Received: 24 January 2020 | Revised: 17 July 2020 | Accepted: 2 September 2020

DOI: 10.1111/sode.12484

ORIGINAL MANUSCRIPT

WILEY

Electroencephalogram frontal asymmetry changes during emotion-eliciting tasks and parent–child interaction dynamics

Maria A. Gartstein | Haven Warwick | Allegra X. Campagna

Department of Psychology, Washington State University, Pullman, WA, USA

Correspondence
Maria A. Gartstein, Department of Psychology, Washington State University, P.O. Box 644820, Pullman, WA 99164-4820, USA.
Email: gartstma@wsu.edu

Abstract

Frontal Electroencephalogram (EEG) asymmetry during emotion-eliciting tasks has been underexplored, and the current study considered changes in infant frontal asymmetry during positive and negative emotion-eliciting tasks relative to baseline, consistent with the capability model. Importantly, variability in parent–child interaction factors related to task-related EEG asymmetry changes was examined. Healthy infants participated in the Peek-a-boo component of the Laboratory Temperament Assessment Battery and the Repeated Still Face, with EEG data collected simultaneously. Asymmetry changes from baseline to Peek-a-boo and the second Still Face administration were considered with respect to parent–child interaction dynamics, coded utilizing an established scheme. ANCOVAs were conducted, with age and child sex as covariates, parent–child interaction factors as dependent variables, and Peek-a-boo/Repeated Still Face asymmetry changes from baseline as independent variables, dichotomized as either positive or negative in direction (i.e., associated with either a shift toward relative left or right frontal activation). Results indicated that groups based on changes in frontal EEG asymmetry from baseline to Still Face were associated with significantly different levels of reciprocity/synchrony, intensity, and directedness in mother–infant play exchanges. Results highlight the importance of understanding task-related EEG activation and links with parent–child interactions, providing further support for the capability model.

KEYWORDS
brain development, infancy, parent-child relations

1 | INTRODUCTION

Mother–infant interactions contribute to major areas of child development, enabling advances in social-emotional and cognitive functioning (Bernier, Calkins, & Bell, 2016; Blair, Raver, Berry, & Family Life Project Investigators, 2014; Hane & Fox, 2006); thus, their links to child brain activity are important to understand. Critical aspects of development are experience dependent (Kolb, 2018), and the most salient experiences in infancy are arguably embedded in parent-child, especially mother–infant interactions. These experiences are capable of maintaining functions (sustaining already achieved states/competencies), facilitating functions (regulating when a more advanced states/competency "comes online"), as well as inducing functions (bringing about previously unattained states/competencies; Gottlieb & Halpern, 2002). Importantly, causes of development necessarily emerge in relationships between two components, such as mother–infant interactions and infant emotion/motivation-related brain activity. The present study is focused on the potential "child effects" aspects of these bidirectional links, as children are active cocreators of their developmental trajectories, shaping the way in which parents approach interactions (Bell, 1968; Scarr & Mccartney, 1983). Despite the longstanding appreciation of children's role in their own development, this direction of effects has been largely understudied. Temperament, reflecting dispositional emotions/motivations, has been examined in this context (Ganiban, Ulbricht, Saudino, Reiss, & Neiderhiser, 2011; van den Boom, 1994; van den Boom & Hoeksma, 1994), however, the study of associated brain activity has lagged behind. Enduring influences of parent–child interactions are rooted in real-time dynamics (e.g., in-the-moment "dance" between the mother and her infant; Tronick, 1989), and child brain activity in response to social stimuli may be contributing to the quality of these exchanges.

It is well-established that qualities of parent-infant interactions are critical determinants of attachment security and relational schemas more broadly (Page, Wilhelm, Gamble, & Card, 2010), starting in the second half of the first year of life. Not surprisingly, maternal responsiveness, most widely linked with secure attachment, and also advanced attention-based regulation during this developmental period, has been frequently studied (Ainsworth, Blehar, Waters, & Wall, 2015; Gartstein, Crawford, & Robertson, 2008; Landry, Smith, & Swank, 2006). Highly responsive mothers appropriately interpret their infant's communication attempts, providing prompt, contingent, and supportive responses, engaging their infant in a genuinely interested and emphatic, rather than intrusive fashion. Reciprocity is another prominent attribute of parent-infant interactions related to emotional attunement and turn-taking, with a mutual nature of responding central to this dimension (Tronick, 1989). Reciprocity in parent-child exchanges was also shown to predict superior cognitive and social-emotional outcomes (Leclère et al., 2014; Lewis & Coates, 1980; Lindsey, Cremeens, Colwell, & Caldera, 2009).

Parent versus child-directed nature of the interactions and their intensity (i.e., volume, complexity, and exuberance) have been studied less frequently. Caregiver direction of early exchanges with the child is critical, given the extent to which young infants depend on caregivers for the regulation of biological and behavioral systems (McKenna & Mosko, 1994). However, older infants become more mature and competent interaction partners, able to participate in an increasingly meaningful manner. Thus, it is not surprising that a more balanced pattern of verbal initiations and responses between the mother and child have been linked with positive social adjustment and academic success, including more advanced performance at school and superior social competence (Baldwin, Cole, & Baldwin, 1982; Lindsey & Mize, 2000). Intensity of parent–child interactions encompasses high versus low levels of complexity and loud versus quiet verbal/vocal exchanges (e.g., how enthusiastically the parent engages the infant). Intensity is also related to the level of stimulation afforded by the exchange with the child. This type of active engagement, wherein the mother provides physical and verbal stimulation during play, has been associated with positive social outcomes in the child, such as more mature play and more socially competent interactions with peers and other caregivers (Alessandri, 1992; Pempek, Demers, Hanson, Kirkorian, & Anderson, 2011). Stimulation (similar to intensity) was also related to attachment security (Belsky, Rovine, & Taylor, 1984; DeWolff & van Ijzendoorn, 1997), with moderate levels resulting in more secure attachment. However, we have also shown that intensity of play exchanges contributed to increases in child fearfulness in the first year of life (Gartstein, Hancock, & Iverson, 2018).

Importantly, all of these parent–child interaction dynamics (i.e., responsiveness, reciprocity, intensity, parent vs. child directedness) have been linked with individual differences in temperament, approach and fear/avoidance in particular (Braungart-Rieker, Hill-Soderlund, & Karrass, 2010; Gartstein et al., 2018; Gartstein, Iverson, Desmarais, & Hancock, 2017). Differences in hemispheric activation, important to understanding individual differences in approach/avoidance emotion and motivation, can also be critical to parent–child interactions. Emerging literature is beginning to demonstrate links between maternal behavior and infant electroencephalogram (EEG) (Bernier et al., 2016; Swingler, Perry, Calkins, & Bell, 2014). For example, more responsive mothers had infants with increases in theta and alpha power from 5 to 10, and again from 10 to 24 months of age. In older children, controlling/punitive parenting emerged as a contributor to greater error-related negativity—negative deflection in the event-related potential (ERP) after error commission thought to reflect activation of the error-detection system (Brooker & Buss, 2014; Meyer, Carlton, Chong, & Wissemann, 2019; Meyer et al., 2015). In addition, studies have been conducted with infants of depressed mothers, demonstrating links between symptoms, low sensitivity, intrusive or withdrawn parenting, and child relative right frontal activation (e.g., Diego, Field, Jones, & Hernandez-Reif, 2006; Jones, Field, Fox, Davalos, & Gómez, 2001; Hardin et al., in press; Wen et al., 2017). Bidirectional relations between parenting and child brain activity are important to elucidate, yet, frontal alpha asymmetry child effects—the extent to which these patterns of activation in the infant contribute to parenting/parent–child interactions, have not been examined to date and will be the focus of the present study.

The importance of emotion/motivation-related lateralization of the frontal brain region has been recognized for some time (Davidson & Fox, 1989; Fox, 1994). Frontal EEG asymmetry is typically examined as a marker of this lateralization, computed as a difference in EEG alpha power between homologous electrodes: right minus left alpha (Reznik & Allen, 2018). As alpha is inhibitory to cortical network activity, higher asymmetry scores reflect relatively stronger left frontal activation compared to the right hemisphere (Allen, Coan, & Nazarian, 2004). Approach motivation and emotions are generally associated with greater activation of the left frontal area whereas avoidance-related experiences recruit the right frontal region (Coan & Allen, 2004; Davidson, 2001). Relative right activation was linked with withdrawal behaviors and emotions (e.g., behavioral inhibition, fear), with infants exhibiting right frontal asymmetry, for example, crying more upon separating from mothers (Bell & Fox, 1994; Davidson & Fox, 1989; Fox, Calkins, & Bell, 1994). Right frontal activation has also been consistently linked with anxiety disorders and more severe symptoms for adults and children, with a meta-analysis providing evidence of a moderately large effect size (Thibodeau, Jorgensen, & Sangmoon, 2006). Positive affectivity typically occurs in the context of relative left frontal activation associated with motivation toward potential rewards, and infants exhibiting left frontal asymmetry expressed greater positive affect and more readily approached an unfamiliar experimenter during a playful episode (Hane, Fox, Henderson, & Marshall, 2008). However, when rewards are blocked, positive affect can turn to frustration and anger (Harmon-Jones & Allen, 1998; Harmon-Jones & Gable, 2018).

A majority of studies to date have relied on EEG recordings in the context of baseline conditions, demonstrating that resting frontal asymmetry reflects trait-like individual differences in approach/avoidance-related motivation and emotions central to temperament and personality theories (e.g., Rothbart, Ahadi, & Evans, 2000). In contrast to these dispositional models, more recently formulated dynamic approaches to asymmetry focus on responsiveness during emotion-eliciting episodes (Coan, Allen, & McKnight, 2006; Reznik & Allen, 2018). That is, unlike the dispositional/trait approach to frontal asymmetry, the capability model focuses on the degree to which individuals rely on approach versus withdrawal information processing biases and actions depending on the demands of the situation (Coan et al., 2006). According to the capability model, individual differences in frontal EEG asymmetry reflect interactions between the emotional demands of specific situations and the emotion-regulatory abilities of individuals. That is, whereas baseline frontal EEG asymmetry conveys information about typical approach versus avoidance orientation, asymmetry that occurs in response to an emotion-eliciting situation reflects the central nervous system (CNS) adaptation to the stimulus. Measuring brain activity associated with this response in the social context (stressful and potentially pleasant) relying on alpha frontal asymmetry will inform our understanding of social development, because of its established emotion/motivation correlates. Infancy is a particularly critical time for such evaluations, given that the blueprint for social interactions (Page et al.., 2010), and presumably the underlying brain activity, are established during this developmental period. Theoretical advances of the capability model are yet to be fully translated into emotion lateralization research in early childhood, and the present study was aimed at addressing this gap in research.

Several EEG asymmetry studies conducted with infants have focused on responses during emotion-eliciting tasks, controlling for baseline (e.g., Buss et al., 2003; Diaz & Bell, 2012; Gartstein, Bell, & Calkins, 2014; Lusby, Goodman, Bell, & Newport, 2014). This approach can be informative in capturing a stimulus-driven response; however, considering changes from baseline to the emotion-eliciting episode via difference scores actually reflects adaptions mounted by the CNS in terms of the frontal asymmetry and associated approach/withdrawal. That is, although an ANCOVA-type approach has been typically utilized in studies addressing the capability theory, this quantitative model addresses questions concerning individual differences after predictively controlling for initial levels. Specifically, ANCOVA addresses the question: "given that participants start with the same score, how do they differ at posttest?" (Smolkowski, 2020). On the contrary, difference score analyses answer questions regarding variability in gains (or losses), and it has been argued that the latter are generally more informative (e.g., Fitzmaurice, Laird, & Ware, 2004). Furthermore, it has been suggested that the use of ANCOVA should be reserved for analyses of randomized controlled trials (Oakes & Feldman, 2001), wherein equalizing groups on covariates at baseline is actually the goal. Although some concerns with the use of difference scores have been voiced, the latter generally involve reliability of scores utilized in the computation of gains, and are minimized herein due to noted reliability of EEG asymmetry indicators (e.g., Gasser, Bächer, & Steinberg, 1985; Towers & Allen, 2009). Moreover, although relatively novel in the area of social development, the difference score approach has been used widely in the study of infant cognition, visual attention, and behavior (Montague & Walker-Andrews, 2001; Oakes & Spalding, 1997; Ross-Sheehy, Perone, Macek, & Eschman, 2017). Thus, the difference score model was considered in this study in order to directly examine changes (gains or losses in frontal EEG alpha power) from baseline to emotion-elicitation.

1.1 | Present study

The present study addresses a gap in research by examining how changes in infant frontal EEG asymmetry during positive and negative emotion-eliciting social tasks relative to baseline translate into differences in parent–child interaction factors: sensitivity/responsiveness, reciprocity/synchrony, directedness (i.e., parent of infant-directed exchanges), and intensity. It should be noted that this study is based on cross-sectional data, which does not afford a conclusive directional interpretation. Thus, although we focus on child effects, bidirectional influences, including parental contributions to infant brain activity, represent potential alternative explanatory mechanisms. It was hypothesized that infants shifting toward relative left frontal activation would experience more responsive and reciprocal interactions. More salient approach motives, especially in the social context, as well as a greater propensity toward positive affect (both associated with relative left frontal activation; Hane et al., 2008) are likely to result in higher quality mother–infant exchanges (i.e., higher levels of responsiveness and reciprocity). Exchanges of left-shifting infants were hypothesized to be more child-directed in nature, and lower in intensity, based on research addressing behavioral fear/avoidance (Gartstein et al., 2018). As relative right frontal activation in infancy was linked with lower quality interactions with caregivers (Hane & Fox, 2006), infants shifting to a more right-dominant frontal alpha pattern were hypothesized to engage in less responsive and reciprocal, and more intense, exchanges with their caregivers, who were in turn expected to direct interactions to a greater extent. Avoidance tendencies and negative affectivity associated with greater relative right frontal activation (e.g., Fox et al., 1994) do not bode well for responsive and reciprocal interactions with parents, and likely contribute to caregivers being more directive in exchanges, possibly intrusive and overly stimulating. A priori hypotheses could not be formulated regarding differences in frontal asymmetry changes in the context of a positive versus a negative emotion-eliciting experimental manipulation due to the dearth of prior research. Thus, this aspect of the present study should be considered exploratory in nature.

2 | METHOD

2.1 | Participants

Mothers with infants 6–12 months of age were recruited via social media (i.e., Facebook) advertisements, local birth centers/parent-infant programs, and pamphlets distributed in locations frequented by families with infants (e.g., pediatricians, local mall, farmers market, and so forth) in two Inland Northwest communities. Children with significant medical or birth complications, including infants born preterm (<37 weeks of gestation) and/or with identified developmental delays/disabilities, were excluded. Non-English-speaking caregivers were also excluded, as instruments utilized for the larger project (not reported herein) are not available in languages other than English. All families received an infant T-shirt (about $10 value) incentive at the end of their laboratory visit for participation in the study. Of the 79 families approached regarding this study, 59 participated (mean age = 8.44 months, *SD* = 1.51 months, 34 girls), with remaining parents citing a lack of time as a reason for declining. Infants, with sufficient usable EEG data across baseline and emotion-eliciting tasks (*N* = 50), contributed to this study. Excluded cases did not provide sufficient EEG data for analyses because of failure to complete the required recording due to excessive infant distress, uninterpretable EEG data as a result of distress/motor activity-related artifacts, or equipment malfunction. Families involved in this study were largely Caucasian (90%), with a number of Asian/Asian-American (3.3%), Latinx (1.7%), Native American (1.7%), and multiracial (3.3%) participants. Mothers were primarily married (90.9%), between 21 and 42 years of age (28.72 years, *SD* = 4.64 years), and well-educated (*M* = 16.01 years, *SD* = 2.04 years), with family income above $30,001 (81.1%). A number of mothers (24%) identified themselves as “stay-at-home” at the time of the evaluation, with the remainder of the sample reporting a variety of occupations (e.g., insurance agent, librarian, physical therapist).

2.2 | Procedure

The laboratory visit involved a parent–child interaction episode, completed prior to electrode placement. This free play interaction was followed by EEG data acquisition in the context of a baseline episode, as well as a two-trial version of the Still Face Procedure (SFP; Haley & Stansbury, 2003; Tronick, Als, Adamson, Wise, & Brazelton, 1978), wherein the mother is instructed to ignore the infant for 2 min on two separate occasions, interspersed with, then, followed by a play episode. The Peek-a-boo episode was subsequently administered, following the Laboratory Temperament Assessment Battery (Lab-TAB; Goldsmith & Rothbart, 1996) protocol. These episodes were selected because both provide a social context for examining an EEG asymmetry response, with the SFP challenging the infant with caregiver's unavailability, and the peek-a-boo activity providing an opportunity for a potentially pleasant interaction.

2.3 | EEG recording

Infants were seated in a highchair with an EEG cap (Cortech Solutions, Inc.; Wilmington, NC) placed on their heads. After the cap's placement, small amounts of electroconductive gel were introduced in each electrode site.

Individual "pin-type" electrodes (BioSemi - Cortech Solutions, Inc.; Wilmington, NC) were then "snapped" into each corresponding site. All of the EEG data were collected via the BioSemi Active Two amplifiers with initial screening via the BioSemi acquisition software at a sampling rate of 1,024 Hz. The EEG was referenced to Cz online. Baseline EEG was recorded for 60 s while infants watched a segment of Baby Einstein, Baby Mozart video, wherein colorful objects are displayed as classical music is played (Perone & Gartstein, 2019a, 2019b). The duration of EEG recording and the stimuli are consistent with existing infant baseline EEG studies (Bell, 2001; Bell & Fox, 1992; Benasich, Gou, Choudhury, & Harris, 2008; Marshall, Bar-Haim, & Fox, 2002; Morasch & Bell, 2011). Unlike older children and adults, infants are not able to follow instructions to sit still; thus, stimuli have to be presented to facilitate a calm/alert state necessary for a baseline EEG recording (Anderson & Perone, 2018). A video presentation rather than a social stimulus (e.g., experimenter blowing bubbles; Dawson, Panagiotides, Klinger, & Spieker, 1997; Lusby, Goodman, Yeung, Bell, & Stowe, 2016), was utilized in this study to provide a more salient contrast with our experimental episodes, which were social in nature.

During baseline, mothers were instructed to limit their interaction with the infant to directing their infants' attention to the screen. EEG was also recorded during SFP and Peek-a-boo episodes. As a repeated version of SFP was administered, EEG recording during the second trial was utilized because it was expected to result in the greatest social challenge for the infant. Baseline, components of SFP procedure, as well as Peek-a-boo, were time-locked to the EEG recording via E-Prime software (Psychology Software Tools, Inc.), preprogramed to transmit triggers initiated by specific keyboard presses into the EEG acquisition software. Operated by a trained research assistant, E-Prime transmitted unique numerical triggers into the BioSemi acquisition software, marking each task's beginning and end points. All of the E-Prime triggers were assigned unique numerical values, allowing baseline, second SFP episode, and Peek-a-boo data to be extracted for further processing.

2.4 | EEG processing

The EEG was processed in Matlab using EEGLAB. The continuous EEG was downsampled to 256 Hz and a high-pass filter at 1 Hz, and a 60 Hz notch filter were applied, to remove high-frequency and low-frequency noise, respectively. Excessively noisy electrodes were removed and interpolated, and the EEG was then re-referenced to the average. A semiautomatic approach was taken with respect to eyeblinks, relying on ICA and also visual inspection, with pairs of research assistants (RAs) scanning EEG data and removing segments wherein peaks indicative of eyeblinks were detected for Fp1 and Fp2, as recommended (Bell & Cuevas, 2012). RAs worked in pairs, with segments for which consensus was achieved eliminated. The continuous EEG was divided into 1 s epochs with 50% overlap. Epochs were rejected if the absolute voltage of any electrode exceeded 100 microvolts for more than 100 ms. Time-frequency decomposition was performed on the remaining epochs using Fast Fourier Transformation (FFT) with a 1 s Hanning window for 3 to 50 Hz. Only infants with at least 10 dfts of baseline, SFP, and Peek-a-boo task data were included. Power was calculated in alpha (6–9 Hz), consistent with prior research (Bell & Fox, 1992; Buss et al., 2003; Degnan et al., 2011) and subsequently natural log transformed. F3 and F4 were used to calculate asymmetry scores: subtracting the natural log of alpha power on the left (F3) from the natural log of alpha power on the right (F4), as previously described (Fox, Henderson, Rubin, Calkins, & Schmidt, 2001), because these frontal sites have been most frequently utilized in the existing research (Reznik & Allen, 2018). Lower levels of alpha reflect cortical activation (Barry, Clarke, Johnstone, Magee, & Rushby, 2007; Buss et al., 2003; Klimesch, Sauseng, & Hanslmayr, 2007); thus, lower asymmetry scores reflect right lateralization, and higher scores signal left lateralization (Hane & Fox, 2006). Excellent test–retest and internal consistency for alpha EEG asymmetry indicators have been reported, along with inter-rater reliability of peak classification (i.e., present, absent, multiple peaks) for component electrodes (Allen et al., 2004; Gasser et al., 1985; Marshall et al., 2002; Towers & Allen, 2009).

2.5 | Measures

2.5.1 | Still face procedure

SFP (Tronick et al., 1978), as described by Haley and Stansbury (2003), was administered collecting EEG data. That is, the repeated version of SFP was used to elicit infant distress in response to the caregiver's emotional unavailability (i.e., mother displaying a flat facial expression and abstaining from communication). The second SFP trial is a standard option commonly employed (e.g., DiCorcia, Snidman, Sravish, & Tronick, 2016; Handal et al., 2017; Lowe et al., 2017) since the initial publication documenting this procedural adaptation (Haley & Stansbury, 2003). The second trial of SFP was initially introduced to facilitate the assessment of physiological responsiveness (e.g., cortisol levels) in the context of a challenging situation, and was leveraged to collect EEG data herein (Gartstein, 2019). SFP began with the experimenter instructing the mother to play with her infant utilizing stacking cups (provided by the experimenter) for 2 min, and then, to display a "still face" (i.e., emotionless, flat facial expression) for an equivalent duration (or stopping after 15 s of hard crying), refraining from any vocal expressions. The SFP trial was followed by a 2-min play sequence, after which the SFP was repeated. The task ended with another 2-min play sequence to reduce infant distress. The SFP often results in distress (including hard crying), reducing the amount of analyzable EEG data. Nonetheless, sufficient usable EEG data (about 1 min) was available for 50 cases.

2.5.2 | Peek-a-boo/The laboratory temperament assessment battery

Peek-a-Boo/The Lab-TAB (Goldsmith & Rothbart, 1996), a reliable and valid observation protocol (Buss et al., 2003; Diaz & Bell, 2012; Gagne, Van Hulle, Aksan, Essex, & Goldsmith, 2011) was utilized, with Peek-a-boo, a positive affectivity-eliciting task administered to infants. With infants in a highchair, mothers were asked to disappear behind a screen and reappear through a series of four windows while simultaneously saying "peek-a-boo" and smiling. This standardized approach minimizes the impact of individual differences in maternal playfulness and enthusiasm on the presentation. The Peek-a-boo episode was shown to elicit smiling, laughter, and other manifestations of joy and positive affectivity (e.g., Gartstein et al., 2018).

2.5.3 | Parent–child interaction observations

Parent–child interaction observations (Gartstein et al., 2008, 2018), were conducted and recorded in the laboratory, prior to cap/electrode placement. Mothers were instructed to play with their infants the way they typically would and were provided a toy telephone to facilitate the interaction. Ratings for sensitivity/responsiveness, reciprocity/synchrony, intensity, and directedness (Table 1), designed to serve as markers of dyadic processes that involve coordinated actions of caregivers and infants, were subsequently assigned by coders demonstrating inter-rater reliability (ICCs 0.62–0.98; mean ICC = 0.83), using data from 20% of the sample. Interactions were observed in the context of free play, with mothers engaging infants in typical play interactions with a toy telephone for 2 min.

2.6 | Analytic strategy

Baseline asymmetry values were subtracted from the Peek-a-boo and the second SFP episode asymmetry scores, respectively: (a) *Peek-a-boo* alpha asymmetry—baseline asymmetry; (b) *SFP* alpha asymmetry—baseline asymmetry. These difference scores were computed to examine hypothesized child neurophysiological effects with respect

TABLE 1 Parent-infant interaction coding scheme

Scales	Codes/Descriptions 1	4	7
Sensitivity/ Responsiveness	Extremely nonresponsive/sensitive: lacks genuine empathy and interest in infant. Parent does not (a) initiate play; (b) reinforce infant activities; (c) draw infant into joint activity; (d) give encouragement; (e) allow infant independent activity; (f) effectively extends infant activity	Moderately responsive/sensitive: moderate empathy and interest in infant. Parent periodically (a) initiates play; (b) reinforces infant activities; (c) draws infant into joint activity; (d) gives encouragement; (e) allows infant independent activity; (f) effectively extends infant activity	Extremely responsive/sensitive: prompt, regular, genuine empathy and interest in infant. Parent consistently (a) initiates play; (b) reinforces infant activities; (c) draws infant into joint activity; (d) gives encouragement; (e) allows infant independent activity; (f) effectively extends infant activity
Reciprocity/synchrony	Extremely asynchronous/nonreciprocal: (a) low frequency of simultaneous movement; (b) low tempo similarity; (c) low coordination/ smoothness	Moderately synchronous/reciprocal: (a) moderate frequency of simultaneous movement; (b) moderate tempo similarity; (c) moderate coordination/smoothness	Extremely synchronous/reciprocal: (a) high frequency of simultaneous movement; (b) high tempo similarity; (c) high coordination/ smoothness
Intensity	Extremely low intensity: (a) very quiet verbal/ vocal exchange; (b) low levels of complexity; (c) low parental exuberance	Moderate intensity: (a) moderately audible verbal/vocal exchange; (b) moderate complexity; (c) moderate parental exuberance	Extremely high intensity: (a) very loud verbal/vocal exchange; (b) high levels of complexity; (c) high parental exuberance
Child versus Parent Directedness	Extremely child-directed interaction: (a) child frequent directs activity—dyad follows direction offered by the child; (b) dyad frequently shifts activity following the child's lead—many instances of dyadic activity changing, after the child's behavior has changed; (c) parent rarely attempts to direct activity	Balanced interaction—mother and child contribute equally: (a) interactions are balanced in control, as dyad's activity follows directions offered by both participants; (b) dyadic activity frequently changes after the child's and the parent's behavior has changed; (c) parent and child demonstrate attempts to direct activity	Extremely parent-directed interaction: (a) mother frequent directs activity—dyad follows direction offered by the parent; (b) dyad frequently shifts activity following the mother's lead—many instances of dyadic activity changing, after the parent's behavior has changed; (c) child rarely attempts to direct activity

Note: All coding scales based on 7-point Likert Scales (1–7).

to mother–infant interaction factors. A positive frontal EEG asymmetry score reflects greater left frontal activation (Hane & Fox, 2006) and classifying children's frontal asymmetry based on positive or negative values was demonstrated as a reliable and valid measure of asymmetry (Diaz et al., 2019; Fox et al., 2001; Smith & Bell, 2010). Thus, the resulting difference scores were dichotomized: one group with values > 0 (shift toward relative left frontal activation) and another group with asymmetry difference scores < 0 (shift toward relative right frontal activation). No infants had symmetry, and thus, all were classifiable into either a left frontal asymmetry group or a right frontal asymmetry group: *SFP2*—64% left frontal asymmetry, 36% right frontal asymmetry; *Peek-a-boo*—52% left frontal asymmetry, 48% right frontal asymmetry. Four analyses of covariance (ANCOVAs) were subsequently conducted, with parent–child interaction factors as the dependent variables: sensitivity/responsiveness, reciprocity/synchrony, intensity, and directedness. Peek-a-boo and SFP asymmetry change from baseline groups served as independent variables. Infant age was included as a covariate due to the age variability in the present sample. Sex was also introduced as a covariate as sex differences have been reported in approach avoidance behavioral tendencies and in studies addressing related alpha frontal asymmetry (Gartstein et al., 2014; Rothbart, 1988).

3 | RESULTS

Descriptive statistics were computed first (Table 2). On average, the shift from baseline to peek-a-boo was negative, reflective of relative right frontal activation whereas asymmetry change from baseline to SFP was positive, associated with relative left frontal activation. However, the overall ranges and standard deviations suggest a number of infants moved in the opposite direction, toward relative left frontal activation during peek-a-boo and relative right frontal activation in the context of SFP. It should be noted that 18% of infants remained consistent in their shift toward relative right frontal activation across SFP and Peek-a-boo, with 26% demonstrating a consistent shift in the direction of left hemisphere dominance in both tasks. Simple correlation coefficients were computed primarily for descriptive purposes (Table 3), demonstrating significant and trend-level effects for covariates included in subsequent analyses.

ANCOVAs were conducted next, yielding a number of hypothesized results (Table 4). Specifically, SFP asymmetry change score groups differed on the dyadic reciprocity/synchrony [$F(1, 44) = 6.95$, $p = .015$]. Infants who shifted toward stronger frontal activation of the left hemisphere experienced greater reciprocity when interacting with mothers (Figure 1). The SFP asymmetry change score groups also differed on intensity [$F(1, 44) = 8.09$, $p = .009$], as well as direction [$F(1, 44) = 5.90$, $p = .023$]. Mother–infant interactions among infants shifting toward greater activation on the right were more directive (Figure 2) and intense (Figure 3), controlling for covariates. Thus, SFP-based asymmetry difference score groups were associated with significantly different parent–child interaction outcomes (i.e., reciprocity/synchrony, intensity, and direction of exchanges), and these effects were

TABLE 2 Descriptive statistics

Variable	Mean	*SD*	Range
Asymmetry scores			
Asymmetry change from baseline to peek-a-boo	−0.056	0.548	−1.09–1.02
Asymmetry change from baseline to SFP	0.017	0.526	−1.44–0.76
Parent–child interaction factors			
Responsiveness	4.78	1.54	2.0–7.0
Reciprocity/Synchrony	4.45	1.36	1.0–7.0
Intensity	4.45	1.32	1.0–7.0
Direction	4.00	1.41	1.0–6.0

TABLE 3 Correlation coefficients: covariates, independent, and dependent variables included in the study

	1	2	3	4	5	6	7	8
1. Asymmetry change/ baseline to peek-a-boo	–							
2. Asymmetry change/ baseline to SFP	0.606**	–						
3. Infant sex	0.024	0.230#	–					
4. Infant age	0.258#	0.139	0.062	–				
5. Responsiveness	0.193	0.238#	0.189	−0.025	–			
6. Reciprocity	0.188	0.282*	0.423**	0.081	0.771**	–		
7. Intensity	0.027	−0.143	0.144	0.154	0.152	0.299*	–	
8. Direction	0.096	−0.073	0.207	0.074	0.446**	0.588**	0.330*	–

Note: Infant sex was coded as 1-girls, 2-boys.
*$p < .01$, **$p < .05$, #$p < .10$.

TABLE 4 ANCOVA *F*-values for comparisons of EEG asymmetry change groups

	Infant age	Infant sex	Peek-a-boo	SFP
Reciprocity/Synchrony	1.53	15.77**	4.23#	6.95*
Sensitivity/Responsiveness	0.01	3.99#	1.66	1.74
Intensity	2.29	7.03**	0.60	8.09**
Direction	2.53	5.13*	3.83#	5.90*

Note: F-statistics related to peek-a-boo and SFP reflect the change in EEG asymmetry from baseline to task group effect: shift toward relative left frontal activation (asymmetry change > 0) versus right frontal activation (asymmetry change < 0) for peek-a-boo and SFP, respectively. *F*-values for covariates (i.e., infant age and sex) are presented to reflect their respective contributions to the dependent variables (mother–infant interaction factors).
#$p < .10$, *$p < .05$, **$p < .01$.

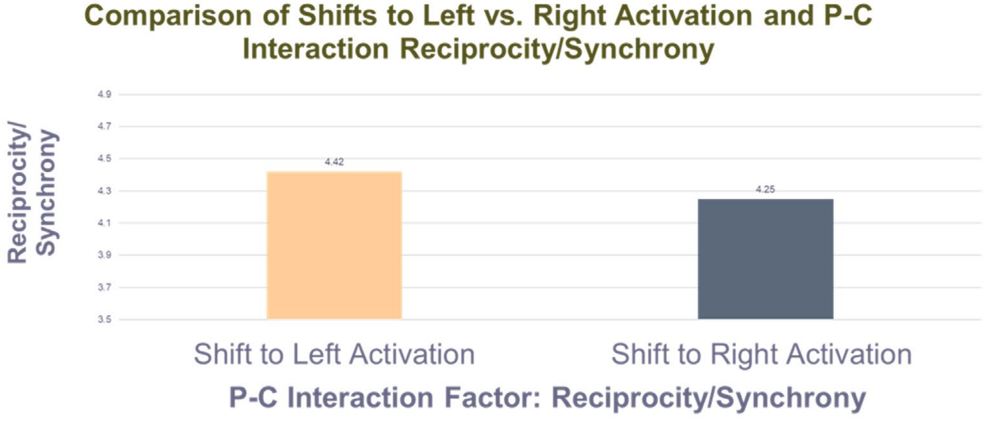

FIGURE 1 Differences between EEG asymmetry shift groups (left vs. right), observed in the context of the Repeated Still Face, on the reciprocity/synchrony parent–child interaction factor

independent of the Peek-a-boo-based indicators, considered simultaneously, despite a significant correlation among the two difference scores (Table 3). The Peek-a-boo asymmetry change score groups were associated with trend-level differences only, and no significant effects of interest were observed for sensitivity/responsiveness

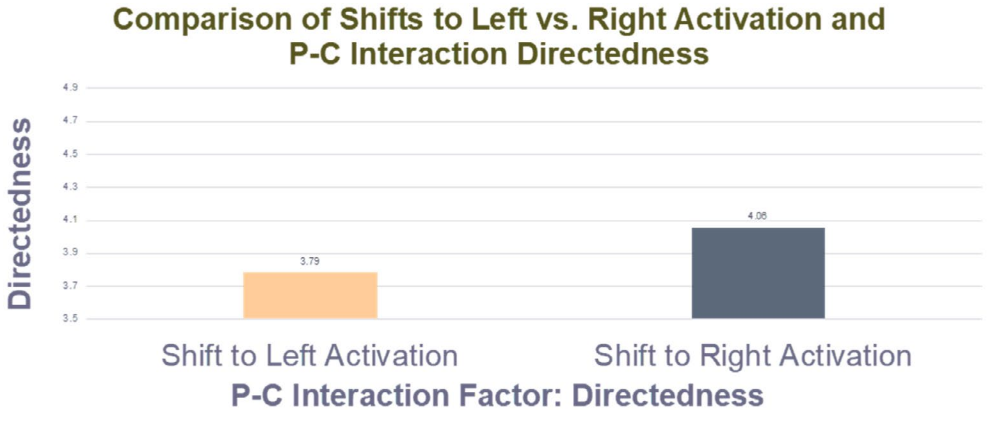

FIGURE 2 Differences between EEG asymmetry shift groups (left vs. right), observed in the context of the Repeated Still Face, on the directedness parent–child interaction factor

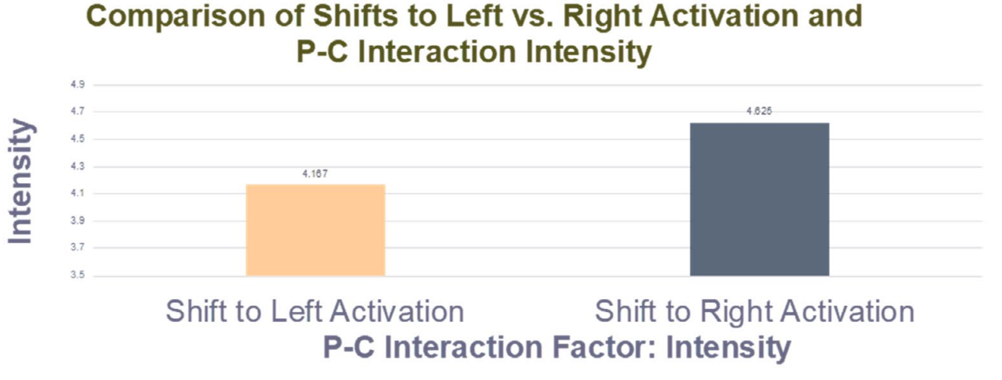

FIGURE 3 Differences between EEG asymmetry shift groups (left vs. right), observed in the context of the Repeated Still Face, on the intensity parent–child interaction factor

of mother–infant interactions (Table 4). We also explored the contribution of an interaction between asymmetry group assignment for SFP and Peek-a-boo tasks—the interaction between asymmetry shift group (left vs. right) assigned based on the difference from baseline to SFP and the asymmetry change group from baseline to Peek-a-boo. However, these terms did not reach statistical significance in any of the ANCOVAs conducted in this study. Although not the focus of the present study, results associated with infant sex should also be noted, as this co-variate emerged as significant for reciprocity/synchrony, intensity, and direction of exchanges, with a trend-level effect for sensitivity/responsiveness (Table 4).

Parallel hierarchical multiple regression analyses were also conducted, examining the contribution of continuous EEG asymmetry difference scores, and producing largely consistent results (Table 5). Infant EEG asymmetry did not account for significant variance in sensitivity/responsiveness of interactions, with baseline to SFP asymmetry change only explaining significant variance for reciprocity/synchrony and intensity of interactions, and a trend-level effect emerging for direction of exchanges. As these analyses were conducted to reflect the same effects as the ANCOVAs, the interaction term (i.e., interaction between asymmetry changes from baseline for SFP and Peek-a-boo tasks) was included. The latter predictor did not make a significant contribution in any of the models.

TABLE 5 Hierarchical multiple regression statistics for EEG asymmetry change scores

Variable	*R*	R^2	R^2 change	*F* change	Beta
Reciprocity/Synchrony					
Overall model	.67	.45	.05	2.16	
Child's sex					.71**
Child's age					.27
Asymmetry change to SFP					.77**
Asymmetry change to peek-a-boo					.17
Asymmetry change interaction SFP*Peek-a-boo					.51
Sensitivity/Responsiveness					
Overall model	.44	.19	.06	1.49	
Child's sex					.35
Child's age					.06
Asymmetry change to SFP					.51
Asymmetry change to peek-a-boo					.07
Asymmetry change interaction SFP*Peek-a-boo					.52
Intensity					
Overall model	.54	.29	.05	1.42	
Child's sex					.49*
Child's age					.36#
Asymmetry change to SFP					−.87**
Asymmetry change to peek-a-boo					−.06
Asymmetry change interaction SFP*Peek-a-boo					.47
Direction					
Overall model	.53	.28	.01	.05	
Child's sex					.48*
Child's age					.31
Asymmetry change to SFP					−.62#
Asymmetry change to peek-a-boo					.34
Asymmetry change interaction SFP*peek-a-boo					.09

Note: Final model results presented in the table.
#$p < .10$, *$p < .05$, **$p < .01$.

4 | DISCUSSION

The primary aim of this study was to examine differences associated with changes in infant frontal EEG asymmetry during positive and negative emotion-eliciting social tasks relative to baseline, focusing on how these asymmetry shifts translate into parent–child interaction factors: sensitivity/responsiveness, reciprocity/synchrony, directedness, and intensity. Consistent with our hypotheses, infants who shifted toward greater left activation during a mildly stressful social task engaged in more synchronous and reciprocal play interaction with their mothers. Previous research has established that greater relative left hemisphere activation is associated with more advanced behavioral regulation (Goodman, Rietschel, Lo, Costanzo, & Hatfield, 2013; Jackson et al., 2003; Papousek, Freudenthaler, & Schulter, 2011) and higher levels of positive affectivity (Coan & Allen, 2004; Davidson

& Rickman, 1999; Fox, 1991; Fox et al., 1994). Our findings extend the existing literature to the context of parent–child interactions and potential facilitation of reciprocal exchanges with caregivers. It may also be that parents who establish more reciprocal exchanges with infants support shifts toward relative left frontal activation in the context of mildly stressful exposures.

Our results also indicated that infants who transitioned to greater activity in the right hemisphere in the same mildly stressful task were involved in more parent-directed interactions, with the play interaction characterized as more intense, stimulating, and engaging. Infants with greater relative right frontal activation tend to present with elevated levels of withdrawal and associated negative emotions (Bell & Fox, 1994; Davidson & Fox, 1989; Fox et al., 1994). Mothers may be inclined to dominate interactions with more distress-prone children in an attempt to modulate their distress, helping them to remain calm and/or recover. Mothers could also be motivated to engage in more intense and stimulating play exchanges (e.g., interacting more enthusiastically) with infants exhibiting withdrawal/negative affectivity associated with relative right frontal activation. At the same time, children may present with shifts toward relative right frontal activation when their mothers dominate interactions and/or engage in an overly simulating manner.

Overall, results of this study support the importance of lateralized hemispheric activation and individual differences in associated approach/avoidant behaviors in relation to parent–child interaction dynamics. However, significant effects were not observed for sensitivity/responsiveness. This pattern of results contradicts our hypotheses and appears inconsistent with the Swingler and colleagues (2014) study. However, the latter design differed substantially from the present study, as 5-month-old infants who exhibited greater left frontal alpha activation during baseline, and also had highly responsive mothers, were able to better regulate their emotions during an arm-restraint task. Perhaps maternal sensitivity/responsiveness is less dependent on child effects, and more a function of parental characteristics (e.g., depressive symptoms; Field, 2010; Goodman et al., 2011).

Furthermore, significant effects for the shift in frontal asymmetry were observed in response to a mild social stressor, but not from baseline to a positive emotion-eliciting episode. It may be that the distress context is more salient in terms of elucidating critical individual differences that shape parent–child interactions described as synchronous, parent versus child directed, and intense in particular. Despite the variability in emotional valence (i.e., SFP was expected to elicit distress and Peek-a-boo typically results in positive affect; Gartstein et al., 2018; Haley & Stansbury, 2003), it is notable that the proportion of infants shifting left versus right was not markedly different across the two conditions (χ^2 = 3.60; NS). Moreover, the shift from baseline was in the negative direction for Peek-a-boo (i.e., toward relative right frontal activation) and positive for SFP, indicative of transitioning toward greater left hemisphere dominance. It is possible that Peek-a-boo would produce a more reliable shift toward left frontal activation if the presentation of a smiling face was interspersed with different emotional expressions. This approach would likely make the happy stimuli more salient and evoke a violation of expectations, similar to SFP (Montague & Walker-Andrews, 2001). An additional explanation involves the sequence of experimental procedures, with Peek-a-boo following SFP, to ensure that infants were able to tolerate the mild stress resulting from mothers' emotional unavailability in the context of SFP. It may be that they did not sufficiently recover from SFP when engaging in Peek-a-boo, or were beginning to experience fatigue as the experimental session progressed, which in turn influenced brain activity.

As already note, another consideration involves the cross-sectional nature of the data, which opens the door to interpretations wherein mother–infant interaction factors influence changes in child asymmetry. Case in point, it may be that mothers' intensity of interactions contributes to infant shifts toward relative right frontal activation during SFP. This interpretation is tenable given that we have previously reported intensity of play exchanges was associated with increases in fearfulness (Gartstein et al., 2018), noting overstimulation as a potential mechanism. The contribution of infant sex is also notable, despite its role as a covariate. The effect of infant sex was significant for three of the four dependent variables (reciprocity, intensity, and direction), and marginally significant for the fourth—responsiveness, with boys experiencing higher levels of all of these dynamics in exchanges with caregivers. Although this pattern of results requires replication for a conclusive interpretation, it may be that caregivers tend to be more engaged in play with boys, which is manifested as greater reciprocity, intensity/stimulation, and providing direction (i.e., initiating play overtures), in particular.

It is important to note that the results observed in this study across both group-based and continuous score analyses do not reflect trait-level asymmetry, but rather support the capability model (Coan et al., 2006). According to the capability model, meaningful individual differences in frontal EEG asymmetry can be interpreted as interactions between the emotional demands of specific situations and the emotion-regulation abilities individuals exhibit. Particularly, the capability model emphasizes the importance of the degree to which individuals are able to demonstrate flexibility in approach versus behavioral inhibition responses, depending on the situational demands. Capability-based indicators were shown as superior predictors in other experimental context (e.g., with respect to information processing biases; Pérez-Edgar, Kujawa, Nelson, Cole, & Zapp, 2013), and studying frontal asymmetry as reflecting flexibility in adaptations to one's social context, rather than a generalized tendency to engage in approach versus avoidance, may lead to a better understanding of relations between the emerging neurophysiological organization and interactional dynamics.

Despite its contributions to the literature, the present study is not without limitations, including a relatively homogeneous small sample. Larger and more diverse samples should be recruited in future efforts, providing more representative and generalizable results. As noted, cross-sectional data provided the basis for the present research, prohibiting a conclusive interpretation with respect to the direction of effects, and future research should include longitudinal evaluations. Unfortunately, maternal and child affect was not coded during the parent–child interaction task, because the recording did not allow for consistent views of mother and infant facial expressions, and the latter should be accomplished in future studies. It should be noted that only frontal asymmetry shifts with respect to social stimuli were examined herein, because of their relevance to questions around social development. However, it will be important to see if similar effects generalize to nonsocial emotion-eliciting situations and whether these shifts are linked to emerging self-regulation. In addition, the social nature of the experimental manipulations may have activated the attachment system, and the role of attachment security in the context of effects examined in this study should be considered in the future. It was not possible to compare responders and nonresponders on their sociodemographic characteristics, which represents a limitation. Finally, results of ANCOVA and hierarchical multiple regression analyses were highly similar, but not identical, with only a trend-level effect observed for direction of interactions in the context of the latter. Although not completely unexpected given the differences across these approaches, direction of interaction should be examined further in future research.

Nonetheless, our findings further support the capability model and contribute to a better understanding of relations between infant lateralized brain activation underlying emotional/motivational tendencies and parent–child interaction dynamics, leveraging emotion-eliciting social situations to gage CNS responsiveness and adaption. The difference score approach utilized in this study provides a direct test to this model, capturing change in brain activity between resting state and response to emotional demands. Results of this study suggest an important role for capability-associated EEG asymmetry in infancy with respect to shaping parent-child exchanges and social-emotional development more broadly. Notably, our findings support developmental models that emphasize the interplay between biologically driven responses and contextual factors (Gottlieb & Halpern, 2002), namely, infant brain activity and the quality of parent–child interactions. These results can also be considered as supportive of potential child effects, long viewed as important (Bell, 1968; Scarr & Mccartney, 1983). This study adds to the growing literature linking infant brain activity measured via EEG and parenting (Bernier et al., 2016; Brooker & Buss, 2014; Diego et al., 2006; Swingler et al., 2014). Importantly, our results suggests that one way in which children may shape their experience, and ultimately trajectories of social development, is through influencing the quality of interactions with their caregivers.

ACKNOWLEDGMENTS

We gratefully acknowledge the contribution of participating families and the help of multiple research assistants.

CONFLICT OF INTEREST

None of the coauthors participating in this research and development of the submitted manuscript have any actual or potential conflicts of interest to disclose, including any financial, personal, or other relationships.

DATA AVAILABILITY STATEMENT

Data will be made available upon request to the first/corresponding author.

ORCID

Maria A. Gartstein https://orcid.org/0000-0002-5866-7751

REFERENCES

Ainsworth, M. D. S., Blehar, M. C., Waters, E., & Wall, S. N. (2015). *Patterns of attachment: A psychological study of the strange situation*. Hove, UK: Psychology Press.

Alessandri, S. M. (1992). Attention, play, and social behavior in ADHD preschoolers. *Journal of Abnormal Child Psychology*, *20*(3), 289–302. https://doi.org/10.1007/BF00916693

Allen, J. J., Coan, J. A., & Nazarian, M. (2004). Issues and assumptions on the road from raw signals to metrics of frontal EEG asymmetry in emotion. *Biological Psychology*, *67*(1–2), 183–218. https://doi.org/10.1016/j.biopsycho.2004.03.007

Anderson, A. J., & Perone, S. (2018). Developmental change in the resting state electroencephalogram: Insights into cognition and the brain. *Brain and Cognition*, *126*, 40–52. https://doi.org/10.1016/j.bandc.2018.08.001

Baldwin, A. L., Cole, R. E., & Baldwin, C. P. (1982). Parental pathology, family interaction, and the competence of the child in school. *Monographs of the Society for Research in Child Development*, *47*(5), 90. https://doi.org/10.2307/1166024

Barry, R. J., Clarke, A. R., Johnstone, S. J., Magee, C. A., & Rushby, J. A. (2007). EEG differences between eyes-closed and eyes-open resting conditions. *Clinical Neurophysiology*, *118*(12), 2765–2773. https://doi.org/10.1016/j.clinph.2007.07.028

Bell, M. A. (2001). Brain electrical activity associated with cognitive processing during a looking version of the A-not-B task. *Infancy*, *2*(3), 311–330. https://doi.org/10.1207/S15327078IN0203_2

Bell, M. A., & Cuevas, K. (2012). Using EEG to study cognitive development: Issues and practices. *Journal of Cognition and Development*, *13*(3), 281–294. https://doi.org/10.1080/15248372.2012.691143

Bell, M. A., & Fox, N. A. (1992). The relations between frontal brain electrical activity and cognitive development during infancy. *Child Development*, *63*(5), 1142–1163. https://doi.org/10.1111/j.1467-8624.1992.tb01685.x

Bell, M. A., & Fox, N. A. (1994). Brain development over the first year of life: Relations between electroencephalographic frequency and coherence and cognitive and affective behaviors. In G. Dawson & K. W. Fischer (Eds.), *Human behavior and the developing brain* (pp. 314–345). New York, NY: The Guilford Press.

Bell, R. O. (1968). A reinterpretation of the direction of effects in studies of socialization. *Psychological Review*, *75*, 81–95. https://doi.org/10.1037/h0025583

Belsky, J., Taylor, D. G., & Rovine, M. (1984). The Pennsylvania Infant and Family Development Project, II: The development of reciprocal interaction in the mother-infant dyad. *Child Development*, *55*(3), 706–717. https://doi.org/10.2307/1130123

Benasich, A. A., Gou, Z., Choudhury, N., & Harris, K. D. (2008). Early cognitive and language skills are linked to resting frontal gamma power across the first 3 years. *Behavioural Brain Research*, *195*(2), 215–222. https://doi.org/10.1016/j.bbr.2008.08.049

Bernier, A., Calkins, S. D., & Bell, M. A. (2016). Longitudinal associations between the quality of maternal parenting behavior and brain development across infancy. *Child Development*, *87*, 1159–1174.

Blair, C., Raver, C. C., & Berry, D. J. (2014). Two approaches to estimating the effect of parenting on the development of executive function in early childhood. *Developmental Psychology*, *50*(2), 554–565. https://doi.org/10.1037/a0033647

Braungart-Rieker, J. M., Hill-Soderlund, A. L., & Karrass, J. (2010). Fear and anger reactivity trajectories from 4 to 16 months: The roles of temperament, regulation, and maternal sensitivity. *Developmental Psychology*, *46*, 791–804. https://doi.org/10.1037/a0019673

Brooker, R. J., & Buss, K. A. (2014). Harsh parenting and fearfulness in toddlerhood interact to predict amplitudes of preschool error-related negativity. *Developmental Cognitive Neuroscience*, *9*, 148–159. https://doi.org/10.1016/j.dcn.2014.03.001

Buss, K. A., Schumacher, J. R. M., Dolski, I., Kalin, N. H., Goldsmith, H. H., & Davidson, R. J. (2003). Right frontal brain activity, cortisol, and withdrawal behavior in 6-month-old infants. *Behavioral Neuroscience*, *117*(1), 11–20. https://doi.org/10.1037/0735-7044.117.1.11

Coan, J. A., & Allen, J. J. (2004). Frontal EEG asymmetry as a moderator and mediator of emotion. *Biological Psychology*, *67*(1–2), 7–50. https://doi.org/10.1016/j.biopsycho.2004.03.002

Coan, J. A., Allen, J. J., & McKnight, P. E. (2006). A capability model of individual differences in frontal EEG asymmetry. *Biological Psychology*, *72*(2), 198–207. https://doi.org/10.1016/j.biopsycho.2005.10.003

Davidson, D. (2001). *Essays on actions and events: Philosophical essays* (Vol. *1*). Oxford, UK: Oxford University Press on Demand.

Davidson, R. J., & Fox, N. A. (1989). Frontal brain asymmetry predicts infants' response to maternal separation. *Journal of Abnormal Psychology*, *98*(2), 127–131. https://doi.org/10.1037/0021-843X.98.2.127

Davidson, R. J., & Rickman, M. (1999). Behavioral inhibition and the emotional circuitry of the brain: Stability and plasticity during the early childhood years. In L. A. Schmidt & J. Schulkin (Eds.), *Series in affective science. Extreme fear, shyness, and social phobia: Origins, biological mechanisms, and clinical outcomes* (pp. 67–87). Oxford, UK: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195118872.003.0005

Dawson, G., Panagiotides, H., Klinger, L. G., & Spieker, S. (1997). Infants of depressed and nondepressed mothers exhibit differences in frontal brain electrical activity during the expression of negative emotions. *Developmental Psychology*, *33*(4), 650–656. https://doi.org/10.1037/0012-1649.33.4.650

De Wolff, M. S., & Van Ijzendoorn, M. H. (1997). Sensitivity and attachment: A meta-analysis on parental antecedents of infant attachment. *Child Development*, *68*(4), 571–591. https://doi.org/10.1111/j.1467-8624.1997.tb04218.x

Degnan, K. A., Hane, A. A., Henderson, H. A., Moas, O. L., Reeb-Sutherland, B. C., & Fox, N. A. (2011). Longitudinal stability of temperamental exuberance and social–emotional outcomes in early childhood. *Developmental Psychology*, *47*(3), 765–780. https://doi.org/10.1037/a0021316

Diaz, A., & Bell, M. A. (2012). Frontal EEG asymmetry and fear reactivity in different contexts at 10 months. *Developmental Psychobiology*, *54*(5), 536–545. https://doi.org/10.1002/dev.20612

Diaz, A., Swingler, M. M., Tan, L., Smith, C. L., Calkins, S. D., & Bell, M. A. (2019). Infant frontal EEG asymmetry moderates the association between maternal behavior and toddler negative affectivity. *Infant Behavior and Development*, *55*, 88–99. https://doi.org/10.1016/j.infbeh.2019.03.002

DiCorcia, J. A., Snidman, N., Sravish, A. V., & Tronick, E. (2016). Evaluating the nature of the still-face effect in the double face-to-face still-face paradigm using different comparison groups. *Infancy*, *21*(3), 332–352. https://doi.org/10.1111/infa.12123

Diego, M. A., Field, T., Jones, N. A., & Hernandez-Reif, M. (2006). Withdrawn and intrusive maternal interaction style and infant frontal EEG asymmetry shifts in infants of depressed and non-depressed mothers. *Infant Behavior and Development*, *29*(2), 220–229. https://doi.org/10.1016/j.infbeh.2005.12.002

Field, T. (2010). Postpartum depression effects on early interactions, parenting, and safety practices: A review. *Infant Behavior and Development*, *33*(1), 1–6. https://doi.org/10.1016/j.infbeh.2009.10.005

Fitzmaurice, G. M., Laird, N. M., & Ware, J. H. (2004). *Applied longitudinal analysis*. Hoboken, NJ: Wiley.

Fox, N. A. (1991). If it's not left, it's right: Electroencephalograph asymmetry and the development of emotion. *American Psychologist*, *46*(8), 863–872. https://doi.org/10.1037/0003-066X.46.8.863

Fox, N. A. (1994). Dynamic cerebral processes underlying emotion regulation. *Monographs of the Society for Research in Child Development*, *59*(2–3), 152–166, 250–283. https://doi.org/10.2307/1166143

Fox, N. A., Calkins, S. D., & Bell, M. A. (1994). Neural plasticity and development in the first two years of life: Evidence from cognitive and socioemotional domains of research. *Development and Psychopathology*, *6*(4), 677–696. https://doi.org/10.1017/S0954579400004739

Fox, N. A., Henderson, H. A., Rubin, K. H., Calkins, S. D., & Schmidt, L. A. (2001). Continuity and discontinuity of behavioral inhibition and exuberance: Psychophysiological and behavioral influences across the first four years of life. *Child Development*, *72*(1), 1–21. https://doi.org/10.1111/1467-8624.00262

Gagne, J. R., Van Hulle, C. A., Aksan, N., Essex, M. J., & Goldsmith, H. H. (2011). Deriving childhood temperament measures from emotion-eliciting behavioral episodes: Scale construction and initial validation. *Psychological Assessment*, *23*(2), 337–353. https://doi.org/10.1037/a0021746

Ganiban, J. M., Ulbricht, J., Saudino, K. J., Reiss, D., & Neiderhiser, J. M. (2011). Understanding child-based effects on parenting: Temperament as a moderator of genetic and environmental contributions to parenting. *Developmental Psychology*, *47*(3), 676–692. https://doi.org/10.1037/a0021812

Gartstein, M. A. (2019). Frontal electroencephalogram (EEG) asymmetry: Exploring contributors to the Still Face procedure response. *International Journal of Behavioral Development*, *44*(3), 193–204. https://doi.org/10.1177/0165025419850899

Gartstein, M. A., Bell, M. A., & Calkins, S. D. (2014). EEG asymmetry at 10 months of age: Are temperament trait predictors different for boys and girls? *Developmental Psychobiology*, *56*(6), 1327–1340. https://doi.org/10.1002/dev.21212

Gartstein, M. A., Crawford, J., & Robertson, C. D. (2008). Early markers of language and attention: Mutual contributions and the impact of parent–infant interactions. *Child Psychiatry and Human Development*, *39*(1), 9–26. https://doi.org/10.1007/s10578-007-0067-4

Gartstein, M. A., Hancock, G. R., & Iverson, S. L. (2018). Positive affectivity and fear trajectories in infancy: Contributions of mother–child interaction factors. *Child Development*, *89*(5), 1519–1534. https://doi.org/10.1111/cdev.12843

Gartstein, M. A., Iverson, S. L., Desmarais, E. E., & Hancock, G. R. (2017, April). *Mother-child interactions across the first year of life: Contributions of infant temperament*. Presentation at the biennial convention of the Society for Research in Child Development, Austin, TX.

Gasser, T., Bächer, P., & Steinberg, H. (1985). Test-retest reliability of spectral parameters of the EEG. *Electroencephalography and Clinical Neurophysiology*, *60*(4), 312–319. https://doi.org/10.1016/0013-4694(85)90005-7

Goldsmith, H. H., & Rothbart, M. K. (1996). *Laboratory temperament assessment battery (Lab-TAB): Prelocomotor Version 3.0*. Available from H. H. Goldsmith, Personality Development Laboratory, Department of Psychology, University of Wisconsin, Madison, WI.

Goodman, R. N., Rietschel, J. C., Lo, L. C., Costanzo, M. E., & Hatfield, B. D. (2013). Stress, emotion regulation and cognitive performance: The predictive contributions of trait and state relative frontal EEG alpha asymmetry. *International Journal of Psychophysiology*, *87*(2), 115–123. https://doi.org/10.1016/j.ijpsycho.2012.09.008

Goodman, S. H., Rouse, M. H., Connell, A. M., Broth, M. R., Hall, C. M., & Heyward, D. (2011). Maternal depression and child psychopathology: A meta-analytic review. *Clinical Child and Family Psychology Review*, *14*(1), 1–27. https://doi.org/10.1007/s10567-010-0080-1

Gottlieb, G., & Halpern, C. T. (2002). A relational view of causality in normal and abnormal development. *Development and Psychopathology*, *14*, 421–435. https://doi.org/10.1017/S0954579402003024

Haley, D. W., & Stansbury, K. (2003). Infant stress and parent responsiveness: Regulation of physiology and behavior during still-face and reunion. *Child Development*, *74*(5), 1534–1546. https://doi.org/10.1111/1467-8624.00621

Handal, A. J., Saavedra, L. G., Schrader, R., Aragon, C. R., Paez, M., & Lowe, J. R. (2017). Assessment of maternal-infant interaction: Application of the Still Face paradigm in a rural population of working women in Ecuador. *Maternal Child Health Journal*, *21*, 458–466. https://doi.org/10.1007/s10995-016-2123-9

Hane, A. A., & Fox, N. A. (2006). Ordinary variations in maternal caregiving influence human infants' stress reactivity. *Psychological Science*, *17*, 550–556. https://doi.org/10.1111/j.14679280.2006.01742.x

Hane, A. A., Fox, N. A., Henderson, H. A., & Marshall, P. J. (2008). Behavioral reactivity and approach-withdrawal bias in infancy. *Developmental Psychology*, *44*(5), 1491–1496. https://doi.org/10.1037/a0012855

Hardin, J. S., Aaron Jones, N., Mize, K. D., Platt, M., & Schmidt, C. E. (in press). Affectionate touch in the context of breastfeeding and maternal depression influences infant neurodevelopmental and temperamental substrates. *Neuropsychobiology*.

Harmon-Jones, E., & Allen, J. J. (1998). Anger and frontal brain activity: EEG asymmetry consistent with approach motivation despite negative affective valence. *Journal of Personality and Social Psychology*, *74*(5), 1310–1316. https://doi.org/10.1037/0022-3514.74.5.1310

Harmon-Jones, E., & Gable, P. A. (2018). On the role of asymmetric frontal cortical activity in approach and withdrawal motivation: An updated review of the evidence. *Psychophysiology*, *55*(1), e12879. https://doi.org/10.1111/psyp.12879

Jackson, D. C., Mueller, C. J., Dolski, I., Dalton, K. M., Nitschke, J. B., Urry, H. L., … Davidson, R. J. (2003). Now you feel it, now you don't: Frontal brain electrical asymmetry and individual differences in emotion regulation. *Psychological Science*, *14*, 612–617. https://doi.org/10.1046/j.0956-7976.2003.psci_1473.x

Jones, N. A., Field, T., Fox, N. A., Davalos, M., & Gómez, C. (2001). EEG during different emotions in 10-month-old infants of depressed mothers. *Journal of Reproductive and Infant Psychology*, *19*(4), 295–312. https://doi.org/10.1080/02646830127204

Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: The inhibition–timing hypothesis. *Brain Research Reviews*, *53*(1), 63–88. https://doi.org/10.1016/j.brainresrev.2006.06.003

Kolb, B. (2018). Brain plasticity and experience. In R. Gibb & B. Kolb (Eds.), *The neurobiology of brain and behavioral development* (pp. 341–389). London, UK: Elsevier.

Landry, S. H., Smith, K. E., & Swank, P. R. (2006). Responsive parenting: Establishing early foundations for social, communication, and independent problem-solving skills. *Developmental Psychology*, *42*(4), 627–642. https://doi.org/10.1037/0012-1649.42.4.627

Leclère, C., Viaux, S., Avril, M., Achard, C., Chetouani, M., Missonnier, S., & Cohen, D. (2014). Why synchrony matters during mother-child interactions: A systematic review. *PLoS ONE*, *9*(12), e113571. https://doi.org/10.1371/journal.pone.0113571

Lewis, M., & Coates, D. L. (1980). Mother–infant interaction and cognitive development in twelve-week-old infants. *Infant Behavior and Development*, *3*, 95–105.

Lindsey, E. W., Cremeens, P. R., Colwell, M. J., & Caldera, Y. M. (2009). The structure of parent–child dyadic synchrony in toddlerhood and children's communication competence and self-control. *Social Development*, *18*, 375–396. https://doi.org/10.1111/j.1467-9507.2008.00489.x

Lindsey, E. W., & Mize, J. (2000). Parent-child physical and pretense play: Links to children's social competence. *Merrill-Palmer Quarterly*, *46*(4), 565–591. https://doi.org/10.1037/t58344-000

Lowe, J., Qeadan, F., Leeman, L., Shrestha, S., Stephen, J. M., & Bakhireva, L. N. (2017). The effect of prenatal substance use and maternal contingent responsiveness on infant affect. *Early Human Development*, *115*, 51–59. https://doi.org/10.1016/j.earlhumdev.2017.09.013

Lusby, C. M., Goodman, S. H., Bell, M. A., & Newport, D. J. (2014). Electroencephalogram patterns in infants of depressed mothers. *Developmental Psychobiology*, *56*(3), 459–473. https://doi.org/10.1002/dev.21112

Lusby, C. M., Goodman, S. H., Yeung, E. W., Bell, M. A., & Stowe, Z. N. (2016). Infant EEG and temperament negative affectivity: Coherence of vulnerabilities to mothers' perinatal depression. *Development and Psychopathology*, *28*, 895–911. https://doi.org/10.1017/S0954579416000614

Marshall, P. J., Bar-Haim, Y., & Fox, N. A. (2002). Development of the EEG from 5 months to 4 years of age. *Clinical Neurophysiology*, *113*(8), 1199–1208. https://doi.org/10.1016/S1388-2457(02)00163-3

McKenna, J. J., & Mosko, S. S. (1994). Sleep and arousal, synchrony and independence, among mothers and infants sleeping apart and together (same bed): An experiment in evolutionary medicine. *Acta Paediatrica*, *83*, 94–102. https://doi.org/10.1111/j.1651-2227.1994.tb13271.x

Meyer, A., Carlton, C., Chong, L. J., & Wissemann, K. (2019). The presence of a controlling parent is related to an increase in the error-related negativity in 5–7 year-old children. *Journal of Abnormal Child Psychology*, *47*(6), 935–945. https://doi.org/10.1007/s10802-018-0503-x

Meyer, A., Proudfit, G. H., Bufferd, S. J., Kujawa, A. J., Laptook, R. S., Torpey, D. C., & Klein, D. N. (2015). Self-reported and observed punitive parenting prospectively predicts increased error-related brain activity in six-year-old children. *Journal of Abnormal Child Psychology*, *43*(5), 821–829. https://doi.org/10.1007/s10802-015-0010-2

Montague, D. P. F., & Walker-Andrews, A. S. (2001). Peekaboo: A new look at infants' perception of emotion expressions. *Developmental Psychology*, *37*, 826–838. https://doi.org/10.1037/0012-1649.37.6.826

Morasch, K. C., & Bell, M. A. (2011). The role of inhibitory control in behavioral and physiological expressions of toddler executive function. *Journal of Experimental Child Psychology*, *108*(3), 593–606. https://doi.org/10.1016/j.jecp.2010.07.003

Oakes, J. M., & Feldman, H. A. (2001). Statistical power for nonequivalent pretest-posttest designs: The impact of change-score versus ANCOVA models. *Evaluation Review*, *25*(1), 3–28. https://doi.org/10.1177/0193841X0102500101

Oakes, L. M., & Spalding, T. L. (1997). The role of exemplar distribution in infants' differentiation of categories. *Infant Behavior and Development*, *20*, 457–475. https://doi.org/10.1016/S0163-6383(97)90036-9

Page, M., Wilhelm, M. S., Gamble, W. C., & Card, N. A. (2010). A comparison of maternal sensitivity and verbal stimulation as unique predictors of infant social-emotional and cognitive development. *Infant Behavior & Development*, *33*(1), 101–110. https://doi.org/10.1016/j.infbeh.2009.12.001

Papousek, I., Freudenthaler, H., & Schulter, G. (2011). Typical performance measures of emotion regulation and emotion perception and frontal EEG asymmetry in an emotional contagion paradigm. *Personality and Individual Differences*, *51*, 1018–1022. https://doi.org/10.1016/j.paid.2011.08.013

Pempek, T. A., Demers, L. B., Hanson, K. G., Kirkorian, H. L., & Anderson, D. R. (2011). The impact of infant-directed videos on parent–child interaction. *Journal of Applied Developmental Psychology*, *32*(1), 10–19. https://doi.org/10.1016/j.appdev.2010.10.001

Pérez-Edgar, K., Kujawa, A., Nelson, S. K., Cole, C., & Zapp, D. J. (2013). The relation between electroencephalogram asymmetry and attention biases to threat at baseline and under stress. *Brain and Cognition*, *82*(3), 337–343. https://doi.org/10.1016/j.bandc.2013.05.009

Perone, S., & Gartstein, M. A. (2019). Mapping cortical rhythms to infant behavioral tendencies via baseline EEG and parent-report. *Developmental Psychobiology*, *61*(6), 815–823. https://doi.org/10.1002/dev.21867

Perone, S., & Gartstein, M. A. (2019). Relations between dynamics of parent-infant interactions and baseline EEG functional connectivity. *Infant Behavior and Development*, *57*, 101344. https://doi.org/10.1016/j.infbeh.2019.101344

Reznik, S. J., & Allen, J. J. (2018). Frontal asymmetry as a mediator and moderator of emotion: An updated review. *Psychophysiology*, *55*(1), e12965. https://doi.org/10.1111/psyp.12965

Ross-Sheehy, S., Perone, S., Macek, K. L., & Eschman, B. (2017). Visual orienting and attention deficits in 5- and 10-month-old preterm infants. *Infant Behavior and Development*, *46*, 80–90. https://doi.org/10.1016/j.infbeh.2016.12.004

Rothbart, M. K. (1988). Temperament and the development of the inhibited approach. *Child Development*, *59*, 1241–1250.

Rothbart, M. K., Ahadi, S. A., & Evans, D. E. (2000). Temperament and personality: Origins and outcomes. *Journal of Personality and Social Psychology*, *78*(1), 122–135. https://doi.org/10.1037/0022-3514.78.1.122

Scarr, S., & McCartney, K. (1983). How people make their own environments: A theory of genotype greater than environment effects. *Child Development*, *54*(2), 424–435.

Smith, C. L., & Bell, M. A. (2010). Stability in infant frontal asymmetry as a predictor of toddlerhood internalizing and externalizing behaviors. *Developmental Psychobiology*, *52*(2), 158–167. https://doi.org/10.1002/dev.20427

Smolkowski, K. (2020, March 26). *Gain score analysis*. Retrieved from https://homes.ori.org//keiths/Tips/Stats_GainScores.html

Swingler, M. M., Perry, N. B., Calkins, S. D., & Bell, M. A. (2014). Maternal sensitivity and infant response to frustration: The moderating role of EEG asymmetry. *Infant Behavior and Development*, *37*(4), 523–535. https://doi.org/10.1016/j.infbeh.2014.06.010

Thibodeau, R., Jorgensen, R. S., & Kim, S. (2006). Depression, anxiety, and resting frontal EEG asymmetry: A meta-analytic review. *Journal of Abnormal Psychology*, *115*(4), 715–729. https://doi.org/10.1037/0021-843X.115.4.715

Towers, D. N., & Allen, J. J. (2009). A better estimate of the internal consistency reliability of frontal EEG asymmetry scores. *Psychophysiology*, *46*(1), 132–142. https://doi.org/10.1111/j.1469-8986.2008.00759.x

Tronick, E. Z. (1989). Emotions and emotional communication in infants. *American Psychologist*, *44*(2), 112–119. https://doi.org/10.1037//0003-066x.44.2.112

Tronick, E., Als, H., Adamson, L., Wise, S., & Brazelton, T. B. (1978). The infant's response to entrapment between contradictory messages in face-to-face interaction. *Journal of the American Academy of Child Psychiatry*, *17*(1), 1–13. https://doi.org/10.1016/S0002-7138(09)62273-1

van den Boom, D. (1994). The influence of temperament and mothering on attachment and exploration: An experimental manipulation of sensitive responsiveness among lower-class mothers with irritable infants. *Child Development*, *65*, 1457–1477. https://doi.org/10.1111/j.1467-8624.1994.tb00829.x

van den Boom, D., & Hoeksma, J. (1994). The effect of infant irritability on mother–infant interaction: A growth-curve analysis. *Developmental Psychology*, *30*, 581–590. https://doi.org/10.1037/0012-1649.30.4.581

Wen, D. J., Soe, N. N., Sim, L. W., Sanmugam, S., Kwek, K., Chong, Y.-S., ... Qiu, A. (2017). Infant frontal EEG asymmetry in relation with postnatal maternal depression and parenting behavior. *Translational Psychiatry*, *7*(3), e1057. https://doi.org/10.1038/tp.2017.28

How to cite this article: Gartstein MA, Warwick H, Campagna AX. Electroencephalogram frontal asymmetry changes during emotion-eliciting tasks and parent–child interaction dynamics. *Social Development*. 2021;30:496–514. https://doi.org/10.1111/sode.12484