, group (CPS-referred vs. low-risk) as the between-subjects factor, and LPP amplitude as the dependent variable. There was a significant main effect of child type on LPP amplitude, $F(1,71) = 43.91, p < .001$, with mothers showing a greater LPP amplitude to own than to other child. There was no main effect of group and no group X child type interaction, suggesting that CPS-referred and low-risk mothers showed similar LPP responses to own and other child faces (See Figure 1a).

Next, we conducted moderation analyses in order to examine whether the association between brain activity and observed maternal sensitivity varied between CPS-referred and low-risk mothers. Analyses were conducted using Model 1 of the PROCESS macro for SPSS (Hayes, 2013). Own-other LPP was entered as a predictor of maternal sensitivity and group (i.e., low-risk versus CPS-referred) as a moderator, and composite risk and ABC intervention participation were included as covariates. The full model accounted for 25% of the variance in maternal sensitivity (See Table 3). The interaction between group and own-other LPP significantly predicted maternal sensitivity, suggesting that the association between own-other LPP and maternal sensitivity varied by group. An analysis of the conditional effects of own-other LPP on sensitivity for each group showed that, among the low-risk mothers, there was no association between own-other LPP and maternal sensitivity. Among CPS-referred mothers, in contrast, there was a significant association between own-other LPP and maternal sensitivity, with a larger own-other LPP (reflecting a greater response to own child than other child) associated with higher maternal sensitivity. Figure 1 displays the grand-average waveforms for each group, as well as scatterplots showing the bivariate associations between own-other LPP and maternal sensitivity.

Discussion

Findings of the current study demonstrated that, among CPS-referred mothers, greater LPP amplitude when viewing a photograph of one's own child versus another child predicted greater maternal sensitivity to child distress. Among low-risk mothers, the association between own-other LPP and maternal sensitivity was non-significant. These findings contribute to the broader literature on the neural correlates of sensitive parenting, adding especially to our understanding of biological risk factors of insensitivity in high-risk mothers.

Given that the LPP reflects sustained motivated attention toward emotional, biologically relevant stimuli (Hajcak, MacNamara, Foti, Ferri, & Keil, 2013), it may not be surprising that CPS-referred mothers and low-risk mothers did not differ in their own-other LPP. Across mothers, LPP response to own child was significantly larger than LPP response to other children, suggesting that one's own child may be a universally salient stimulus that captures and sustains attention.

Although the magnitude of the difference between own-other LPP did not differ between CPS-referred and low-risk mothers, the association between own-other LPP and maternal sensitivity differed by group. Specifically, own-other LPP predicted maternal sensitivity for CPS-referred mothers, but not for low-risk mothers. For CPS-referred mothers, who may experience heightened stress, lack social support, and have poor emotion regulation, a large LPP to own child, reflecting reward sensitivity and sustained attentional processes, may be a critical neurobiological mechanism supporting optimal care. CPS-referred mothers with an attenuated LPP in response to their own child, then, may be especially at risk for insensitive caregiving. Perhaps this neural mechanism of enhanced attention towards one's own child is less important, however, for low-risk mothers. In low-risk contexts, when mothers have ample social support, motivation, and emotional resources to support optimal caregiving, the neurobiological processes indexed by the LPP may be less necessary for sensitive parenting. Thus, even low-risk mothers who show attenuated LPP responses to their own child may still be able to provide sensitive care.

Recent studies examining children's developmental outcomes similarly highlight the importance of examining the *interactive* effects of biological processes and environmental risk. Such work has resulted in a number of theoretical conceptualizations of the interaction between biological factors and environment, including the diathesis-stress framework and biological sensitivity to context theory (Belsky & Pluess, 2009; Boyce & Ellis, 2005; Ellis, Boyce, Belsky, Bakermans-Kranenburg, & van Ijzendoorn, 2011), both of which converge upon the idea that variations in neurobiology make individuals more or less susceptible to environmental influence. Similar to the current findings and in line with these theories, a number of studies have identified associations between biomarkers and behavior present in high-risk – but not low-risk – contexts. For example, Ellis et al. (2011) found that, among children with high stress reactivity, parental supportiveness predicted pubertal timing; by contrast, the association between parent supportiveness and pubertal timing was non-significant among children considered less context-sensitive (i.e., showing low stress reactivity) (Ellis, Shirtcliff, Boyce, Deardorff, & Essex, 2011). A similar example comes from a study examining the effects of parenting on children's physical health, showing that risk (i.e., high-risk/CPS-referred vs. low-risk) interacted with maternal sensitivity in predicting children's telomere length, a marker of cellular aging (Asok, Bernard, Roth, Rosen, & Dozier, 2013). Whereas the association between maternal sensitivity and telomere length was non-significant for the low-risk comparison group, there was a significant, positive association between maternal sensitivity and telomere length among children with a history of CPS involvement. Along with the current study, such findings of the moderating effects of risk suggest that sensitive parenting may function differently under varying conditions of environmental, temperamental, and biological vulnerability.

Our finding that mothers' neural responses predict behavioral sensitivity has important clinical implications for mothers at risk for insensitive parenting. Examining maternal ERP responses may be an approach for identifying high-risk mothers who may be especially prone to insensitive parenting. By targeting resources to mothers who are most likely to need them, interventions may potentially operate with greater efficiency and effectiveness. Additionally, examining whether own-other LPP responses are modifiable in response to intervention efforts may further inform neural mechanisms involved in optimal parenting.

This may lead to identification of maternal LPP to own child as a target for interventions aimed to increase maternal sensitivity. Although the ABC intervention has been shown to enhance mothers' ERP responses (i.e., N170 and LPP) to child emotional expressions and mothers' responsiveness (i.e., following the child's lead in play interactions) (Bernard et al., 2015), the current study did not find evidence of intervention effects on LPP to own child or maternal sensitivity to distress. These null findings may reflect the specificity of the ABC intervention in changing certain neural mechanisms and maternal behaviors but not others, or may have resulted from examining a subset of the full sample years after the intervention had been implemented. Future randomized clinical trials of attachment-based interventions offer exciting opportunities to explore the biological correlates of sensitive parenting.

The present study benefitted from a number of strengths, including use of both biological and behavioral indices of parent-child interaction and recruitment from a high-risk, CPS-referred sample. Despite these strengths, certain limitations should be noted with regard to sample characteristics and the ERP task. First, with regard to our sample, the sample size was relatively small; thus, replication of these findings will be important. Second, criteria for inclusion in the study were not as stringent as those of some previous studies examining the neurobiology of maternal behavior: we did not limit participation in the study on the basis of being a first-time mother or define a specific period of motherhood (e.g., postpartum). That we found a significant effect despite a mixed and complex sample suggests that the phenomenon may be both robust and generalizable to the broader population. Third, we were unable to obtain information about the specific reasons for CPS-referred mothers' CPS involvement (i.e. abuse, neglect, substance abuse, domestic violence). Although CPS involvement of any kind represents a significant risk factor, future research may benefit from examining the extent to which parenting neurobiology differs across various risk factors or types of maltreatment. Finally, the CPS-referred and low-risk groups differed on more than just their history of CPS involvement. Although we controlled for other group differences in risk factors, such as income and education, it would be important in future research to examine whether similar effects are found when using a comparison group well-matched on income and education.

With regard to the ERP task, there are several limitations to consider. First, we did not standardize children's facial expressions in the own child photograph. Given that parents exhibit an enhanced LPP to certain infant emotional expressions (e.g., Bernard et al., 2015), it is important that future research examine whether the association between own-other LPP and maternal sensitivity is moderated by emotion type. Additionally, in the current study, we only examined the LPP, which is a rather nonspecific index of emotional attention; future research may examine other psychophysiological responses and their associations with maternal sensitivity to determine the specificity of particular physiological mechanisms.

Future research should consider a number of relevant child and parent factors that may influence associations between psychophysiology and maternal behavior. Increasing attention has been paid to the role that children play in eliciting parenting, with evidence supporting bidirectional associations between child characteristics (e.g., difficult infant temperament, behavior problems) and parenting behavior (Micalizzi, Wang, & Saudino, 2017; Waller et al., 2014). Thus, future studies should examine to what extent child

characteristics affect parental brain responses, ideally in the context of longitudinally studies. Additionally, given that the CPS-referred mothers in our study represented a sample generally enriched for risk factors, future research would benefit from examining more specific maternal variables that may influence the associations between psychophysiology and maternal behavior. Such variables may include stress (both related to parenting and general), social support, history of adversity, and emotion regulation, as well as other physiological indices of attention and emotion. Understanding how these more specific factors influence maternal psychophysiological responses, maternal parenting behavior, and/or their association, can advance our understanding of mechanisms involved in parenting and offer novel targets for intervention.

In sum, the results of the present study indicate that increased LPP response to one's own child, compared to an unfamiliar child, predicts maternal sensitivity among CPS-referred mothers. This finding suggests that the neurobiological processes recruited in parenting – especially attention to emotionally salient stimuli – may be especially important for supporting sensitive parenting among mothers who do not have other protective environmental factors. Our study fills an important gap in the parenting neurobiology literature by demonstrating the interaction between psychophysiology and environmental risk, and may help inform intervention efforts for enhancing sensitive parenting.

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Figure 1.

Grand-averaged ERP waveforms of (a1) low-risk mothers and (a2) CPS-referred while viewing own, familiarized, and unfamiliar child faces; and scatterplots of the bivariate correlations between own-other LPP and maternal sensitivity for (b1) low-risk mothers, $r = -.03$, $p = .89$, and (b2) CPS-referred mothers, $r = .44$, $p = .004$. Higher own-other LPP scores reflect larger responses to own versus other child than lower own-other LPP.

Table 1

Demographic Information and Descriptive Statistics for CPS-referred and Low-risk Mothers

Variable	CPS-referred (<i>n</i> = 42)		Low-risk (<i>n</i> = 31)	
	<i>n</i>	%	<i>n</i>	%
Mother ethnicity				
African American	32	76.2	21	67.7
White	4	9.5	8	25.8
Hispanic	4	9.5	1	3.2
Biracial	2	4.8	1	3.2
Child gender				
Male	27	64.3	11	34.4
Female	15	35.7	20	62.5
Dichotomized Risk Factors				
Low income	36	85.7	9	29.0
Low education	17	40.5	2	6.5
Ethnic minority	38	90.5	23	74.2
Single mother	27	64.3	13	41.9
Adolescent mother	14	33.3	7	22.6
High Depression	3	7.1	1	3.2
	M (SD)	Min – Max	M (SD)	Min – Max
Mother age	31.70 (7.93)	19.75 – 49.0	32.81 (6.50)	23.42 – 45.33
Child age	4.92 (0.54)	4.11 – 6.20	5.07 (0.60)	4.13 – 6.52
Household income	\$15,185 (12,830)	\$3,816 – 60,000	\$60,770 (57,327)	\$2,400 – 200,000
Risk composite	3.21 (1.18)	1 – 5	1.77 (1.50)	0 – 5
Maternal sensitivity	2.82 (1.20)	1 – 5	3.55 (1.29)	1 – 5
LPP Amplitude: Own	7.67 (5.22)	–2.36 – 21.62	8.14 (4.47)	0.88 – 16.67
LPP Amplitude: Familiar	5.54 (4.10)	–2.51 – 14.82	5.86 (3.60)	–1.73 – 13.91
LPP Amplitude: Unfamiliar	4.77 (3.70)	–2.12 – 16.88	5.43 (4.27)	–4.81 – 18.80

Table 2
Bivariate Correlations among Study Variables for Full Sample, CPS-Referred, and Low-risk Groups

Full sample (N = 73)	1	2	3	4	5	6	7	8
1. Number of risk factors								
2. Income to needs ratio	-.60**							
3. Child age	.02	-.06						
4. Caregiver age	-.43**	.31**	-.01					
5. Maternal sensitivity	-.37**	.40**	-.14	.04				
6. LPP amplitude to own child	-.09	.08	-.12	-.09	.20			
7. LPP amplitude to familiarized child	-.13	.13	-.04	.10	.02	.70**		
8. LPP amplitude to unfamiliar child	-.19	.21	.02	-.07	.17	.68**	.65**	
9. LPP own-other residualized difference	.06	-.08	-.17	-.15	.20	.72**	.11	.08
CPS-referred sample (n = 42)								
1. Number of risk factors								
2. Income to needs ratio	-.55**							
3. Child age	-.13	.13						
4. Caregiver age	-.34*	-.01	-.01					
5. Maternal sensitivity	-.17	.31	-.13	-.13				
6. LPP amplitude to own child	-.20	.20	-.05	-.02	.38*			
7. LPP amplitude to familiarized child	-.17	.10	-.02	.14	.05	.69**		
8. LPP amplitude to unfamiliar child	-.18	.17	.16	-.11	.21	.70**	.61**	
9. LPP own-other residualized difference	-.11	.17	-.15	-.06	.45**	.78**	.16	.20
Low-risk sample (n = 31)								
1. Number of risk factors								
2. Income to needs ratio	-.55**							
3. Child age	.31	-.24						
4. Caregiver age	-.64**	.57**	-.05					

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Full sample (N = 73)	1	2	3	4	5	6	7	8
5. Maternal sensitivity	-.38**	.41*	-.25	.24				
6. LPP amplitude to own child	.08	.05	-.23	-.23	-.06			
7. LPP amplitude to familiarized child	-.07	.18	-.08	.03	-.07	.72**		
8. LPP amplitude to unfamiliar child	-.17	.25	-.14	-.05	.10	.68**	.71**	
9. LPP own-other residualized difference	.28	-.21	-.21	-.34	-.13	.62**	.01	-.09

*
p < .05,
**
p < .01

Table 3
Regression Analysis Testing the Interaction of Group and Own-Other LPP on Maternal Sensitivity

Variable	B	SE	t	LLCI	ULCI
Covariates					
Composite risk	-0.22	0.11	-2.03 *	-0.43	-0.00
ABC intervention	0.32	0.37	0.87	-0.14	1.05
Main Effects					
Group (1 = CPS)	-0.62	0.38	-1.62	-1.38	0.14
Own-other LPP	-0.10	0.28	-0.35	-0.67	0.47
Interaction					
Group X LPP	0.72	0.36	2.01 *	.006	1.44
Conditional effect of own-other LPP on sensitivity for each risk group					
Low-risk	-0.10	0.28	-0.35	-0.67	0.47
CPS	0.62	0.21	2.91 **	0.20	1.05

Note.

* $p < .05$

**

$p < .01$. R^2 change for interaction = 0.05, $p < .05$. ABC intervention was coded 1 for participation in ABC and 0 for participation in DEF or low-risk group; Group was coded 1 for CPS-referred and 0 for low-risk; Own-other LPP represents the residualized difference score calculated by regressing mothers' LPP amplitude to own child on LPP amplitude to other children; Group X LPP represents the interaction term calculated by multiplying Group by Own-other LPP.