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Infant Frontal EEG Asymmetry and Negative Emotional Reactivity as Predictors of Toddlerhood Effortful Control

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Abstract

Given the importance of children's self-regulation, relations were examined between two fundamental components of self-regulation, specifically temperamentally-based reactivity and regulation. Infant negative emotional reactivity and regulation, measured via frontal EEG asymmetry, were examined as potential precursors to understanding toddlerhood regulation, conceptualized as effortful control. Our longitudinal design allowed for examination of two perspectives on the interplay of reactivity and regulation: 1) early negative affectivity interferes with the development of later regulation or 2) regulation is necessary to modulate negative affectivity and thus buffer the effects of negative affectivity on later regulation. Mother-child dyads participated in a 3-wave longitudinal study. Baseline frontal EEG asymmetry was assessed at 10 months (T1). Mothers rated children's negative reactivity at both 10 and 24 months (T2). Children's effortful control, measured at 30–36 months (T3), was a composite score of maternal ratings and observed behavior during a snack delay. Negative affectivity was related to effortful control; however, significant interactions between negative affect and frontal EEG asymmetry were found. Higher levels of negative affectivity, at both T1 and T2, were associated with lower levels of effortful control at T3 but only for toddlers who also had right frontal EEG asymmetry. Negative affectivity was not associated with effortful control for the left frontal EEG asymmetry group. Our moderation findings highlight the complex relations of negative affect and frontal EEG asymmetry in understanding children's development of self-regulation, specifically effortful control. The interaction between early reactivity and physiological regulation indicate that both may be important precursors of effortful control.

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Keywords

negative reactivity; EEG; effortful control; infancy; toddlerhood

Self-regulation is a hallmark of children's development (Shonkoff & Phillips, 2000) because children who can regulate their emotions and behaviors are more socially competent, display fewer behavior problems, make successful transitions to school, and have higher academic achievement (for reviews see Blair, 2002; Blair & Diamond, 2008; McClelland & Cameron, 2012). Because self-regulation is a broad, encompassing term, we chose to examine effortful control, which is a component of children's self-regulation. Effortful control, defined as “the efficiency of executive attention – including the ability to inhibit a dominant response and/or to activate a subdominant response, to plan, and to detect errors” (Rothbart & Bates, 2006, p. 129), has also been associated with many optimal developmental outcomes (Eisenberg, Hofer, Sulik, & Spinrad, 2014; Eisenberg et al., 2005, 2009; Ponitz, McClelland, Matthews, & Morrison, 2009; Spinrad et al., 2007). Given the role that effortful control can play in children's development, it is important to understand how early factors in children's lives relate to individual differences in effortful control. The current study examined two factors, negative emotional reactivity and early brain electrophysiology (i.e., the electroencephalogram, EEG), as early predictors of children's effortful control. We proposed that early indicators of regulation reflected in frontal EEG asymmetry will interact with negative affectivity to predict later regulation as measured through children's effortful control.

Relations between emotional reactivity and regulation are complex, especially when considering the developmental course of each and the interaction of the two. In Rothbart's (1989) framework, children's effortful self-regulation was proposed to be influenced by both components of reactivity (positive and negative affect) and modulation of that reactivity, which in very young infants involves approach and withdrawal behaviors (for example, turning attention away from something that is overly stimulating). When looking at the interplay of reactivity and regulation, there are two perspectives discussed in the literature. First is the idea that high levels of emotional negativity can interfere with the development of regulation skills, while the other perspective is that children need a certain level of regulation in order to control negative affectivity. Even though these two perspectives are not mutually exclusive, empirical work addressing the relations between reactivity and regulation typically focuses on one of the perspectives.

Supporting the view that children need certain levels of regulation to control emotion, empirical work has found, for example, that children high in effortful control and who use regulation strategies such as distraction, were less apt to be high on negative emotionality (Buss & Goldsmith, 1998; Eisenberg et al., 1993; Eisenberg, Fabes, Nyman, Bernzweig, & Pineaulas, 1994; Fabes et al., 1999; Gilliom, Shaw, Beck, Schonberg, & Lukon, 2002; Grolnick, Bridges, & Connell, 1996). Braungart-Rieker, Hill-Soderlund, and Karrass (2010) found that poor attentional regulation, operationalized as less object oriented focus, was associated with more fear and more increased anger from infancy into toddlerhood. Spinrad et al. (2007) also found that less effortful control in toddlerhood was associated with more

behavior problems and separation distress as rated by parents and caregivers. In this case, the researchers took the perspective that a lack of early regulation, in particular attentional and effortful control, would predict levels of emotionality (distress and anger, in particular). Empirical findings, both concurrent and longitudinal, also support the idea that high levels of negative reactivity can interfere with the development of regulation as indexed by measures of attentional control including distraction and effortful control (Calkins, Dedmon, Gill, Lomax, and Johnson, 2002; Calkins & Johnson, 1998, Gaertner, Spinrad, & Eisenberg, 2008; Hill-Sonderlund & Braungart-Rieker, 2008; Kochanska & Knaack, 2003; Rothbart, Ziaie, & O'Boyle, 1992).

Despite empirical support for both perspectives, emotional reactivity and regulation, including effortful control, are considered to be aspects of temperament (Rothbart & Bates, 2006), and whereas temperamental reactivity is proposed to be present very early in infancy, aspects of temperamental regulation develop more slowly (Fox & Stifter, 1989). As children learn more conscious, effortful control, which typically begins to emerge in the second half of the first year of life, they can modulate reactivity and no longer be driven by emotions (Rothbart, 1989; Rothbart, Derryberry, & Posner, 1994). Given that reactivity can be observed very early in infancy, we follow the perspective that reactivity, including high levels of negative emotionality, could interfere with the development of regulation skills, measured through effortful control. Longitudinal assessments, however, are necessary to fully understand if negative affectivity interferes with the development of effortful control, but previous longitudinal assessments typically examined associations between reactivity and regulation within a single developmental period. For example, Rothbart et al. (1992) examined these issues within the first year of infancy, whereas Spinrad et al. (2007) and Gaertner et al. (2008) examined the issues within toddlerhood. Our study adds to this literature by examining early negative emotionality as a predictor of effortful control in late toddlerhood. We expected that higher levels of negative emotionality in both infancy and early toddlerhood would be associated with less effortful control in late toddlerhood.

Because regulation, specifically effortful control, is still developing across the early years, the ability to regulate distress in early infancy is primarily controlled externally by caregivers (Kopp, 1982); however, Posner and Rothbart (2007) proposed that the shift from external regulation to self-regulation is due in part to development in the frontal cortex, which allows children to display the voluntary control needed for regulation. The frontal lobe has even been called the “emotional manager” due to its role in modulating emotion and overriding emotional impulses (Goleman, 1995, p. 26). Examining early physiological predictors of effortful control is especially important during infancy because effortful control is just beginning to emerge.

According to a model proposed by Fox (1991, 1994), frontal EEG patterns may be early markers for children's later regulation skills. In this model, Fox proposed that it is the balance between the left and right frontal region hemispheres that is particularly important to children's regulation of emotion. Left frontal asymmetry during a resting baseline condition was proposed to be associated with a tendency to display approach types of behaviors and positive emotions (e.g., joy, surgency), whereas right frontal activation was associated with withdrawal types of behaviors and negative emotions (e.g., sadness, fear). Building on this

model, Fox and colleagues have consistently found that the patterns of frontal EEG asymmetry related to how children regulate emotion (Fox, Bell, & Jones, 1992; Fox, Calkins, & Bell, 1994; Fox & Davidson, 1987; Fox, Henderson, Rubin, Calkins, & Schmidt, 2001; Fox, Schmidt, Calkins, Rubin, & Coplan, 1996). In particular, infants with right frontal activation have been found to be more likely to express negative emotion and less able to regulate it, whereas infants with left frontal activation were more likely to express positive emotion and more able to regulate negative affect. Following from Fox's work, we expected that children with right frontal EEG asymmetry would be less likely to regulate distress than would children with left frontal EEG asymmetry.

Given the potential importance of early negative reactivity and regulation, via frontal EEG asymmetry, on later effortful control, the combined, interactive effect of both aspects of reactivity and regulation is important to consider. In a review of the literature on EEG asymmetry, Coan and Allen (2004) provided evidence of the role of frontal EEG asymmetry as a moderator of emotional responses. The literature reviewed by Coan and Allen provided support for the idea that patterns of EEG asymmetry have the potential to either facilitate or diminish emotional responses, which relates to our idea of frontal EEG asymmetry as a measure of regulation. Henderson, Fox, and Rubin (2001) found that EEG asymmetry moderated the relation of maternal report of negative affectivity in infancy on preschool social wariness, such that negative emotionality was associated with social wariness in cases where infants also had right frontal EEG asymmetry, whereas no relations were found for infants with left frontal EEG asymmetry. Specifically, the effects of early reactivity on later development were exacerbated by also having a pattern of right frontal EEG asymmetry in infancy. Based on these prior findings as well as others who have examined the potential interactive effects of frontal EEG asymmetry (Fox et al., 1996; Lopez-Duran, Nusslock, George, & Kovacs, 2012), we proposed that frontal EEG asymmetry would moderate the association of early negative reactivity on later effortful control.

Because it is important to study both behavioral domains of temperament as well as physiological markers (Rothbart, 1989), we examined frontal EEG asymmetry in infancy as a predictor of negative affectivity, concurrently and longitudinally. In addition to examining potential direct effects of early negative affectivity on later regulation, conceptualized as effortful control, we also hypothesized that EEG frontal asymmetry would moderate the association of negative affectivity to effortful control. Given that infants with right frontal EEG asymmetry have been found to be less regulated, we hypothesized that children with right frontal EEG asymmetry coupled with high levels of negative affect would have lower levels of effortful control. Given that infants with left frontal asymmetry may be better at regulating negative affect, infants with left frontal asymmetry may have higher levels of effortful control, and this pattern maybe present even if levels of negative affectivity are high because the left EEG frontal asymmetry may be serving as a buffer.

Method

Participants

Participants of this study were part of an ongoing longitudinal examination of cognition and emotion from infancy through early childhood. Three time points were used in the current

study: when children were 10 (T1), 24 (T2), and 30 (T3) months old. At T1, participants included 95 healthy infants (47 male, 48 female; 88 Caucasian, 1 African American, 5 Hispanic, 1 Multi-Racial) and their mothers recruited from 3 small towns surrounding a research university in the mid-Atlantic region. Infants were born within 2 weeks of their expected due dates, experienced no prenatal or birth complications and had no neurological diagnoses. Nineteen percent of the mothers had a high school education, 7% attended trade school, 47% were college graduates and 22% had advanced degrees. Mothers mean age at infant's birth was 29.71 years of age (range 20–38 year of age). The demographics of the sample reflect those of the population where the study was conducted.

For the T2 assessment, families were contacted when the children had their 24-month birthdays and seen no later than 4 months after their birthday. Of the original 95 families, 81 agreed to participate again. This subgroup of 81 families (43 male children, 38 female children) who participated in the T2 visit had significantly older mothers compared to the families who did not participate $t(93) = -2.11, p < .04$. However, the groups did not significantly differ in regard to child sex, child race/ethnicity, maternal education, negative affect, or asymmetry group.

Families were contacted again for the third wave of data collection, and 65 mothers and toddlers (36 male, 29 female) agreed to participate. Children were seen when they were between 30–36 months of age. As with the T2 visit, participants who participated in T3 had older mothers, $t(93) = -2.88, p = .005$, but did not significantly differ in sex, race, maternal education, negative affect, or asymmetry group.

Procedure

For all assessments, families were greeted by a research assistant who explained the study procedures and obtained signed consent from the mothers. Child assent was obtained at the T2 and T3 assessments as well. For the T1 assessment, infants visited the research lab on or within 2 weeks after their 10-month birthdays. After a brief warm-up period, infants sat on their mother's lap and were distracted with toys in order to place an EEG Electro-cap on the infant's head. Baseline EEG was recorded for 1 minute while infants sat in a highchair and watched a video of a musical segment from Sesame Street. Mothers were asked not talk to infants during the EEG recording unless they needed to comfort their infants. Prior to the laboratory visit, mothers were asked to complete the Infant Behavior Questionnaire-Revised (IBQ-R; Gartstein & Rothbart, 2003). Parents were paid for their participation in this wave of the data collection.

Baseline EEG recordings were collected from 16 left and right scalp sites (frontal pole (Fp1, Fp2); medial frontal (F3, F4); lateral frontal (F7, F8); central (C3, C4); temporal (T7, T8); parietal (P3, P4, P7, P8); and occipital (O1, O2) referenced to Cz during recoding). A small amount of abrasive gel was placed into each recording site and the scalp gently rubbed. Next, conductive gel was placed in each site, and the scalp was gently rubbed. Electrode impedances were measured and accepted if they were below 10K ohms. The electrical activity from each lead was amplified using separate SA Instrumentation Bioamps (San Diego, CA) and bandpassed from 1 to 100 Hz. Activity for each lead was displayed on the monitor of the acquisition computer. The EEG signal was digitized on-line at 512 samples

per second for each channel so that the data were not affected by aliasing. The acquisition software was Snapshot-Snapstream (HEM Data Corp., Southfield, MI). The raw data were stored for later analyses.

For the T2 assessment, mothers were mailed the Early Childhood Behavior Questionnaire (ECBQ; Putnam, Gartstein, & Rothbart, 2006). Mothers brought the completed questionnaire with them when they came in for their laboratory visit (not part of this study). Mothers were paid for their participation in the 24-month visit, and children were given a packet of crayons.

At the T3 assessment, mothers again completed the ECBQ, and toddlers completed a snack delay task as an observed measure of effortful control. Following procedures outlined by Kochanska (Kochanska, Murray, & Harlan, 2000; Kochanska, Murray, Jacques, Koenig, & Vandegest, 1996), toddlers were seated at a small table. During the consent process, mothers were asked for permission to give children M&Ms. If mothers preferred a different snack item or in cases where the mothers indicated that their children did not like M&Ms, an alternate food item, such as goldfish crackers or raisins, was used. Experimenters placed a mat with hands printed on it in front of the toddlers. An M&M was placed at the top of the mat and covered with a cup that was placed upside down over the M&M, and a bell was placed beside the mat to the right of the children. Experimenters told children that they must wait to eat the M&M until she rang the bell. Several practice trials were completed to ensure that the children understood the directions. Four timed trials (delays were 10, 20, 30, and 15 sec) were then completed. Half way through each trial, experimenters picked up the bell but did not ring it until the end of the trial. At the end of each trial, children were encouraged to retrieve and eat the candy, if they had not already done so. As with the previous assessments, mothers were paid for their participation, and children were given two small gifts to take home.

Measures

EEG frontal asymmetry—Infant EEG data from T1 were examined and analyzed using EEG Analysis System software developed by James Long Company (Caroga Lake, NY). First, the data were re-referenced via software to an average reference configuration. The average reference EEG data were artifact scored for eye movements and gross motor artifact. These artifacts scored epochs were eliminated from all subsequent analyses. The EEG data were then analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-second width and 50% overlap. Power was computed for the 6 to 9 Hz frequency band, as infants at this age have a dominant frequency between 6 and 9 Hz (Bell & Fox, 1994; Marshall, Bar-Haim, & Fox, 2002). This particular frequency band is thought to approximate the alpha band in adults and has been used in previous studies of infant frontal asymmetry (e.g., Bell & Fox, 1994; Buss et al., 2003; Diaz & Bell, 2012; Fox et al., 1992; Fox et al., 2001; Smith & Bell, 2010). For the current study, EEG power was expressed as mean square microvolts and the data transformed using the natural log (ln) to normalize the distribution.

Frontal EEG asymmetry values were computed by subtracting ln power at left frontal (F3) from ln power at right frontal (F4). In the EEG literature, brain activation is indicated by

lower EEG power values in the alpha frequency band (Lindsley, 1936). Thus, a negative asymmetry score reflects greater right frontal activation, whereas a positive asymmetry score reflects greater left frontal activation. Because classifying infant's frontal asymmetry based on positive or negative asymmetry scores has been shown to be a reliable and valid measure of asymmetry (Allen, Coan, & Nazarian, 2004; Coan & Allen, 2004; Fox et al., 1992; Schmidt, 2008), two groups were formed based on their asymmetry scores: Infants who exhibited right frontal EEG asymmetry and infants who exhibited left frontal EEG asymmetry.

Negative affectivity—The IBQ-R completed by mothers at the T1 assessment is a 191-item questionnaire assessing 3-to-12-month old infants' emotional and behavioral responses across a number of situations, measuring 14 domains of infant temperament. Mothers rated each item on a 7-point, Likert-type scale (1 = never, 4 = half the time, 7 = always). The subscales of sadness (e.g., When it was time for bed or a nap and your baby did not want to go, how often did s/he whimper or sob?), distress (e.g., How often did the baby seem angry (crying and fussing) when you left her/him in the crib?), fear (e.g., When introduced to an unfamiliar adult how often did the baby cling to a parent?), and loading negatively, falling reactivity/soothability (e.g., When rocking your baby, how often did s/he soothe immediately?) were used. Based on Gartstein and Rothbart (2003), these four subscales were combined to form a negative affectivity scale which was used in the current study ($\alpha = .65$).

The ECBQ, completed at the T2 and T3 assessment, is a 201-item questionnaire assessing 18 domains of child temperament that mothers rated on a 7-point Likert scale (1 = never, 4 = half the time, 7 = always). This questionnaire is considered an “upward extension” of the IBQ-R for ages 1.5 to 3 years of age. The subscales of discomfort (e.g. During everyday activities, how often did your child become distressed when his/her hands were dirty and/or sticky?), fear (e.g., During everyday activities, how often did your child seem frightened for no apparent reason?), sadness (e.g. While having trouble completing a task (e.g., building, drawing, dressing), how often did your child become sad?), frustration (e.g., When told that it was time for bed or a nap, how often did your child react with anger?), motor activation (e.g., While bathing, how often did your child sit quietly?), perceptual sensitivity (e.g., During everyday activities, how often did your child notice that material was very soft (cotton) or rough (wool)?), and loading negatively, shyness (e.g., When approached by an unfamiliar person in a public place pull back and avoid the person?) and soothability (e.g., After getting a bump or scrape, how often did your child forget about it in a few minutes?) were used. Following Putnam et al. (2006), a negative affectivity scale was computed by combining these 8 subscales ($\alpha = .75$)

Effortful control—The snack delay was coded according to Kochanska's procedures (Kochanska et al., 1996, 2000). For coding purposes, each trial was broken into two parts. Part I was before experimenters lifted the bell and Part II was after the experimenters lifted the bell. The children's responses were coded using a 7-point scale (1= child eats the M&M during Part I, 2= child eats the M&M during Part II, 3= child touches M&M during Part I, 4= child touches M&M during Part II, 5= child touches cup and/or bell during Part I, 6=

child touches cup and/or bell Part II, 7= child waits until bell is rung). One extra point was given if the children kept their hands/palms on the mat during the entire Part I *or* during the entire Part II. Two extra points were given if the children kept their hands/palms on the mat during the entire time during both Parts I *and* II. Children could earn a total of 9 points for each trial.

A team of two coders independently scored 20% of the children to establish reliability. The intraclass correlation between the two coders for the total snack delay score was .98 or higher for each of the trials. The total score for the four trials were significantly correlated (all correlations were .74 or higher, $ps < .001$); therefore, the mean score from the four trials was computed to form a snack delay summary score.

The maternal report of effortful control was measured from three scales of the ECBQ: attentional focusing (e.g., When engaged in play with his/her favorite toy, how often did your child play for more than 10 minutes?), attentional shifting (e.g., After having been interrupted, how often did your child return to a previous activity?), and inhibitory control (e.g., When asked to wait for a desirable item (such as ice cream), how often did your child wait patiently?). Mothers used a 7-point scale (1 = never, 4 = about half of the time, 7 = always) to rate these items. These scales were chosen based on theoretical conceptualizations of effortful control (Eisenberg, Smith, & Spinrad, 2011). The three scales were significantly correlated (all correlations were .27 or higher, $ps < .05$); therefore, the three subscales were combined ($\alpha = .61$).

Maternal report of effortful control was significantly correlated with observations of maternal report from the snack delay, $r(64) = .24, p = .05$. Thus, in order to create a multidimensional variable of effortful control, both variables were standardized and averaged to create a composite of effortful control from maternal report and observations. By combining both measures of effortful control, we were able to create a summary score of regulation that captures the more long-term, day-to-day regulatory behaviors of the toddlers, as reported by mothers, and the toddlers' regulatory behaviors as observed in a situation designed to tax children's regulation skills (see Rothbart & Bates, 1998, 2006).

Results

Preliminary Analyses

Preliminary analyses revealed no sex differences in study variables. T1 and T2 negative affect were positively correlated, $r(71) = .35, p = .002$, indicating the stability of negative affect from 10-months to 24-months. Negative affect was negatively correlated with T3 effortful control, $r(63) = -.24, p = .05$ and $r(57) = -.29, p = .03$, for T1 and T2, respectively. The two infant asymmetry groups did not differ in negative affect at T1 or T2 or in effortful control at T3.

Moderation Analyses

Two regression analyses (one for T1 negative affect and one for T2 negative affect) were conducted to examine frontal EEG asymmetry as a moderator of the association of negative affect to later effortful control. Following Cohen, Cohen, West, and Aiken (2003), negative

affect was centered and infant frontal EEG asymmetry group was dummy coded. In the first step of the regression analysis, infant asymmetry group and negative affect were entered. The interaction term between infant frontal asymmetry and negative affect was entered on the second step. Given the difficulty in detecting significant interaction terms in the social sciences, we followed recommendations (McClelland & Judd, 1993; Whisman & McClelland, 2005) to probe interaction terms at p -values of .10 and lower, and significant interaction terms were probed following Cohen et al. (2003).

The results for the regression analysis examining T1 frontal EEG asymmetry and T1 negative affect as predictors of effortful control at T3 are presented in Table 1. The direct effect for T1 frontal EEG asymmetry was not significant, but T1 negative affect was negatively related to T3 effortful control. The main effect for negative affect, however, was qualified by a significant interaction term. The interaction term of T1 EEG asymmetry and T1 negative affect explained a significant increase in the variance in effortful control at T3, $R^2 = .05$; the change in R^2 was significant, $F(1, 61) = 3.37, p = .07$. Negative affect at T1 was negatively associated with toddler effortful control for the infant right frontal asymmetry group, $\beta = -.27, p = .03$, but not for left frontal asymmetry group, $\beta = -.09, p = .45$. Higher levels of infant negative affectivity were associated with less effortful control in toddlerhood, but this association was found only for toddlers who also had right frontal EEG asymmetry in infancy.

A similar regression analysis was performed with T1 frontal EEG asymmetry and T2 negative affect as predictors of T3 effortful control (see Table 2). Both the main effects for T1 EEG asymmetry group and T2 negative affect were significant; however, these main effects were qualified by a significant interaction term. The interaction term between T1 EEG asymmetry and T2 negative affect explained a significant increase in the variance of effortful control at T3, $R^2 = .05$; the change in R^2 was significant, $F(1, 55) = 3.29, p = .08$. The interaction was probed following the same procedures as in the previous analysis. T2 negative affect was negatively associated with T3 effortful control only for the T1 right frontal asymmetry group, $\beta = -.36, p = .01$, but not for the left frontal asymmetry group, $\beta = -.13, p = .28$.

Discussion

The current study longitudinally examined the complex relations of infant emotional reactivity and regulation, which was measured physiologically, to later effortful control. Because of the importance of the frontal cortex to the development of voluntary control of emotions and behaviors (Posner & Rothbart, 2007), we examined frontal EEG asymmetry as a moderator of the relation of negative affect to effortful control. Even though early negative affectivity at two time points, in infancy and early toddlerhood, was directly related to effortful control measured during later toddlerhood, these direct effects were qualified by the interaction of negative affectivity, at both time points, with infant frontal EEG asymmetry. We found that higher levels of negative affectivity were associated with less effortful control but only for toddlers with a pattern of right frontal EEG asymmetry. Negative affectivity was not associated with later effortful control for toddlers with left frontal EEG asymmetry.

Our findings provide an interesting view on the interplay of reactivity and regulation. We found direct relations where more negative affect in infancy and early toddlerhood related to less effortful control in later toddlerhood. Even though these findings would seem to support the perspective that early patterns of reactivity interfered with the development of later regulation, the associations between negative affect and effortful control were moderated by patterns of frontal EEG asymmetry, which have been proposed to reflect emotion regulation (Fox 1991, 1994). Because temperamentally-based emotional reactivity is proposed to be present earlier than regulation, we expected that negative affect would interfere with the development of later effortful control; however, our findings did not fully support this idea.

Findings from our moderation analyses seem to suggest that aspects of regulation, as measured through patterns of EEG asymmetry, were important to understanding when negative affect may interfere with the development of later regulation, which we conceptualized as effortful control. Frontal EEG asymmetry has been found to be associated with specific patterns of regulation, with left frontal EEG asymmetry associated with better regulation and right frontal EEG asymmetry associated with more negative affect and less regulation (Fox et al., 1992, 1994, 1996, 2001; Fox & Davidson, 1987). Therefore, we proposed that young children with patterns of left frontal EEG asymmetry may have higher levels of effortful control because having left EEG asymmetry would serve as a buffer for the effects of negative affect. Although no direct relations between EEG asymmetry and later effortful control were found, our moderation findings revealed more complex relations that highlight the interactive effect of negative affect and frontal EEG asymmetry.

Our moderation findings support Coan and Allen's (2004) review describing the role of frontal EEG asymmetry as a moderator of children's emotional responses. Specifically, left frontal EEG asymmetry appeared to have a buffering, protective effect, whereas right frontal EEG asymmetry may exacerbate the effects of early infant negative reactivity on later effortful control. For toddlers with right frontal EEG asymmetry, high levels of negative affect in infancy and early toddlerhood were associated with less effortful control in later toddlerhood. In this case, it did appear that early negative affect, when coupled with a pattern of right frontal EEG asymmetry, could be interfering with the development of later regulation, conceptualized in this study as effortful control.

We did not, however, find any relations between negative affect and effortful control for toddlers with left frontal asymmetry. It may be that the left frontal EEG patterns were protecting the development of later effortful control from earlier negative affectivity. Past work (e.g., Lopez-Duran et al., 2012) supports the potential buffering role of left frontal EEG asymmetry. Henderson et al. (2001) also interpreted the lack of findings between infant negative reactivity to preschool social wariness to indicate that left frontal EEG asymmetry served as a protective factor. In our study, there were no differences in the mean levels of negative affectivity between children with left versus right EEG asymmetry; thus, it was not the case that infants who had left frontal EEG asymmetry were not experiencing negative affect, but, in this case, the negative affect was not interfering with the development of effortful control for these toddlers. Because the relations of negative affect to effortful control varied as a result of infant frontal EEG asymmetry, we cannot rule out the idea that

aspects of regulation present in infancy were associated with how early negative affect later related to the development of effortful control.

With regulation starting to develop at the end of the first year (Fox & Stifter, 1989; Rothbart, 1989; Rothbart et al., 1994), infants in our study may have already had some rudimentary regulation processes in place that may have been reflected in our EEG asymmetry measure. It is interesting that our findings were very similar when looking at negative affect at 10 and 24 months and similar moderation findings were found where EEG asymmetry at 10 months continued to moderate the association of negative affect at 24 months to effortful control later in toddlerhood. The stability in our longitudinal findings may suggest that patterns of regulation, as reflected by the infant EEG asymmetry, develop early and thus have the potential to either support or undermine children's emotional development.

Our findings relied on maternal report for negative affectivity. While that may be viewed as a limitation of our study, it can also be viewed as a strength. Mothers were rating their children's negative affectivity during infancy and early toddlerhood, times when regulation of negative affect is more external than internal; therefore, the mothers' ratings of their children's negative affect was particularly relevant. Although socialization factors were not considered within this study, hopefully mothers who saw their children to be high in negative affect would be providing more external regulation, which may relate to the findings that we had on the interplay of reactivity and regulation. Even though not examined in this study, we acknowledge that caregiving will most likely play an important role in how early precursors, including physiological regulation, relate to later regulation (see Calkins, 2011).

Although mothers may often be criticized for being biased reporters, Rothbart and Bates (1998, 2006) outlined the advantages to using maternal report, including capturing general patterns of responding across a variety of contexts where parents have more opportunities to observe children. Because of the developmental age of the children, using maternal report allowed us to have a broad, global measure of negative affectivity across infancy into early toddlerhood. By using Rothbart's temperament measures, we could also limit potential maternal bias because of how these measures were constructed to ensure for reliable and valid caregiver reports, by including comprehensive instructions and providing very specific behaviors for mothers to rate within a well-defined time frame. We also found meaningful relations of negative affectivity to effortful control, which incorporated both maternal ratings as well as observations. By using maternal report, observations, and physiological indicators, we were able to measure reactivity, regulation, and effortful control in different contexts, and using multiple measures from different perspectives provides a strong test of our hypothesized relations.

Limitations to our study include the small number of participants and the lack of diversity in the sample's demographics. Although our findings point to the importance of early patterns of frontal EEG activity to the development of regulation, we measured EEG asymmetry once in infancy during a baseline period, and only two sites of frontal EEG activity were considered. Different relations may be found when considering different EEG sites, when

considering the stability of markers of physiological regulation, or when examining EEG patterns during regulation tasks. Additionally, we did not consider the role of frontal EEG asymmetry as it relates to positive emotions, which may show relations to left frontal EEG asymmetry. Despite these limitations, our findings highlight the complex associations related to the development of children's self-regulation, which includes both patterns of early reactivity as well as regulation. It seems clear that relations between reactivity and regulation are complex, and most likely they will continue to influence each other over time. Longitudinal findings like ours are necessary to fully understand how these factors interact and develop over time.

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- Examined 10- and 24-month temperament and 36-month effortful control
- Infant temperament was assessed as negative affect
- Infant frontal EEG asymmetry used as measure of emotion regulation
- Negative affect predicted less effortful control only for right EEG asymmetry group

Table 1

Regression Analysis Predicting T3 Effortful Control from 10-mos Frontal EEG Asymmetry and Maternal Ratings of Negative Affect

	T3 Effortful Control Composite (<i>n</i> = 65)				
	<i>b</i>	<i>SE b</i>	β	<i>t</i>	<i>p</i>
1. T1 EEG asymmetry group	-.31	.21	-.18	-1.50	.14
T1 Negative affect	-.88	.33	-.64	-2.67	.01
2. T1 EEG asymmetry $\times$ T1 Negative affect	.70	.38	.44	1.84	.07

Note. Step 1: $R^2 = .09$, $F(2,62) = 2.96$, $p = .06$; Step 2: $R^2 = .14$, $F(3,61) = 3.17$, $p = .03$

Table 2

Regression Analysis Predicting T3 Effortful Control from 10-mos Frontal EEG Asymmetry and 24-month Maternal Ratings of Negative Affect

	T3 Effortful Control Composite (<i>n</i> = 59)				
	<i>b</i>	<i>SE b</i>	β	<i>t</i>	<i>p</i>
1. T1 EEG asymmetry group	-.46	.22	-.27	-2.13	.04
T2 Negative affect	-1.04	.36	-.66	-2.89	.01
2. T1 EEG asymmetry $\times$ T2 Negative affect	.78	.43	.41	1.81	.08

Note. Step 1: $R^2 = .13$, $F(2,56) = 4.29$, $p = .02$; Step 2: $R^2 = .18$, $F(3,55) = 4.07$, $p = .01$