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The Application of Electroencephalography to Investigate the Neural Bases of Parenting: A Review

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Introduction

Given the significant role that parents play in their child's development (Bowlby, 1969), and the accumulating evidence that parenting practices are transmitted across generations (Bouvette-Turcot, Bernier, & Meaney, 2013; George, Kaplan, & Main, 1985; Van IJzendoorn, 1992), understanding parenting is of critical significance to developmental science. Recent research has employed neuroimaging techniques to identify potential changes to neural circuitry that accompany parenthood, providing a deeper level of understanding of parental processes and how psychopathology may impact parenting at a neurobiological level (Squire & Stein, 2003). The majority of this research has utilized functional magnetic resonance imaging (fMRI) to identify the brain regions that are engaged when parents and non-parents view photographs of infant faces or listen to infant vocalizations (Rutherford & Mayes, 2011; Swain, 2011). However, while fMRI may be well suited to capturing the “where” question of the neural architecture of human parenting, here we propose that the “when” question of the neural response to these infant affective cues also warrants attention.

Central to our proposal that we need to examine the temporal component of parent-child interactions is the intuitive nature of parenting – the rapid and sensitive responding to infant cues that may promote infant well-being (Papoušek, 2000) and have lasting consequences for the developing child (Beebe et al., 2010). While microsecond analyses of parent-child interactions illuminate the temporal dynamics of parenting, we propose that understanding the neural basis of these interactions is also needed. Specifically, assessing the detection of infant cues as well as the response to those cues will provide significant insight into

parenting, especially in the clinical domain where there is insufficient evidence delineating the stage(s) of processing in which psychopathology may compromise parenting. With this in mind, a number of studies are now employing electroencephalography (EEG) and event-related potentials (ERPs) to explore the neural correlates of parental sensitivity to infant cues, benefitting from the millisecond temporal resolution this neuroimaging technique affords.

The waveforms of EEG reflect voltages generated by thousands of synchronized and summated postsynaptic potentials of cortical pyramidal neurons, measured at the surface of the scalp via precisely positioned electrodes (Luck, 2005). While the raw EEG signal can be assessed (e.g., Killeen & Teti, 2012), EEG can also be time-locked to a stimulus event, and averaged across a series of trials in which that event is presented (e.g., multiple presentations of infant faces). This event-related potential (ERP) approach results in a clearly defined waveform consisting of positive (P) and negative (N) peaks, which are believed to index sensory and cognitive processes that manifest over time (Figure 1). The polarity of these peaks are typically labeled in respect of the numerical order or time they onset. Critically, the magnitude (amplitude in microvolts) as well as the temporal onset (latency in milliseconds) of ERPs vary dependent on experimental manipulations, providing an index of variability in the strength, as well as speed, of stimulus detection. Notably, latency measurements are of particular relevance to the ERP approach, given the temporal precision of this methodology. Amplitude and latency measures provide an additional advantage with the examination of both within-subjects variation of stimulus perception (e.g., within a sample of mothers) as well as between-subjects variation (e.g., comparing a sample of mothers to a sample of non-mothers). Understanding the speed (as well as the size) of the neural response to experimental stimuli may have important implications for behavioral functioning.

Here we review parenting studies that have examined ERP components associated with auditory processing (N100; i.e., negative peak appearing around 100 ms after stimulus onset), visual processing of faces (P1, N170, N245), and attentional engagement and extended processing of stimuli (P300; N/P600; late positive potential or LPP). The earlier responses (N100 and N170) represent the initial stages of perceptual processing of auditory or visual stimuli respectively, whereas the later responses (P300; N/P600; LPP) reflect cognitive evaluation and attentional engagement with these infant stimuli (Batty & Taylor, 2013; Eimer & Holmes, 2007; Luck, 2005; Ritter & Ruchkin, 1992; Streit, Wolwer, Brinkmeyer, Ihl, & Gaebel, 2000). Therefore, another unique advantage of the ERP technique is that it is possible to tease apart potential differences in the detection and processing of stimuli by examining early and late ERP components. In reaction time (RT) experiments, the RT represents the endpoint of a stage of processes encompassing perception, attention, and cognition. Finding group differences in RTs in responding to infant cues may suggest that there is a difference in speed of processing infant cues between these groups, but this finding will not provide insight into the potential mechanisms underlying that difference. ERPs enable us to tease apart at what stage of processing this difference emerges, whether at the level of perception, attentional processing, or cognitive evaluation. The purpose of this review is to introduce the value of EEG and ERPs to

parenting research, documenting the current literature in this domain as well as the directions for future investigations.

Neural Response to Infant Cries

Cries are often the first signal a newborn provides to elicit a caregiving response. Converging evidence shows heightened detection and emotional response to infant auditory cues, as well as possibly increased arousal more generally to auditory stimuli when comparing parents to non-parents (Purhonen, Kilpelainen-Lees, et al., 2001; Purhonen, Paakkonen, Ypparila, Lehtonen, & Karhu, 2001; Purhonen, Valkonen-Korhonen, & Lehtonen, 2008). Purhonen, Kilpelainen-Lees, and colleagues (2001) evaluated whether the N100 differed in recent mothers and non-mothers when listening to their own infant cries (in mothers), a novel infant cry (in non-mothers), and neutral word stimuli (both groups). Mothers' N100 amplitudes were enhanced in response to cries and the neutral word relative to non-mothers. Thus new mothers may have an altered perceptual sensitivity and alertness to sensory stimuli, which may signal a heightened arousal response in these women more generally. Purhonen and colleagues (2008) further explored infant cry perception in a second study, where new mothers and non-mothers were presented with infant cries and standard (frequently occurring) and deviant (infrequent) conventional tones. Again, recent mothers' N100 amplitudes were enhanced for all stimulus types compared to non-mothers; however, no differences were found for later ERP components (N200, P300). Thus new mothers may have a heightened response to the initial detection of auditory stimuli, which is not infant specific. Taken together, these findings suggest that new mothers may have a lower perceptual threshold whereby emotional and non-emotional auditory cues elicit a greater neural response relative to non-mothers in early stimulus detection (Purhonen et al., 2008).

Neural Response to Infant Faces

The field of social neuroscience has extensively studied facial recognition and perception by relying on adult face stimuli. However, parenting is marked by an increased exposure to infant cues, including affective facial expressions. Building on prior research that supports the use of ERP techniques to explore the specificity of face perception using adult faces (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Rossion et al., 2000), evaluating maternal response to infant faces can provide informative cues for parental behavior, especially if these facial stimuli convey affective information such as discomfort or pain.

Proverbio, Brignone, Matarazzo, Del Zotto, and Zani (2006) evaluated the ERP response to unfamiliar infant facial expressions (novel infant faces expressing pleasure, comfort, discomfort, or distress) in parents and non-parents, and investigated whether gender and parental status influenced responsiveness to these affective cues. The lateral occipital P1 response was greater in women than in men, irrespective of parental status. A significant lateralized response was found in mothers only for the P1. The N170 amplitude was modulated by infant emotional expression, with larger amplitudes in response to the distress expressions relative to the other emotional expression conditions, and larger N170 responses in mothers compared to fathers. Consistent with ERP findings, RTs were significantly faster to evaluate negative emotional states compared to positive ones, with the fastest times in

response to distress expressions. More recently, Peltola and colleagues (2014) replicated this ERP finding in a sample of women: the N170 amplitude in response to infant faces was larger to negative affective infant faces compared to positive affect across a sample of mothers and non-mothers.

Both these studies of ERPs elicited by unfamiliar infant faces included a behavioral response task in addition to measures of the neural response to these stimuli. Proverbio and colleagues (2006) found that the N245 was larger, and RTs were faster, in response to strong positive and negative emotions (i.e., pleasure and distress) compared to weaker emotions (i.e., comfort and discomfort), and the N245 was highly sensitive to distressed facial expressions in parents compared to non-parents. Similarly, Peltola and colleagues (2014) also found an association between the ERPs and RTs in respect of the strength of emotional expressions of infant faces: participants (mothers and non-mothers) who had faster RTs during a facial recognition task evidenced shorter frontal N100 latencies in response to strong (i.e., pleasure and distress) compared to mild (i.e., neutral and discomfort) infant faces, and greater accuracy was associated with slightly larger LPP amplitudes in response to negative compared to positive infant facial expressions in mothers only. Finally, these studies evidenced the P300 (Proverbio et al., 2006) and an early posterior negativity (Peltola et al., 2014) were sensitive to infant facial expressions, with infant distress eliciting the greatest response, particularly in mothers. Taken together, these results support heightened detection and alertness in new mothers to infant faces, including greater neural responses and faster RTs in response to strong affective facial cues. Further, these findings demonstrate convergence between behavioral and electrophysiological modalities increasing the validity of these results and the value of both methodologies to investigating parenting.

Other studies have explored the impact of familiarity on parental responses to infant facial cues. In a cross-sectional study, Bornstein, Arterberry, and Mash (2013) evaluated the effects of parenthood on early (N/P100 and N170) and late (N/P600) ERP components. Primiparas of 3- and 6-month-old infants viewed photographs of their own infant or matched unknown infant's neutral faces. Mothers showed equivalent N/P100 and N170 responses to familiar and unfamiliar faces, but had larger N/P600 responses to their own infant's face. There were no differences in ERPs found between mothers of 3- and 6-month-old infants. Similarly, Doi and Shinohara (2012b) evaluated early (P100 and N170) and late (P300) ERPs in mothers while they viewed crying, smiling, and neutral facial expressions of their own and unknown infants. Although there were no N170 latency effects, the amplitude of the N170 was larger in mothers when viewing crying expressions compared to smiling and neutral expressions, irrespective of infant familiarity. However, when examining the earlier portion of the P300 (272 ms to 328 ms after stimulus onset), this neural response was larger in mothers viewing their own infant crying compared to the other familiar conditions (own infant smiling and neutral expressions) and the unfamiliar crying condition. Additionally, the latency of the P300 and behavioral RT were both affected by familiarity and distress, in which the P300 onset earlier and RTs were faster when mothers viewed photographs of their own crying infants. Taken together, these results reveal the unique temporal course of infant face processing in mothers in which earlier responses (N/P100, N170) may reflect more automatic perceptual processes affected by the distress level of the

infant and later responses (P300; N/P600) may reflect higher-order cognitive processes affected by both infant distress and familiarity.

Doi and Shinohara (2012a) extended this work by evaluating whether mothers showed differentiated neural responses when viewing their own and unknown child faces where eye gaze was either straight or averted – the authors speculating that eye gaze may be a prerequisite for attachment and play an important role in synchronous interactions between the mother and her child. In this study, N170 amplitude was largest when mothers viewed their own child's face (mean age 5.6 years) when the gaze was directed straight ahead rather than averted. In contrast, mothers' P300 amplitudes were significantly larger in response to an unfamiliar child's gaze compared to their own child's gaze in the straight condition only. The P300 latency and behavioral RT were both significantly longer to straight gaze faces than to averted gaze faces, regardless of child familiarity. Consequently, these findings suggest that eye-gaze may have implications for the neural correlates of early stages of infant face perception, as well as later stages of attentional engagement with infant stimuli in maternal samples (Doi & Shinohara, 2012a). These findings more generally indicate the importance of controlling for eye-gaze in infant stimulus sets in parenting ERP studies in future research. Taken together, this work extends earlier studies that have relied primarily on affective facial images to include evaluation of maternal sensitivity to child gaze information, which may be informative to the dyadic relationship.

Biological and Non-Biological Parental Neural Responses

Research in this area has primarily concentrated on biological parents; however, others have begun to investigate the differences, if any, between biological and non-biological parents. Grasso, Moser, Dozier, and Simons (2009) explored differences in ERP patterns in biological mothers and non-biological mothers (foster/adoptive mothers) who viewed photographs of their own child, an unfamiliar child, a familiar adult, and an unfamiliar adult. Mothers (biological and non-biological) exhibited significantly more positivity in response to viewing photographs of their own children compared to all other stimuli during both early (N100 and N200) and late (P300 and LPP) stages of face processing. This increased neural response across all mothers when viewing their own child's face suggests that heightened processing of child facial cues may not be limited to biological processes, but could be related to parenting experience.

In keeping with this, Bick, Dozier, Bernard, Grasso, and Simons (2013) found that foster mothers' P300 responses were significantly larger when viewing photographs of their own foster child compared to a familiar and an unfamiliar child. Furthermore, there was a changing relationship between maternal oxytocin levels (a neuropeptide important to maternal and affiliative behavior; MacDonald & MacDonald, 2010) and the P300 response over time: 3 months after placement, there was an association between oxytocin levels and the P300 elicited when mothers viewed their own infant's face – an effect which was absent when this relationship was assessed shortly after placement (within 60 days). Therefore, the increasing time foster mothers spent with their foster child seems to be associated with the relation between oxytocin levels and the neural response to viewing photographs of the child. In keeping with the role of oxytocin and the neural response to infant cues, Peltola et

al. (2014) reported that the variation in the oxytocin receptor gene (OXTR) in women (mothers and non-mothers) might play an important role in determining the neural response to infant cues. Specifically, they found carriers of the rs53576 OXTR evidenced earlier latencies (N100) in response to strongly affective (i.e. distress and pleasure) infant faces. This effect was infant-specific and not found in response to adult facial stimuli. Together, these studies further support a role for parental experience in the shaping of neural, as well as hormonal, functioning in the maternal brain.

Parenting ERP and Psychopathology

Understanding individual differences in response to infant cues at the neural level, along with factors that may compromise sensitivity to cues, could provide important information on differential outcomes in infants and help to identify potential mechanisms that could be targeted by intervention and treatment efforts in vulnerable parents (Rutherford & Mayes, 2011). To date, few studies have examined how psychopathology, or related processes, may modulate these neural responses to infant cues in maternal samples.

Noll, Mayes, and Rutherford (2012) examined the relation between early visual processing of infant faces and individual differences in depression symptomatology in mothers and non-mothers. Participants viewed photographs of infant faces that varied in emotional expression (pleasure, discomfort, or distress) during EEG recording. There was no parental status group effect and the N170 was not modulated by infant emotional expression. However, a significant relation between sub-clinical depressive symptomatology and the N170 response was found. Although the authors anticipated that depression would attenuate the neural response to infant cues, their findings instead showed that the amplitude of the N170 was greater with increasing depression symptomatology. This result is counterintuitive, given the inherent reward of infant faces, and these findings may instead reflect the degree of attentional engagement with these stimuli which has previously been suggested as a strategy employed by depressed patients with anhedonia to regulate their mood (i.e., anhedonic patients may increase their attention to positive stimuli with a view to improving their mood; Keedwell, Andrew, Williams, Brammer, & Phillips, 2005). However, future research is needed to further elucidate these findings in clinically depressed samples with assessments of both anhedonic and depressive symptomatology.

Building on their study of child familiarity and eye-gaze, Doi and Shinohara (2012a) also examined whether maternal neural responses were affected by feelings of anxiety as measured via the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). They found no association between maternal anxiety and the N170, but maternal state anxiety predicted the P300 amplitude elicited by unfamiliar child faces with straight gaze and familiar child faces with averted gaze conditions. In understanding these findings, the authors speculated that there may be an association between maternal anxiety and familiarity, eye-gaze and negative emotionality, such that a straight gaze from an unfamiliar child may be perceived as threatening, and an averted gaze from one's own child may be perceived as rejecting. Further work is required to fully understand this finding, but these results echo the importance of examining child eye-gaze in parenting research.

Another study by Rodrigo and colleagues (2011) evaluated neural sensitivity to infant faces in neglectful and non-neglectful mothers who viewed photographs of unfamiliar infant faces that varied in emotional expression (crying, laughing, and neutral). In general, parents had faster reaction times during a classification task in response to laughing and crying faces compared to neutral faces, regardless of group status (neglectful vs. non-neglectful). The N170 was modulated by infant emotional expression in non-neglectful mothers; specifically, the N170 was larger in non-neglectful mothers in response to infant cry images. The LPP was modulated by infant emotional expression in both groups, but it was attenuated across all three emotional expressions in neglectful mothers. This study was not exclusively examining parental psychopathology as it pertains to neglect and sensitivity to infant cues, but it is worthwhile noting that neurobiological models related to clinical disorders have speculated that there may be potential neurobiological mechanisms that underscore neglectful parenting behaviors (e.g., addiction; Landi et al., 2011; Rutherford, Williams, Moy, Mayes, & Johns, 2011).

Limitations

EEG is minimally invasive, can be used safely during pregnancy and postpartum, and can be used to delineate the neural stages of processing of infant stimuli. However, it is important to consider the limitations of ERPs in parenting research at both technical as well as conceptual levels. One important limitation is the relatively poor spatial resolution and localization capabilities of ERPs, termed the inverse problem. The majority of the EEG signal is generated by postsynaptic potentials from superficial, cortical pyramidal cells, mainly from gyri of the brain perpendicular to the skull. From the raw signal there is no indication of the source of the signal, and which different neuroanatomical regions may have contributed to it. This absence of source localization is a relevant limitation to consider in the field of parenting research, as many laboratories have demonstrated a broad network of both cortical and sub-cortical regions involved in parenting behaviors using fMRI (Rutherford & Mayes, 2011; Swain, 2011).

Despite this spatial resolution limitation, some researchers have made attempts to reconstruct the sources of ERPs. For instance, Proverbio, Riva, Zani, and Martin (2011) employed low-resolution brain electromagnetic tomography (LORETA), which uses an algorithm to compute a three dimensional map of the most likely source of activity, based on the synchronization and strength of the electrical signal from different areas. Subtracting activity from ERPs in response to adult faces from ERPs in response to infant faces, they found that the main sources of activation were likely generated by the left and right medial occipital/fusiform gyrus, the right uncus, the right medial orbito frontal gyrus, and the anterior cingulate cortex, which is consistent with fMRI studies that implicate these regions in parenting (Rutherford, Potenza, & Mayes, 2013). These findings suggest some promise in understanding potential neural generators of EEG as it relates to infant cue perception, though this question of which brain regions are recruited during processing of infant stimuli may be better served by techniques with either higher spatial resolution (e.g., fMRI) or with strengths in spatial as well as temporal resolution (e.g., magnetoencephalography or MEG; Kringelbach et al., 2008; Parsons et al., 2013).

A second related technical limitation includes the sensitivity of EEG recordings to movement and other environmental artifacts, and thus many trials are needed for each experimental condition for appropriate statistical analysis and interpretation (Luck, 2005). Third, it is important to consider the reliability and consistency of EEG recording across research settings. Variability in the application of EEG has led to the introduction of reports to guide the importance of standards and criteria for data collection, analysis, and reporting of these processes in publications (Keil et al., 2014; Picton et al., 2000). As with other neuroimaging techniques, sufficient equipment is needed for the recording of EEG data and may introduce feasibility issues with reaching more at-risk or isolated samples in contrast to self-report, interview, or laptop-based assessments. However, the introduction of portable recording equipment has begun to increase the accessibility to community samples (Aspinall, Mavros, Coyne, & Roe, 2013; Mostow, Chang, & Nelson, 2011).

Finally, it is worthwhile considering the conceptual limitations of EEG/ERP as applied to research questions relevant to parenting. Despite the value of this approach in teasing apart how infant stimuli are processed, this technique may not be well suited in capturing the complexities of parenthood. The experiments discussed here probe the neural correlates of parenting in highly controlled and typically static paradigms (consistent with a scientific method). However, laboratory-based studies are far removed from the true parenting experience and may limit the validity and generalizability of the data reported. Therefore, it will be important to use converging methodologies, including self-report, biological, behavioral, and observational measures to fully advance the endeavor of understanding parenting.

Summary and Future Directions

We have considered the application of EEG, and more specifically ERP methods, to studying parental responses to infant stimuli. Across both visual and auditory modalities there is accumulating support for the notion of increased sensitivity to infant cues in parents, especially if those cues are negatively valenced and are from the parent's own infant. Enhanced ERPs to infant stimuli are consistent with increased activation measured in brain regions recorded using functional neuroimaging techniques (Rutherford & Mayes, 2011; Swain, 2011), but are additive in delineating the stages of stimulus processing that may be sensitive to (1) variability in factors associated with the stimuli employed and (2) characteristics of the participants engaged with those stimuli. The studies presented here highlight the value of ERPs to interrogating the neural responses of parents to infant cues, but it is also important to consider the variability in these studies in respect of their design characteristics. Some studies are limited by small sample sizes, a focus on maternal and not paternal responding, variability in child age, and limited detail and assessment of important parental characteristics such as parity (i.e., primiparous or multiparous) and demographic factors (e.g., age, ethnicity, and socioeconomic status – see Table 1). Further characterizing the differences between parents and non-parents is needed. Therefore, there is some convergence on heightened sensitivity to infant cues of familiarity and negative affect in parenting samples, but larger studies systematically assessing the impact of these factors, as well as others, on ERP responses to infant cues are warranted. It will also be important to validate whether these neural markers of processing infant stimuli are associated with more

overt measures of parenting, including parent-child interactions and self-report measures, as well as their association with neuromodulators, such as oxytocin (e.g. Bick et al, 2013; Peltola et al., 2014). Such an endeavor may also benefit from more advanced statistical analysis techniques to fully exploit the utility of EEG and ERPs (e.g., spectral analysis; Esposito, Valenzi, Islam, Mash, & Bornstein, 2014; Killeen & Teti, 2012).

Across the studies presented here, ERPs were assessed in paradigms that required simple key press responses to the presented stimuli, or instead had participants passively view the stimuli presented. These experimental paradigms provide an important first step in understanding the basic neural response to these salient infant stimuli, but more dynamic ERP paradigms will be a valuable addition. For instance, a number of studies in adults and children have examined the neural correlates of social exclusion using a virtual ball-toss paradigm where participants are both included and excluded by fictional players (Crowley et al., 2009; Crowley, Wu, Molfese, & Mayes, 2010; Williams, Cheung, & Choi, 2000; Williams & Jarvis, 2006). Building on this work, one study reported that the level of dismissing attachment in an early adolescent sample was associated with the ERP response to social exclusion by unfamiliar peers (White et al., 2012). Further adaptation of this paradigm to examining the neural correlates of rejection by mother and child has recently been advanced (Sreekrishnan et al., 2014). A natural extension of this work would be to examine the attachment style of mothers and their children and how the quality of dyadic relationships influences the response both to infant cues and to similar social exclusion paradigms (e.g., Fraedrich, Lakatos, & Spangler, 2010). Further, ERPs associated with error or feedback processing when elicited by infant stimuli and embedded in decision-making tasks may provide a novel measure of parental responding to infant cues that may not be captured by simpler passive viewing tasks. It is also worth noting that ERPs have been employed to examine emotion regulatory processes (Hajcak, Moser, & Simons, 2006; Krompinger, Moser, & Simons, 2008; Moser, Hajcak, Bukay, & Simons, 2006), which in the presence of affective infant signals could provide insight into both parental reactivity and regulation toward salient signals of infant emotion.

Given the nature of EEG, it is minimally invasive and can be used safely during pregnancy (Keunen, Vliegen, Pol, Gerretsen, & Stam, 1997; Smirnov, Batuev, & Korsakova, 2002), and therefore, presents a unique opportunity for longitudinal investigations of brain responses in pregnancy as well as during the postpartum period. To our knowledge, no human studies have systematically evaluated the hypothesized changes that occur as adults transition from non-parents to parents. While Bornstein and colleagues (2013) found no differences in the maternal brain response in mothers at 3 and 6 months postpartum, extending this approach earlier to examine sensitivity to (albeit unfamiliar) infant cues before pregnancy, during pregnancy and throughout the postpartum period may provide a novel opportunity for investigation. Normatively it would allow for insight into the shaping of the maternal brain, but clinically this work may be informative in identifying factors that may influence the apparent emerging sensitivity to infant cues. For example, behavioral studies have suggested that depression symptoms impact attentional processing of images of distressed infant faces during pregnancy (Pearson, Cooper, Penton-Voak, Lightman, & Evans, 2010), with attentional bias to these distressed faces being associated with the quality

of the mother-child relationship 3-6 months postpartum (Pearson, Lightman, & Evans, 2011).

It is also important to acknowledge that very few studies have employed ERPs to examine the impact of individual differences and psychopathology on parental sensitivity to infant-relevant stimuli. In addition to the normative characterization of parental responding, understanding how this may be altered by individual differences, including psychopathology, is a noteworthy direction for future research. Functional neuroimaging techniques have begun to probe how depression (Laurent & Ablow, 2012, 2013), addiction (Landi et al., 2011), and trauma (Schechter et al., 2011) may impact the neurophysiological response to infant cues in recent mothers; however, at which stage of stimulus processing potential impairments occur in these paradigms is not known. The dearth of knowledge in clinical domains on parental processes further highlights the need for the temporal sensitivity of ERPs where the neural correlates of perception as well as cognition can be probed. Given the tight coupling of ERPs to neurotransmission, reliability in ERP findings across or within clinical disorders may prove useful in search of potential biomarkers of vulnerability in at-risk parents as long-term goals of ERP research (Luck et al., 2011). Accompanying a clinical ERP approach is the importance of understanding the state or trait nature of ERPs and their suitability as dependent measures in parenting intervention programs – including how they relate to overt behavior. Indeed, bridging of brain and behavior is critical across developmental and social neuroscience.

Implications for Practice, Application, Theory, and Policy

The application of ERPs to parenting research has important implications at clinical and theoretical levels. Clinically, ERPs may provide sensitive, stable, and reliable measures of neural events that underlie the complexities involved in parenting. Consequently, ERPs may prove value as dependent measures in cross-sectional and longitudinal research as well as in intervention studies in efforts to elucidate underlying processes that may be important to parenting. Concurrently, it is important to note that while behavioral measures are frequently relied on to assess parent-child interactions, providing critical insight into the dyad, observational and self-report measures may be subjectively biased and vary from one interaction to another. Additionally, in the clinical domain, ERPs may be useful in characterizing more objective profiles of risk to serve as a screening tool or early identification method for preventive treatment in parents that may not be better captured behaviorally. Theoretically, the promise of electrophysiology is in the identification of different stages of infant cue perception, including the detection, perception, and processing of infant stimuli – bringing the field of parenting research into a cognitive neuroscience framework that has facilitated our understanding of the neural correlates of social interactions and behavior more generally.

Conclusion

EEG/ERP methodology can be employed to examine the temporal dynamics of infant cue perception in biological and non-biological parents, expectant parents, and non-parents. Further, it can be used to complement studies that more frequently rely on behavioral, self-

report, and fMRI techniques, which miss the exploration of rapid and sensitive parental response to infant cues. This work is of significance in normative as well as clinical populations, given the insights it can provide to the developing parent-child relationship. Converging evidence highlights increased parental sensitivity to infant faces and cries in biological and non-biological parents, but it will be necessary to examine the generalizability of these findings to larger and more diverse samples, as well as employ innovative paradigms and data analytic techniques in using this methodology to further our understanding of parenting.

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Synopsis

Parents play a significant role in their child's development. Recent neuroimaging research has begun to evaluate the neural circuitry of human parenting to better understand parental responsiveness to infant affective cues. Here we introduce the value of using electroencephalography (EEG) and event-related potentials (ERPs) as a methodology to probe the neural correlates of parenting. Given the precise temporal resolution of this technique, it affords the opportunity to explore with millisecond accuracy the temporal dynamics of stimulus processing. We review the emerging research that has utilized EEG/ERP to explore typical normative processes and mechanisms in parental responsiveness, and consider how these processes might be compromised by psychopathology. Limitations and directions for future research are discussed as we highlight the unique contribution this approach can make to the field of parenting research.

Figure 1.

Typical ERP components examined in parenting research. Each waveform graph is presented as a function of latency (horizontal axis) and amplitude (vertical axis). Representative location of electrode sites are indicated for the P1/N170 (checkered electrode sites), N100 (white electrode sites), and P300 (gray electrode sites). F = Front of the head; B = Back of the head.

Table 1

Overview of published papers employing EEG/ERP to examine the neural correlates of parenting.

	Author (year)	N	Age of children	Chils stimuli	ERP component	Parity
Infant Cries	Purhonen et al. (2001)	38; 20 mothers, 18 non-mothers	2-5 days	Cries (own infant, unfamiliar for controls) vs. neutral word stimulus	N100	Unknown
	Purhonen et al. (2008)	38; 20 mothers, 18 non-mothers	2-5 days	Cries (own infant, unfamiliar for controls) vs. standard & deviant tones	N100, N200, P300	Unknown
Infant Faces	Proverbio et al. (2006)	38 adults; 10 non-mothers, 10 non-fathers, 9 mothers, 9 fathers	Youngest child of parents was 2 years 11 months (females) and 2 years 5 months (males)	Unfamiliar emotional infant faces	P110, N170, N245, P300	Unknown
	Bornstein et al. (2013)	22 mothers	3 and 6 months	Own & unfamiliar infant face	N/P100, N170, N/P600	Primiparous
	Weisman et al. (2011)	65; 24 parents, 19 lovers in new relationships, 22 singles	6 months	Parents saw own & unfamiliar infant; non-parents saw unfamiliar infant	N170, P3a, P300	Primiparous
Birth and Foster Care	Doi & Shinohara (2012)	16 mothers	12 months (M=12.3)	Own & unfamiliar infant faces	P1, N170, P300	Unknown
	Doi & Shinohara (2012)	16 mothers	5-6 years (M=5.6)	Own & unfamiliar child faces	P1, N170, P300	Unknown
	Peltola et al. (2014)	94; 48 mothers, 46 nulliparous females	7 months	Adult and infant emotional faces	N1, N170, EPN, LPP	Unknown
	Fraedrich et al. (2010)	16 mothers	Unknown	Emotional infant faces	N170, N200, P300	Unknown
	Grasso et al. (2009)	28 mothers; 14 birth, 14 foster/adoptive	1.6-4.7 years	Own child, familiar & unfamiliar children & adults	N100, N170, P200, N200, P300, LPP	Unknown
Psychopathology	Bick et al. (2013)	43 foster mothers	0.5 - 35 months	Own foster, familiar and unfamiliar infants	P300	Unknown
	Rodrigo et al. (2011)	28 mothers; 14 neglectful, 14 controls	3 years	Unfamiliar emotion baby faces	N170, P200, LPP	Mean of less than 3 children
	Noll et al. (2012)	30; 17 mothers & 13 non-mothers	1.5-48 months	Unfamiliar emotional baby faces	P100, N170	Unknown
EEG	Killeen & Teti (2012)	27 mothers	5-8 months	Video clips of own infant's emotion	N/A	12 primiparous, 15 multiparous

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Author (year)	N	Age of children	Child stimuli	ERP component	Parity
Esposito et al. (2014)	21 mothers	3 and 6 months	Own & unfamiliar infant face	N/A	Primiparous