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Brief Report

Investigating the links between parent–child interactions and context-specific electroencephalography asymmetry: Neurophysiology behind a frustrating task

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A R T I C L E I N F O

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A B S T R A C T

This study investigated the relations between parent–child interactions and infant brain activity in the context of a frustration eliciting task. Specifically, electroencephalography (EEG) data were recorded and processed to provide alpha frontal asymmetry indicators linked with approach/avoidance emotions and motivation. These data were collected from 53 mother–infant dyads during baseline and a toy retraction task, with play interactions coded for caregiving quality indicators. Hierarchical multiple linear regression analyses indicated that infants of more sensitive/responsive mothers and those engaging in more fast-paced/active play exchanges with caregivers demonstrated a relative left frontal activation response during toy retraction. Reciprocity/synchrony and directedness (parent vs. child directed) did not account for significant amounts of toy retraction EEG asymmetry response variance. It may be that infants experience greater frustration in the context of an attractive toy being removed when their typical play exchanges with caregivers are marked by sensitivity to their needs and are physically/verbally engaging. The findings are discussed in the context of the capability model of EEG asymmetry with regard to infant EEG.

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Introduction

The importance of emotion/motivation-related lateralization of the frontal brain region has been recognized for some time (Davidson & Fox, 1989). Approach motivation and emotions are generally associated with greater activation of the left frontal area, whereas avoidance-related experiences recruit the right frontal region. Frontal electroencephalography (EEG) asymmetry is typically examined as a marker of this lateralization, computed as a difference in alpha power between homologous electrodes: right minus left alpha (Reznik & Allen, 2018). Importantly, because alpha is inhibitory with respect to cortical network activity, activation is inversely related to power. That is, higher power values reflect lower activation at a particular electrode site, whereas lower power is indicative of greater activation (Lindsley & Wicke, 1974).

In contrast to traditional dispositional models, more recently formulated dynamic approaches to asymmetry focus on responsiveness during emotion-eliciting episodes and the degree to which individuals rely on approach versus withdrawal information processing biases and actions depending on the demands of the situation (Coan, Allen, & McKnight, 2006). According to this capability model, individual differences in frontal EEG asymmetry reflect interactions between the emotional demands of specific situations and the emotion-regulatory abilities of individuals. Whereas baseline EEG asymmetry conveys information about typical approach versus avoidance orientation, asymmetry occurring in response to an emotion-eliciting situation reflects the central nervous system adaptation to the stimulus. Previous research, including task-based research with infants, has demonstrated the utility of the capability model (Bell & Wolfe, 2007; Buss et al., 2003; Diaz & Bell, 2012; Gartstein, 2020; Gartstein, Warwick, & Campagna, 2021). Although infant research has not compared the capability model and the traditional dispositional approach directly, Dennis and Solomon (2010) provided evidence favoring the capability model over the dispositional framework with adults. Frontal EEG activity during both baseline and mood induction tasks was associated with changes in participants' self-report of affect; however, these associations were significantly stronger when EEG activity was measured during mood induction (i.e., during the emotion-eliciting episodes). Capability model studies relied on a variety of methodological procedures to elicit emotion, including rejection tasks (Beeney, Levy, Gatzke-Kopp, & Hallquist, 2014), simulated exam situations (Papousek et al., 2019), and social contact (Uusberg, Allik, & Hietanen, 2015), among others. Work with adults includes some experimental manipulations aimed at eliciting anger. Specifically, Harmon-Jones (2007) examined adults' reactions to emotion-evoking pictures, including those designed to elicit anger responses. However, the capability model has not been examined during infancy in the context of frustration-eliciting tasks, a gap addressed by the current study through the use of a blocked goal task.

There has been considerable discussion regarding related questions in the literature, with relative consensus regarding the fact that the interpretation should focus on the motivational systems rather than discrete emotional reactions (e.g., Reznik & Allen, 2018). That is, dominance of the approach motivational system neurophysiologically indexed by relative left frontal activation can manifest differently behaviorally depending on context. Although associated positive affect traditionally has been emphasized and can be expected in situations where rewards are being anticipated, greater expression of frustration may accompany relative left frontal activation in instances where rewards are being blocked (e.g., a desirable toy is being removed). Nonetheless, relative left frontal activation is generally interpreted as adaptive and advantageous, indicative of greater regulation, resilience, and reliance on approach to cope with stressful circumstances (e.g., Curtis & Cicchetti, 2007; Fox, 1994; Gartstein, 2020).

Parent–child interaction factors can be expected to be critical with respect to individual differences in hemispheric activation, providing the neurophysiological basis for approach/avoidance emotion and motivation. Emerging literature is beginning to demonstrate links between maternal behavior and infant EEG (Bernier, Calkins, & Bell, 2016; Brooker & Buss, 2014). However, these effects have not been widely examined for tempo or directedness of play exchanges between infants and caregivers, nor have they been studied in the context of a frustration-eliciting task.

Mother–infant interactions contribute to major areas of child development, enabling advances in social–emotional and cognitive functioning (Blair, Raver, & Berry, 2014). Enduring influences of the parent–child relations are rooted in real-time dynamics such as the in-the-moment "dance" between the mother and her infant (Tronick, 1989), and effects of interactional quality on child brain activity in response to emotion-eliciting tasks require further study, especially during infancy—a period that is foundational to social–emotional and cognitive development.

Maternal responsiveness, linked with secure attachment and advanced attention/regulation, frequently has been studied during infancy (Ainsworth, Blehar, Waters, & Wall, 1978; Landry, Smith, & Swank, 2006). Reciprocity in parent–child exchanges was also shown to predict superior cognitive and social–emotional outcomes (Leclère et al., 2014; Lewis & Coates, 1980). Who directs interactions and play activity is also important because 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. A more balanced pattern of interactions between the mother and child has been linked with positive social adjustment and academic success (Lindsey & Mize, 2000). Tempo of interactions, reflecting the pace of exchanges between the child and caregiver, is another important dynamic because appropriate pace/stimulation has been linked with more optimal outcomes such as secure attachment (Belsky, Taylor, & Rovine, 1984; Egeland & Farber, 1984; van IJzendoorn & De Wolff, 1997). Most relevant to this study, tempo emerged as protective with respect to fearfulness and positive affectivity, suggesting that faster exchanges may be optimal for infants. Specifically, higher tempo contributed to decreases in fear reactivity and increases in smiling and laughter during the first year of life (Gartstein, Hancock, & Iverson, 2018). Thus, responsiveness, reciprocity, parent versus child directedness, and tempo were related to individual differences in temperament (approach/avoidance tendencies in particular; Braungart-Rieker, Hill-Soderlund, & Karrass, 2010; Gartstein et al., 2018) and are considered here.

The goal of the current study was to address an important gap in research by examining parent–child interaction factors—sensitivity/responsiveness, reciprocity/synchrony, directedness (i.e., parent- or infant-directed exchanges), and tempo (e.g., pace of play, level of verbal and physical activity)—and their links to EEG asymmetry changes during a frustration-eliciting task. It was hypothesized that these qualities of parent–child exchanges would be associated with the EEG asymmetry response during the blocked goal task (i.e., frustration related to preventing the infant from reaching the desired toy). Specifically, higher sensitivity/responsiveness, reciprocity/synchrony, and tempo were expected to independently contribute to a shift toward relative left frontal activation, whereas greater directedness (parent–child exchanges) was hypothesized to be associated with a relative right frontal activation response.

Method

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). Children with significant medical or birth complications, including infants born preterm (<37 weeks of gestation) and/or with identified developmental delays/disabilities, were excluded. The study included 53 infants (M_{age} = 37.08 weeks [~8.5 months], SD = 7.83 weeks; 24 girls).

Measures

Laboratory visit

The laboratory visit involved a parent–child interaction episode completed prior to electrode placement. Specifically, the mother was instructed to play with the infant the way they typically would at home for 2 min (Bernier et al., 2016; Hane & Fox, 2006; Swingler, Perry, Calkins, & Bell, 2014), using a toy provided by the experimenter (a toy telephone). This baseline episode was subsequently coded using an established rating scheme that relies on a 7-point Likert scale, with low scores generally reflecting lower levels of the interaction dynamic (Gartstein, Crawford, & Robertson, 2008; Gartstein et al., 2018). Maternal sensitivity/responsiveness addressed the mother's interest, empathy, and appropriateness of reactions to infant cues (M = 4.60, SD = 1.43), whereas reciprocity/synchrony was indicative of how similar the tempo of play was between the two interaction partners (i.e., mother and infant) and the extent of coordination in their activity (M = 4.06, SD = 1.56). Directedness reflected who charted the course for play activities (with low scores indicative of infants providing direction; M = 3.58, SD = 1.66), and tempo involved the frequency of shifts in play and amount of physical and verbal activation for the dyad (M = 3.83, SD = 1.42). This free play interaction was followed by EEG data acquisition in the context of a baseline episode. Baseline EEG was recorded for 1 min while the infant watched a segment of a *Baby Einstein, Baby Mozart* video, where colorful objects were displayed as classical music was played (Perone & Gartstein, 2019a, 2019b). The toy retraction episode was subsequently administered, following the Laboratory Temperament Assessment Battery (Lab-TAB) protocol (Goldsmith & Rothbart, 1996), where the mother was instructed to play with the infant for 90 s with the toy (an attractive teething ring). After the initial 90 s, the mother was asked to take the teething ring from the infant and place it just out of the infant's reach while assuming a neutral expression for the next 60 s. Once this 60-s period had elapsed, the mother was instructed to resume play with the infant. The above interaction coding was not applied to the toy retraction episode given the stressful nature of this activity. It should be noted that the frustration-inducing portion (i.e., when the toy was actually placed out of the infant's reach) was only 1 min in duration and so was comparable to baseline.

EEG acquisition

Infants were seated in a high chair with an EEG cap (Cortech Solutions, Wilmington, NC, USA) placed on their head. After the cap's placement, small amounts of electroconductive gel were introduced in each electrode site. A total of 32 individual "pin-type" electrodes (BioSemi; Cortech Solutions, Wilmington, NC, USA) were then "snapped" into each corresponding site. EEG data were collected via the BioSemi Active Two amplifiers with initial screening via the BioSemi acquisition software at a sampling rate of 1024 Hz. The EEG was referenced to Cz online. MATLAB/EEGLAB was used, with continuous EEG downsampled to 256 Hz. A high-pass filter at 1 Hz and a 60-Hz notch filter were applied, with excessively noisy electrodes removed and interpolated, re-referencing EEG to the average. Continuous EEG was divided into 1-s epochs with 50% overlap, with epochs rejected if the absolute voltage of any electrode exceeded 100 μV 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. Power was calculated in alpha (6–9 Hz), consistent with prior research (Bell & Fox, 1992; Buss et al., 2003), and subsequently was natural log transformed.

Procedure

The EEG data were cleaned both automatically using the eeglab plug-in for MATLAB (e.g., eliminating flawed channels) and by visual inspection—removing epochs affected by movement

Table 1
Descriptive statistics.

Variable	Mean	Standard deviation	Range
Age in weeks	37.08	7.83	25–52
Sensitivity	4.60	1.43	1–7
Tempo	3.83	1.42	1–6
Reciprocity	4.06	1.56	1–7
Direction	3.58	1.66	1–7
Baseline asymmetry	−0.19	0.42	−2.03–0.69
Toy retraction asymmetry	−0.16	0.56	−1.61–2.06

artifacts (e.g., eyeblinks indefinable via their signature in the Fp1/Fp2 signals). Descriptive statistics were computed first (Table 1), followed by simple correlations between baseline and toy retraction asymmetry scores as well as parent–child interaction variables. Only data from infants who provided at least 50% of artifact-free data (i.e., at least 30 s in duration) for toy retraction were included in the analyses. F3 and F4 were used to calculate asymmetry scores for baseline and toy retraction episodes: 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 used in the existing research (Reznik & Allen, 2018). With regard to frontal alpha asymmetry, positive numbers are indicative of left frontal activation (i.e., more approach motivation), whereas negative numbers are indicative of right frontal activation (i.e., avoidance-related experiences) because of alpha inhibitory effects on cortical activity. Hierarchical multiple linear regression (HMLR) analyses were subsequently performed, enabling us to control for covariates (infant sex and age), with the toy retraction asymmetry score used as the dependent variable. These HMLR analyses provided an opportunity to quantify parent–child interaction contribution to toy retraction EEG asymmetry after controlling for baseline values, consistent with the capability model.

Results

The HMLR analyses demonstrated that both sensitivity/responsiveness and tempo of exchanges were associated with significant effects after controlling for covariates and baseline frontal EEG asymmetry (Table 2). Specifically, positive beta coefficients associated with both effects are indicative of links with left frontal dominance. Notably, this does not refer to greater alpha power in the left hemisphere (i.e., F3) but rather refers to greater activation (i.e. less alpha power) in the left hemisphere determined via the asymmetry computation. Reciprocity/synchrony and directedness (parent vs. child directed) did not account for significant amounts of toy retraction EEG asymmetry response variance in HMLR models.

Table 2
Hierarchical regression models: Predicting toy retraction asymmetry.

Variable	*R*	R^2	R^2 change	*F* change	Beta
Predictors: Parent–child interaction factors					
Model 1	.53	.28	.09	4.69*	
Gender					−.01
Age in weeks at visit					.33*
Base asymmetry					−.41**
Sensitivity/responsiveness					.30*
Model 1	.56	.31	.12	6.54*	
Gender					−.09
Age in weeks at visit					.25#
Base asymmetry					−.48**
Tempo					.35*
Model 1	.47	.22	.03	1.41	
Gender					−.02
Age in weeks at visit					.28
Base asymmetry					−.41
Reciprocity					.17
Model 1	.50	.25	.25	4.32	
Gender					−.00
Age in weeks at visit					.01
Base asymmetry					.19
Direction					.05

# $p < .10$.
* $p < .05$.
** $p < .01$.

Discussion

Our results further demonstrate the utility of the capability model in infant research, showing unique effects of mother–infant interaction dynamics in predicting frontal EEG asymmetry in the context of a frustration-based task relative to baseline. Infants of more sensitive/responsive mothers and those engaging in more fast-paced/active play exchanges with caregivers demonstrated a relative left frontal activation response during toy retraction. It may be that infants experience greater frustration in the context of an attractive toy being removed when their typical play exchanges with caregivers are marked by sensitivity to their needs and are physically/verbally engaging because their experience of this task is marked by a greater violation of expectations. Importantly, consistent with the capability model, our results can be interpreted as indicating that aspects of mother–infant interactions are influential in shaping child in-the-moment regulation required during emotion-eliciting situations in terms of the underlying brain activity.

Given the nature of this task, the observed leftward shift in activation is likely a marker of greater frustration when unable to reach a newly inaccessible attractive toy. This interpretation is in line with existing adult literature demonstrating associations between left frontal dominance and anger responses when the potential reward is blocked (Harmon-Jones, 2007; Harmon-Jones & Allen, 1998; Harmon-Jones & Gable, 2018). Specifically, Harmon-Jones and Allen (1998) showed that dispositional anger was related positively to the anterior asymmetry in alpha activity, suggesting that left frontal dominance is related to higher levels of frustration-related motivation. Although relative left frontal activation is often described as associated with positive affect (Palmiero & Piccardi, 2017), this is not inconsistent with anger/frustration with respect to underlying motivation, specifically reward orientation/approach tendencies. That is, individuals high in approach tendencies behaviorally and demonstrating a reward-favoring attentional bias are more likely to manifest positive emotionality (i.e., intense joy/pleasure) when rewards are in fact attainable, yet when these are blocked they present with greater anger/frustration. Moreover, anger has been associated with some adaptive functions, shown to result in high levels of goal-directed and -focused activity in adults (Harmon-Jones & Allen, 1998; Izard, 1991). In infant research, relative left frontal alpha activation has been generally interpreted as indicative of greater approach, reward-related motivation, and typically positive affect such as smiling (Palmiero & Piccardi, 2017). An alternative interpretation is plausible given this existing disposition-oriented asymmetry research (Fox, 1994), namely that the relative left frontal shift observed in this study could be reflective of more advanced emotional regulation rather than risk for dysregulation. Future studies examining behavioral and attentional parameters concurrently with brain activity during frustration-eliciting tasks will help to discern the most appropriate explanation of results obtained here.

It should be noted that the current study is cross-sectional in nature, and future studies should seek to extend this research by conducting longitudinal evaluations. Future research should also seek to further examine infant EEG lateralization during frustration- and anger-provoking tasks conducted with different adults (i.e., strangers or fathers) and foci for the interaction (e.g., food vs. toys) to determine the specificity of reactions observed in this study. Considering different aspects of parent–child interactions to enhance our understanding of the role parents play in building their children's ability to tolerate distress resulting from blocked goals could be potentially beneficial to developing effective parent-oriented interventions. If left frontal dominance can be conclusively interpreted as a marker of greater frustration and related risk, identifying caregiving qualities that diminish the shift toward relative left frontal activation during a blocked goals task could be leveraged in early intervention. That is, relative left frontal activation in response to a frustrating event needs to be linked with behavioral manifestations and later outcomes (e.g., behavior problems, school readiness) to determine whether this pattern of brain activity bodes risk in terms of broader social–emotional and cognitive development. If such connections are documented, parents could be coached to interact with their infants in a manner that supports coping with not readily attainable goals, potentially translating into resilience in other contexts requiring frustration tolerance (e.g., academic challenges).

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