CHILDREN'S EMOTION REGULATION: FRONTAL EEG ASYMMETRY AND BEHAVIOR DURING A DISAPPOINTMENT

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The approach-withdrawal model of emotion regulation posits that emotional behaviors are associated with a balance of activity in left and right frontal brain areas that can be explained in an asymmetry measurement. According to the model, approach emotions such as joy are associated with greater relative activity in left frontal brain areas and withdrawal emotions such as fear are associated with greater relative activity in right frontal brain areas (Davidson, 1992; Fox, 1991). The hypothesis tested in the present study is that children's approach and withdrawal behavior are related to resting and task-related brain electrical activity. Fifty-eight children from age 3-9 years were assessed during a laboratory task designed to elicit disappointment. In this task, children were led to believe that they would receive their favorite of a group of toys but instead were given their least favorite toy. Electroencephalogram (EEG) activity was measured during rest and during the task condition in which the child received the least-favorite toy, and asymmetry scores for midfrontal sites were computed. Approach behaviors (e.g., smiling) and withdrawal behaviors (e.g., facial expressions of disgust) during the task were coded from videotape. Children with right frontal asymmetry at rest exhibited more withdrawal behavior and were more likely to express sadness during the task. Approach behavior was not associated with frontal asymmetry. Sadness expressions decreased with age, smiling increased with age, and children whose parents had high depressive symptoms exhibited anger more frequently. These findings provide limited support for the approach-withdrawal model and suggest that the relation between resting asymmetry and withdrawal behavior might be stronger than that for resting asymmetry and approach behavior.

PREFACE

This dissertation focuses on questions about the neurobiology of emotion regulation that I have hoped to address since my earliest days in graduate school. I am thrilled that I was able to conduct the project. Jeff Cohn and Nathan Fox were generous in allowing me to use data from their larger study on the psychophysiology of risk for depression, and I appreciate the training I received through my involvement in that study. Jeff, my advisor, has always supported my efforts to develop my own interests, and I am grateful for the freedom he has given me. Nathan, who has been a shadow advisor, has provided encouragement and has helped me to understand the conceptual and methodological issues of developmental psychophysiology. Marika Kovacs, the director of the program project of which the psychophysiology study is part, has given mentorship and has challenged me to consider the importance of emotion regulation in depression.

Several other staff members of the program project were important to the completion of this study. Marc Ware and Charlei George, my statistics gurus, helped me to achieve my goal of being "honest" about analyzing clustered data. Ian Reed and Vicki Gettinger helped with behavior coding and digitizing, and they provided hours of insightful comments during our weekly eggs-toast-and-Lyonnaise-potatoes breakfast journal club. Rachel Chung and Rachel Levenstein contributed to processing EEG data. Marike Essl provided technical expertise, read an early draft, and gave me loads of support and advice. Lala Ambadar helped with last-minute tasks, Kirsten O'Hearn sent thoughtful feedback on a draft, and Karen Schmidt gave constructive criticism in the days of the proposal. Anita Miller has been a research role model and a valued teacher on topics of clinical affective neuroscience throughout my graduate training.

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INTRODUCTION

Emotion regulation is a central part of socioemotional development. Emotions serve the function of preparing for action (Frijda, 1986; Frijda & Tcherkassof, 1997), and through the generation, maintenance, or modulation of emotion states (Dodge & Garber, 1991; Kopp, 1989; Thompson, 1994) emotion regulation allows children to control their behavior. Children can thus achieve goals such as avoiding harm, communicating their subjective experience to others, and conforming to sociocultural norms (Campos, Campos, & Barrett, 1989; Campos, Mumme, Kermoian, & Campos, 1994).

Emotion regulation enables children to respond with flexibility to a variety of environmental events. The ability to change behavior with changes in stimulus contingencies is crucial to adaptive emotional functioning (Rolls, 1999), and accordingly, individual differences in emotion regulation can influence effective functioning in the social environment. When extreme, individual differences in emotion regulation can put children at risk for behaviors such as withdrawal from peer interactions (e.g., Fox et al., 1995) and can interact with other factors to confer risk for psychopathology (Cummings, Davies, & Campbell, 2000; Fox, Schmidt, Calkins, Rubin, & Coplan, 1996). Early difficulties with regulating negative emotions in particular can influence the trajectory of behavior problems across childhood (Campbell, Shaw, & Gilliom, 2000; Shaw, Owens, Giovannelli, & Winslow, 2001).

The term *emotion regulation* refers to attempts to change or modulate an emotional state, and it has been used most often to describe the modulation of negative affect. When extreme or inappropriate to the context, negative affect can present a challenge to adaptive functioning because it creates discomfort, disrupts a child's engagement with others, and interferes with compliance with cultural demands. Negative affect also has adaptive functions, however. These range from removing obstacles to goals (in the case of anger) to avoiding harm (in the case of fear). Regulating negative affect can enable children to use it effectively and adaptively; as a result, the acquisition and use of regulatory skills is an important developmental issue.

Emotion regulation is conceptualized as related to but different from emotion expression. Emotion regulation is involved at many stages in the process of emotion expression because it influences the intensity and quality of the emotions expressed (Gross & Muñoz, 1995). Although it may involve conscious processes, emotion regulation does not require awareness or explicit strategies (Gross & Muñoz, 1995). Emotion regulation also plays a role in managing emotions that are responses to an aversive event once they are expressed (Saarni, Mumme, & Campos, 1998). In some respects, therefore, emotion regulation can be seen as similar to coping. The development of emotion regulation during childhood involves increasing competence using strategies to inhibit or change the intensity or quality of emotional responses (Saarni et al., 1998).

Both physiological and behavioral components (Frijda & Tcherkassof, 1997; Kagan, 1994) are theorized to contribute to emotion processes, but few studies of emotion regulation in children have measured these characteristics simultaneously. The pattern of brain electrical activity – in particular, the balance of left and right frontal electroencephalogram (EEG) activity – is a physiological characteristic believed to play an important role in emotion (Davidson, 1984, 1992, 1994; Fox, 1991; Tomarken & Keener-Miller, 1998). *Frontal asymmetry*, as this pattern will be called in the current study, has been investigated as an index of both stable individual differences and universal emotional states (Coan & Allen, in press). Behavioral components of emotion, such as facial expressions, are the fundamental output of emotion (Campos et al., 1994). Aside from temperament models (e.g., Rothbart & Derryberry, 1981) and studies of behaviorally inhibited children (e.g., Fox, Henderson, Rubin, Calkins, & Schmidt, 2001) the literature on emotion regulation in children has rarely considered both physiology and behavior.

The current study examined physiological and behavioral emotion regulation responses in children. Specifically, it addressed frontal asymmetry and emotional behaviors during a task designed to elicit disappointment. To place the current study in a theoretical and empirical context, the following literatures are reviewed below: frontal asymmetry and emotion regulation, behavior and emotion regulation, and emotion regulation in response to a disappointment experience.

Frontal Asymmetry and Emotion Regulation

The theoretical basis for research on anterior EEG asymmetry in adults and children is the approach-withdrawal model of hemispheric lateralization in emotional systems (Davidson, 1984, 1992, 1994; Fox, 1991; Tomarken & Keener-Miller, 1998). The model integrates motivation-based views of behavioral activation and behavioral inhibition (e.g., Gray, 1987; Schneirla, 1959) with neuropsychology accounts of frontal laterality effects of lesions on emotion regulation (Robinson, Kubos, Starr, Rao, & Price, 1984). The central claim is that left anterior areas, especially midfrontal areas, are associated with facilitating approach in the presence of reward, whereas right anterior areas are associated with facilitating withdrawal from aversive contexts or stimuli. In the predictions of the approach-withdrawal model, *left frontal asymmetry*, or greater relative EEG activity in left frontal sites, is associated with approach behavior. In contrast, *right frontal asymmetry*, or greater relative EEG activity in right frontal sites, is predicted to be associated with withdrawal behavior.

From the approach-withdrawal perspective, emotions have motivational qualities and can be conceptualized as being approach-related, as with joy, or withdrawal-related, as with fear (Fox, 1991). Figure 1 places the basic emotions into approach and withdrawal categories as proposed by Fox (1991).

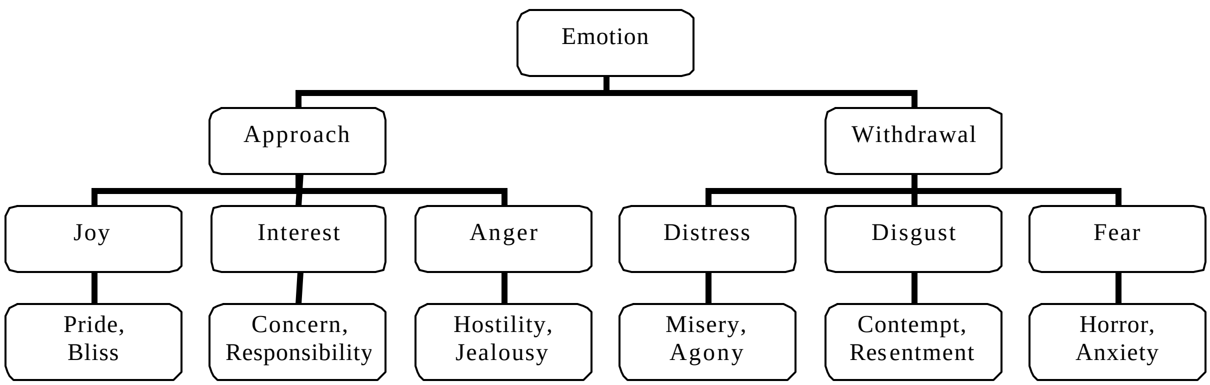

Figure 1. Approach-withdrawal model of emotion (adapted from Fox, 1991).

Resting and task-related frontal asymmetry are believed to index different emotional qualities. Resting asymmetry is seen as a measure of trait-like, stable individual differences in emotional response, while task-related asymmetry is seen as a measure of universals in emotional state (Coan & Allen, in press). For example, resting left frontal asymmetry is hypothesized to indicate a stable predisposition to respond to events with approach behaviors, but task-related left frontal asymmetry is hypothesized to accompany positive hedonic states. The stability of resting frontal asymmetry across time (Jones, Field, Fox, Lundy, & Davalos, 1997; Sutton & Davidson, 1997; Tomarken, Davidson, Wheeler, & Kinney, 1992; Tomarken, Davidson, Wheeler, & Doss, 1992; Wheeler, Davidson, & Tomarken, 1993) lends support to claims that frontal asymmetry indexes trait-like qualities. Furthermore, Fox (1994) has extended the definition of resting frontal asymmetry to include individual differences in emotion regulation strategies. Trait-like tendencies measured from resting asymmetry may thus predict the ways that children approach emotion regulation. A child with left frontal asymmetry might be more likely to use positive affect and social interaction to manage distress. A child with right frontal asymmetry, in contrast, might be more likely to actively avoid the circumstances associated with distress.

Resting frontal asymmetry and trait emotion. Examinations of frontal asymmetry as a trait marker assume that it reflects dispositional differences in tendencies to experience and express approach and withdrawal emotions (Fox, 1991, 1994). Studies of frontal asymmetry as a trait tend to test associations between asymmetry and personality, temperament, or socioemotional behavior. Appendix 1 summarizes the results of relevant studies on frontal asymmetry as a trait variable.

Studies with infants and children have focused on withdrawal behavior, reporting that behaviors such as shyness are associated with greater relative right frontal EEG activity. The studies in the literature on the approach-withdrawal model and children either have not considered approach behavior or have reported that approach behavior is not related to frontal asymmetry (e.g., Calkins, Fox, & Marshall, 1996). In infants, resting EEG asymmetry is related to the likelihood of crying and the tendency to cry during maternal separation (Davidson & Fox, 1989; Fox, Bell, & Jones, 1993).

Behavioral inhibition, which is characterized by restraint and caution in response to unfamiliar people and events (Kagan, Reznick, & Snidman, 1988), is associated with greater right frontal EEG activity. Infants classified at 4 months as having high levels of both motor activity and negative affect have greater right frontal asymmetry at 9 months than infants classified as having either high motor activity and high positive affect or low motor activity and low negative affect (Calkins et al., 1996). Infants with stable right frontal activity across infancy are more likely to exhibit inhibited behavior at 14 and 24 months than are infants with stable left frontal activity (Fox, Calkins, & Bell, 1994). Children who retain a classification of inhibited over the first 4 years of life have right frontal asymmetry (Fox, Henderson, Rubin, Calkins, & Schmidt, 2001).

Frontal asymmetry is involved in the relation between children's temperament and social behavior, but only for withdrawn, fearful behavior, and not for approach behavior. Right frontal asymmetry is present in children who are socially reticent or anxious (Fox et al., 1995), and asymmetry moderates the relation between boys' negative reactivity at 9 months of age and social wariness at 4 years (Henderson, Fox, & Rubin, 2001). Specifically, negative reactivity and social wariness are related only for children who had right frontal asymmetry. Although it was implicated in children's wary behavior with peers, frontal asymmetry was not related to 4-year-olds' sociability with peers.

Similarly, shy children with greater relative right frontal asymmetry are more likely to have parent-reported internalizing behavior problems (Fox et al., 1996). Internalizing behavior problems are characterized by withdrawal emotions such as sadness and worry, and asymmetry is thus related to abnormal levels of withdrawal behavior. In sociable children, greater relative right frontal EEG activity is associated with externalizing behaviors. Externalizing behaviors are seen as more similar to approach than to withdrawal because it includes behaviors such as impulsivity, and it is surprising that this type of unusual behavior is not related to greater relative left frontal EEG activity.

Studies that have examined approach behavior in children have also failed to find the expected relation with left frontal EEG activity. Children classified as high motor and high positive at 4 months do not have greater relative left frontal asymmetry at 9 months (Calkins et al., 1996). As mentioned above, frontal asymmetry does not moderate the relation between temperament at 9 months and to sociability at 4 years (Henderson et al., 2001) or the relation between sociability and externalizing problems (Fox et al., 1996).

In adults, the investigations of frontal asymmetry and behavior have focused on self-reported personality and emotion. Asymmetry is associated with positive and negative affectivity (Tomarken et al., 1992) and behavioral activation and behavioral inhibition tendencies (Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997). One study, however, reported that left frontal EEG activity is related to negative affectivity but unrelated to positive affectivity (Hagemann et al., 1999). Adults with greater relative left EEG activity at rest report more positive affect in response to pleasant films (Wheeler et al., 1993) or more change in positive affect from pleasant to unpleasant films (Tomarken, Davidson, & Henriques, 1990), and those with greater right activity report more negative affect in response to unpleasant films (Tomarken et al., 1990; Wheeler et al., 1993). In one study of subjective experience of emotion, however, asymmetry was associated with the subjective experience of negative affect but not positive affect (Tomarken et al., 1990).

Models of emotion dysregulation and depression have claimed that right frontal asymmetry is a trait marker for affective disorders (Tomarken & Keener-Miller, 1998). This claim is based on models of the presence of increased negative affect (i.e., higher withdrawal) and reduced engagement in rewarding activities (i.e., lower approach) in depression (Clark & Watson, 1991; Depue & Iacono, 1989; Fowles, 1988). Generally, research findings on depression and frontal asymmetry have provided support for this claim in adults with current or remitted depression (Henriques & Davidson, 1990, 1991; Miller et al., 2002), adolescent children of depressed mothers (Tomarken, Simien, & Garber, 1994), and infants of mothers with depressive symptoms (Dawson et al., 1999; Dawson, Klinger, Panagiotides, Hill, & Spieker, 1992; Field, Fox, Pickens, & Nawrocki, 1995; Jones et al., 1997).

Overall, studies of resting frontal asymmetry with children and adults have found that right frontal asymmetry is related to withdrawal behavior. But left frontal asymmetry is not as consistently related to approach behavior. An important issue is whether the relation of frontal asymmetry and behavior exists for both types of emotional behavior. Drawbacks of the studies to date include the tendency for child studies to focus on withdrawal behaviors and the tendency for adult studies to rely on self-report measures of emotion. If approach behavior is examined and if actual behavior is the dependent variable, perhaps the postulated relation between frontal asymmetry and approach will be supported.

Task-related frontal asymmetry and state emotion. Studies of frontal asymmetry as an emotional state tend to examine frontal asymmetry during emotion-eliciting tasks such as films. Such studies with adults and infants have reported that frontal asymmetry is associated with approach and withdrawal emotions in adults and children. Appendix 2 summarizes the results of relevant studies on frontal asymmetry as a state variable.

In infants, greater relative right EEG activity accompanies maternal separation, a laboratory task that elicits distress (Fox & Davidson, 1987). During a mother-approach and stranger-approach paradigm, infants' Duchenne smiles are accompanied by greater left frontal activity, and non-Duchenne smiles are accompanied by greater right frontal activity (Fox & Davidson, 1988). Duchenne smiles involve activity in the *Orbicularis oculi* muscle, which surrounds the eye, and they are presumed to indicate genuine pleasure (Ekman, 1992). The same study reported that anger and sadness displays are associated with right frontal asymmetry during crying, but with left frontal asymmetry otherwise. In adults, left anterior temporal asymmetry occurs with the expression of happiness and right frontal asymmetry occurs with expressions of disgust (Davidson, Ekman, Saron, Senulis, & Friesen, 1990). Duchenne smiles occur with left frontal activation whereas non-Duchenne smiles do not (Ekman & Davidson, 1993).

Evidence from studies of frontal asymmetry during tasks designed to elicit emotional responses also suggests that approach and withdrawal emotional contexts are related to frontal asymmetry. Infants watching videotapes of an adult posing facial expressions of happiness have left frontal asymmetry (Davidson & Fox, 1982), and infants' left frontal activity increases during a maternal separation (Davidson & Fox, 1987). Shy children exhibit greater task-related increases in right frontal activity during a social presentation task than do other children (Schmidt, Fox, Schulkin, & Gold, 1999). Adults engaged in computer tasks with reward and punishment conditions show greater relative left activity during reward trials (Miller & Tomarken, 2001; Sobotka, Davidson, & Senulis, 1992) and greater relative right activity during punishment trials (Sobotka et al., 1992). In a study of emotion-inducing tasks with personal content, adults have greater relative left frontal EEG activity during tasks intended to induce happiness (Waldstein, Kop, Schmidt, Haufler, Krantz, & Fox, 2000).

Anger, an emotion conceptualized as a response to blocked goals, is hypothesized to involve patterns of brain electrical activity that indicate approach motivation (Fox, 1991; Harmon-Jones & Allen, 1998). This claim is consistent with an appraisal-tendency framework of emotions, in which anger is seen as defined by a sense of control and certainty, and angry people are considered to be similar to happy people in their risk perceptions (Lerner & Keltner, 2001). In studies of frontal asymmetry, infants' expressions of anger with crying during a maternal separation task and adults' self-reported anger during an anger induction are associated with greater left frontal activity (Harmon-Jones & Sigelman, 2001). These findings suggest that examinations of state-dependent changes in frontal asymmetry should take the approach or withdrawal quality of negative emotions into account when making predictions about asymmetry patterns. In particular, research paradigms that elicit anger may elicit left frontal EEG activity.

The findings of studies on EEG asymmetry and emotional state are fairly consistent, but there are two issues that could be clarified. First, asymmetry does not seem to be consistently associated with both approach and withdrawal emotional states. In one case, greater relative left activity occurred during reward trials but greater relative right activity did not occur during punishment trials (Miller & Tomarken, 2001). In another study, asymmetry effects were found for one form of approach (happiness) but not another (anger; Waldstein et al., 2000). Second, studies to date have focused on infants and adults but have not included children. Because competence in emotion regulation develops during childhood, it is important to consider the relation between frontal asymmetry and emotion regulation during childhood.

Generally, studies of anterior EEG asymmetry as a trait marker have reported that asymmetrical activity is related to temperament, personality, and depression. Findings have not been unequivocal, and there are several issues that remain to be resolved. With regard to temperament and personality factors, the relation does not seem to hold equally for positive and negative affect. Right frontal asymmetry seems to be consistently related to negative affect and to expression of withdrawal-related emotion. But left frontal asymmetry is not as consistently related to positive affect. In adults, one study found that greater right frontal activity at rest was related to higher self-report of negative affect, but there was not the analogous relation with positive affect for those with greater left frontal activity (Tomarken et al., 1990). In a study with children, resting asymmetry scores were related to children's social wariness but not to sociability (Henderson et al., 2001).

Frontal asymmetry as an index of both trait and state emotion. Few published studies have considered frontal asymmetry as a marker of both trait emotion and state emotion. Although some studies have measured both resting and emotion-related EEG activity, most of these studies have tested hypotheses related to either trait or state, but not both. A recent review of findings on frontal asymmetry notes that although this variable has been associated with both normative emotional changes and stable individual differences, the relation between the two remains to be investigated (Coan & Allen, in press).

Summary of literature on frontal asymmetry and emotion. The above review of the literature on the approach-withdrawal model of emotion regulation highlights two patterns of findings: (1) frontal asymmetry is consistently related to withdrawal behavior but less consistently related to approach behavior, and (2) individual differences in approach and withdrawal behavior seem to be related more to resting frontal asymmetry than to task-related frontal asymmetry. To address these possibilities, it would be valuable to examine the relation of frontal asymmetry to both approach and withdrawal behavior and the contributions of both resting and task-related frontal asymmetry to emotional behavior.

Further issues in the study of frontal asymmetry and emotion regulation include the need for research with children and the importance of extending research to investigations of EEG asymmetry during social contexts involving the expression of emotion. Resting frontal asymmetry and behavior have been examined in children (e.g., Fox et al., 2001), but studies of EEG asymmetry and emotional state have tended to focus on either adults or infants. Given the development of cortical and subcortical areas related to emotion regulation that occurs during childhood (Casey et al., 2000; Davidson, 2002; Durston et al., 2001), it would be worthwhile to investigate the relation of task-related frontal asymmetry to concurrent emotional behavior during an emotion regulation context. Examining frontal asymmetry in relation to behavior is important because many studies have been focused on examinations of self-reported or parent-reported emotional characteristics rather than on emotional behavior. The correspondence between actual behavior and EEG asymmetry – whether at rest or during an emotional state – remains a salient question.

Behavior and Emotion Regulation

With increased interest in emotion regulation as a central aspect of emotional development, research on emotion regulation has addressed both normative behavior and individual differences. From a normative perspective, the development of emotion regulation involves the increasing ability to flexibly adapt emotional responses to situational demands. By the preschool years, children have made remarkable progress in emotion regulation skills, a change that may be due in part to development of cognitive and self-awareness abilities (Kopp, 1982, 1992).

The social context of emotion regulation has received particular attention in the emotion regulation literature. The presence of other people creates support for and challenges to emotion regulation. Adults, especially caregivers, can facilitate the regulation of emotion through evaluating children's emotional behavior and intervening to influence characteristics such as arousal level or duration of emotion expression (Kopp, 1982; Thompson, 1994). Emotions can serve an important signaling function (Thompson, 1993); thus, when children are in a social context, they might endeavor to control or modify their emotions in order to communicate their needs and wishes to others. Through cultural factors such as display rules, the presence of others can also contribute to the environment in which emotions are regulated (Cole, 1986). The presence of others creates expectations about the intensity and type of emotions that are expressed. Children themselves are aware of the influence of social contexts on emotion expression. When asked to describe their emotion regulation, early school-age children noted that the presence of others, as well as the identity of those present, can be an important motivation for their attempts to control negative emotions (Zeman & Garber, 1996; Zeman & Shipman, 1996).

Normal individual differences in emotion regulation behavior. The sources of individual differences in emotion regulation are postulated to include internal and external processes. For emotion regulation behavior that does not occur in the presence of a caregiver, internal, within-child sources are particularly of interest. The internal sources of individual differences include neuroregulatory systems, behavioral traits, and cognitive components (Calkins, 1994). Behavioral traits, which have been studied the most extensively of the three, influence the ways that children respond to stimuli and express emotion. When encountering frustration, for example, some children will display higher levels of distress than others. In such a context, children will vary in soothability. Some children will be more easily soothed by themselves or other people and some children will be more difficult to soothe.

The regulation of negative emotions has long been considered a fundamental aspect of emotion regulation (Kopp, 1989). Negative emotions arise frequently in children's experience. Encountering novel situations or people, being denied a desired object, and finding that access to a goal has been blocked are common events in children's lives. Because emotion regulation is theorized to bear more on the intensity of emotional state than the presence of discrete emotions (Thompson, 1994), the appropriate regulation of negative affect is likely to involve behaviors that decrease arousal or enhance positive affect.

Individual differences exist in many aspects of children's regulation of negative emotions. One area in which children exhibit differences is facial expressions of emotion. During a negative mood induction, preschool-age children vary in their facial expressiveness, with some relatively inexpressive and others highly expressive (Cole, Zahn-Waxler, Fox, Usher, & Welsh, 1996). Differences are also evident in other types of motor activity. Behaviorally inhibited children display extreme levels of fearfulness in withdrawal responses such as clinging to the mother or failing to approach novel people and objects (Kagan et al., 1988). Differences in the regulation of fearfulness are evident during infancy and remain stable in social contexts during childhood.

Difficulties in regulating negative emotions can be related to behavior problems and to psychiatric diagnoses. A combination of parent-rated tendency to express negative affect, parent-rated soothability, and observed social behavior are reported to predict adaptive social behavior (Rubin, Coplan, Fox, & Calkins, 1995). Children who are classified as having poor emotion regulation and who interact little with unfamiliar peers exhibit more anxious behaviors and internalizing problems, whereas those with poor emotion regulation and high levels of social interaction have more externalizing problems. In children with diagnoses of externalizing disorders, high levels of negative emotionality during infancy are associated with conduct disorder during early childhood (Shaw et al., 2001).

Emotion regulation during disappointment. A context that can challenge children's abilities to flexibly change the intensity or quality of their emotions is disappointment. If children's expectations of reward or pleasure are not met, they may feel sad, angry, or anxious. These forms of distress may require emotion regulation. If the situation also involves a social demand to be polite or to mask negative affect, display rules will augment the demand for children to control their expression of negative affect (Cole, 1986; Saarni, 1984).

The disappointment paradigm developed by Saarni (1984) and Cole (1986) is effective at creating a demand that children regulate their negative emotions and control their facial expressions. The paradigm has been used in children ranging from preschool-age to middle childhood, and it elicits a variety of emotional behaviors from children (Cole, Zahn-Waxler, & Smith, 1994). In the paradigm, a child is encouraged to develop the expectation – through previous experience (Saarni, 1984) or though a request to express preferences (Cole, 1986; Cole et al., 1994) – of receiving an appealing toy. Instead, the child is given an inappropriate or unappealing toy without an explanation. The experimenter gives the child the unappealing toy and remains with the child, thereby adding a social component to the task. The experimenter's presence invokes a display rule about controlling the expression of negative emotions the child is experiencing (Saarni, 1984). This social condition of the task is followed by a second, nonsocial condition, in which the child is left alone with the unwanted toy and which allows the more open expression of negative affect (Cole, 1986). The social condition is especially valuable because it creates a demand for emotion regulation and elicits a range of emotional behavior. Upon receiving the unwanted toy, children display both approach and withdrawal emotions, including joy, anger, sadness, and worry (Cole et al., 1994; Cole, 1986; Saarni, 1984).

The disappointment that arises from failing to receive what one wants can be expressed as a variety of negative emotions. Depending upon the interpretations a child makes about the disappointing event (Lazarus, 1991), the emotions expressed during the social bad toy condition may take the form of anger, sadness, or worry. Each of these is associated with a different action tendency (Frijda, 1986; Frijda & Tcherkassof, 1997). If the disappointment is perceived as a disruption of progress toward a reward, the child may react to the event with anger. This emotional state may be expressed by knitting the brows and tightening the lips, or by demanding that someone repair the error. If the experience leads to the belief that there will be no further opportunity to receive something valued, the child may react with sadness. This may be expressed by drawing the corners of the mouth downward, crying, or withdrawing from social interaction. If the child interprets the disappointing event as unpredictable and threatening, the response may be worry or fear. In that case, the child might display widened eyes or turn away from the experimenter.

The most detailed analysis of children's behavior upon receiving the unwanted toy has been conducted by Cole et al. (1994). Behaviors observed in that study included the expression of basic emotions such as anger and the use of self-regulatory behaviors (Cole et al., 1994). Three types of self-regulatory behavior have been quantified during the task: active self-regulation, passive self-regulation, and disruptiveness. Each of these behaviors has a specific pattern of relation to emotion expression. Active self-regulation is related to high levels of joy, low levels of anger, and low levels of negative affect. Passive self-regulation is related to low levels of joy and anger. This occurs especially for girls. Disruptiveness is related to anger and negative affect. Although the self-regulatory behaviors were not examined from an approach-withdrawal perspective, it is possible to postulate that active self-regulation and disruptiveness reflect approach and passive self-regulation reflects withdrawal.

Mixed findings have been reported for the influence of gender and age on emotion regulation during the disappointment task. Boys and girls respond differently to the disappointment task, especially during the social condition. Generally, boys display more negative affect during this condition, and girls display more positive affect (Cole, 1986; Cole et al., 1994; Davis, 1995; Garner & Power, 1996; Saarni, 1984). Despite assumptions that the ability to mask emotion will improve with development, there have been mixed findings on the effect of age on task behavior. A study that included children ranging from 3 to 9 years of age found no age effects on emotion expression (Cole, 1986). Another study included first, third, and fifth graders and reported an age-by-gender interaction effect (Saarni, 1984). First- and fifth-grade boys displayed an increase in negative emotion from a rewarding task to a disappointment task relative to girls. In a study with children at risk for behavior problems, extreme levels of externalizing and internalizing behaviors were also associated with anger and negative affect during the task, and an interaction between behavior problems and gender in influenced the amount of negative affect expressed (Cole et al., 1994).

In all, a disappointment experience is an effective way to elicit and measure children's emotion regulation. A laboratory disappointment task has several strengths. It creates a demand to regulate negative emotions, it elicits a variety of emotions, it involves a social context, its circumstances are ecologically valid, and it can be used with children from preschool-age through middle childhood. What is needed to expand understanding of emotion regulation during disappointment is an examination of corresponding physiological processes. Physiological factors such as brain electrical activity have not been measured during this paradigm, but their importance to emotion regulation suggests that their inclusion would provide a valuable contribution to knowledge about emotion regulation.

Several considerations are germane to the study of emotion regulation in children. First, two aspects of the approach-withdrawal model remain to be tested. These are the relation of frontal asymmetry to approach behavior and the relation of resting and task-related frontal asymmetry to behavior. Second, in keeping with that model, it is critical to measure both behavior and physiology when examining emotion regulation. Emotion regulation research typically has examined emotional behavior, and several studies have considered both physiological and behavioral aspects of emotion (e.g., Fox et al., 2001). Relatively few studies, however, have considered expressive behavior in the context of both resting and task-related physiological characteristics. Expanding investigations of emotional processes beyond a single component will enhance the understanding of emotion regulation. Third, because emotion regulation influences effective interpersonal behavior (Calkins, 1994; Campos et al., 1989; Campos, et al., 1994; Garber & Dodge, 1991; Thompson, 1994), it is valuable to elicit and measure emotion regulation using social contexts.

The Current Study

The current study examined the relations among children's frontal asymmetry and emotional behaviors during a disappointment task. The *social bad toy* condition of the task, in which the child receives the unwanted toy, was the context in which children's frontal asymmetry and emotional behavior were measured. During this condition, children are likely to experience emotions and are challenged to regulate the expression of negative emotions. Figure 2 presents the design of the study. Frontal asymmetry, or the difference between electrical activity at left and right frontal sites, was examined using resting and a task-related conditions. Accordingly, the relative influences of task-related and resting asymmetry on emotion regulation were considered. Within the theoretical context of approach and withdrawal in emotional behavior, this study addressed approach and withdrawal responses during an experience that elicits the regulation of negative emotions.

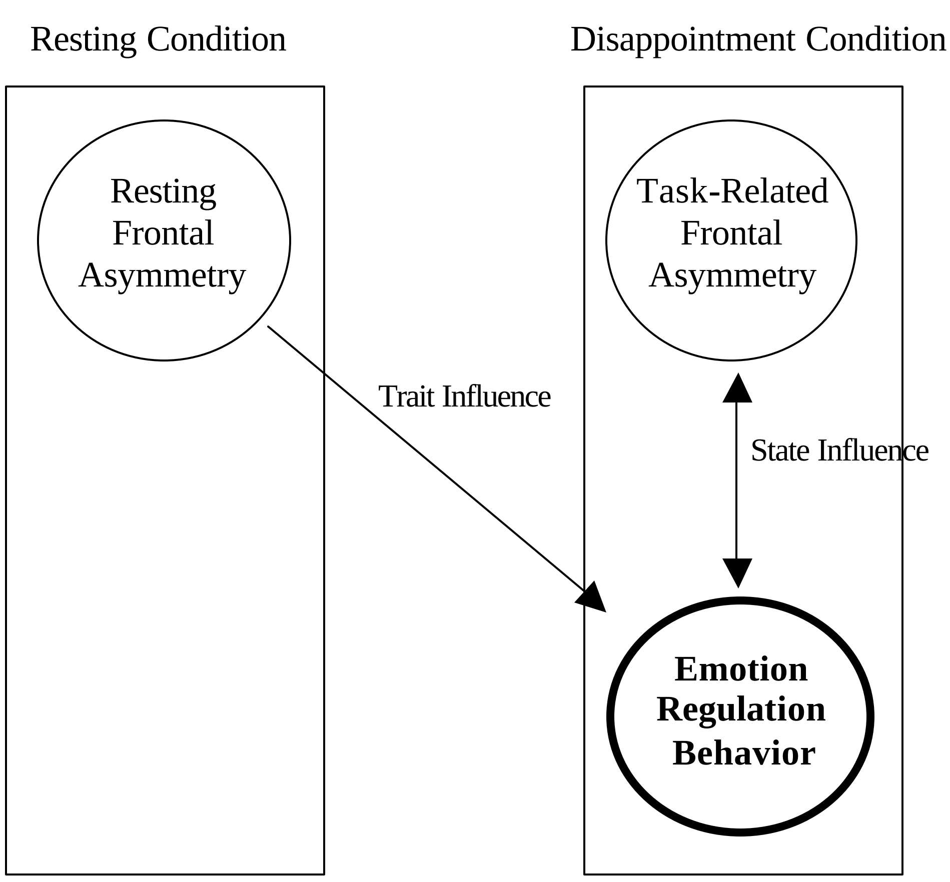

Figure 2. Design of the current study, which examined the association of emotion regulation behavior during a disappointment with resting and task-related frontal asymmetry.

To obtain a broad range of variability in emotion regulation, children were recruited from a longitudinal study of offspring of parents with childhood-onset depression (COD) and offspring of a comparison group of parents with no psychiatric disorders. The offspring of parents with COD are at risk for behavior problems and affective psychopathology (Bland, Newman, & Orn, 1986; Downey & Coyne, 1990; Kupfer, Frank, Carpenter, & Neiswanger, 1989; Mendlewicz & Barron, 1981; Moldin, Reich, & Rice, 1991; Price, Kidd, & Weissman, 1987). As a result, they are likely to exhibit emotion dysregulation more than are children without a family history of COD. There were unequal proportions of children in the COD and control groups (two-thirds of the sample was in the COD group), which resulted in low statistical power for detecting group differences in emotion regulation. Consequently, hypotheses about group differences were not proposed as a central part of the study. Instead, the focus of the study was normal individual differences in emotion regulation, and all participants were included in tests of the main hypotheses. An important consideration in this decision is that although the COD offspring are at risk for behavior problems, they may not have experienced or exhibited psychopathology. Therefore, children in the COD group can be seen as representing a more extreme end of the spectrum of normal individual differences in emotion regulation.

Hypotheses

The overall hypothesis of this study is that children's emotion regulation behavior is related to their anterior EEG asymmetry. Based on the approach-withdrawal model of emotion regulation, approach-related behaviors were predicted to be associated with left frontal asymmetry, and withdrawal-related behaviors were predicted to be associated with right frontal asymmetry.

Primary hypotheses (Hypotheses 1–4) of the study concerned two issues: (1) the relation of resting and task-related frontal asymmetry to emotional behavior during a disappointment task, and (2) the relative contributions of resting and task-related asymmetry to emotional behavior.

Hypothesis 1: Approach behavior will be related to *left* frontal asymmetry. For example, smiling or attempts to engage in play with the unwanted toy will be accompanied by left frontal asymmetry at rest and during the task.

Hypothesis 2: Withdrawal behavior will be related to *right* frontal asymmetry. For example, looking away from the toy or expressing worry will be accompanied by right frontal asymmetry at rest and during the task.

Hypothesis 3: Disruptive anger, which reflects approach motivation, will be related to *left* frontal asymmetry. For example, expressing anger and throwing the unwanted toy on the floor will be accompanied by left frontal asymmetry at rest and during the task.

Hypothesis 4: Task-related frontal asymmetry will be related to emotion regulation behavior once the influence of resting frontal asymmetry has been accounted for. In other words, in regression models predicting emotion regulation behavior (either approach-related or withdrawal-related), state measures of frontal asymmetry will predict additional variance in behavior after the relation of trait-like frontal asymmetry has been controlled.

Secondary hypotheses (Hypotheses 5–6) were intended to be tested if support for the primary hypotheses did not emerge from data analyses. The basis for the secondary hypotheses was the prediction that individual emotional behaviors that were part of composite behavior variables will be related to frontal asymmetry. Secondary hypotheses were as follows:

Hypothesis 5: Individual approach-related behaviors will be related to *left* frontal asymmetry. As with the composite approach and disruptive anger variables, individual emotional behaviors that are postulated to be related to approach (i.e., smiling, anger, and active self-regulation) were expected to be related to left frontal asymmetry.

Hypothesis 6: Individual withdrawal-related behaviors will be related to *right* frontal asymmetry. As with the composite withdrawal variable, individual emotional behaviors that are postulated to be related to withdrawal (i.e., disgust, sadness, worry, and passive self-regulation) were expected to be related to right frontal asymmetry.

METHOD

Participants

Participants were 58 children between the ages of 3 and 9 years. Originally, 69 children participated in the study, but complete data were not available for 11 children. Of the 11 participants who were not included in the final sample, 7 did not participate in the disappointment task, 2 were not videorecorded due to experimenter error, 1 did not have physiology data for the resting condition, and 1 did not have physiology data for the disappointment condition.

The age range, 3–9 years, was selected because it is a period during which children are developing emotion regulation skills (e.g., Kopp, 1982). This range of ages is consistent with the ages of children included in previous studies using the disappointment task (Cole, 1986; Cole et al., 1994; Davis, 1995; Garner & Power, 1996; Saarni, 1984).

All children in the study are also participants in a longitudinal study investigating the psychophysiological characteristics of the offspring of adults with COD. Inclusion in the current study was based on history of or risk for psychopathology, not current diagnosis. As a result, parents and children in the COD group did not necessarily carry current psychiatric diagnoses or exhibit psychiatric symptoms at the time of the assessment. COD parents were recruited during childhood from treatment programs at the Western Psychiatric Institute and Clinic in Pittsburgh, Pennsylvania. Control parents were recruited during the past 4.5 years through a marketing directory, newspaper advertisements, and other studies.

The demographic characteristics of the sample are presented in Table 1. The sample ethnicity was 43% European American, 52% African American or mixed African American and European American, 2% Asian American, and 3% Latino. Fewer than half of the parents of the participants had education beyond a high school diploma.

Within the COD group, all offspring in the target age range were included in the study. The 58 children in the sample represent 47 families. One family contributed 4 children, 2 contributed 3 children, and 4 contributed 2 children. All other COD families contributed 1 child. Within the control group, only 1 child per family was assessed. As

Table 1
Demographic Characteristics of the Sample

Variable	Mean (SD) or Frequency
Age	5.17 (1.82)
Age Group	
3–5 years	34
6–9 years	24
Sex	
male	37
Female	21
Ethnicity	
European American	25
African American	9
Asian American	1
Latino	2
Mixed[a]	21
Parent Education Level	
college degree	5
some college	19
high school diploma	31
some high school	2
grade school diploma	1
Child Handedness[b]	
right	50
Left	7
Parent History of Psychopathology[c]	
childhood-onset depression	41
childhood-onset anxiety	1
no history	16
Parent Current Depressive Symptoms[c]	9.00 (9.23)

Note: *N* = 58. Data on child age, child sex, child ethnicity, parent education level were obtained through parent-report demographic questionnaires. Child handedness was derived from a 10-item form of the Edinburgh Handedness Questionnaire (Oldfield, 1971) adapted for use with children. Parent history of psychopathology determined with the ISCA (Sherrill & Kovacs, 2000) for the depression group and with the SCID (First, Spitzer, Gibbon, & Williams, 1995) for the control group. Current depressive and anxiety symptoms measured with the Follow-up Depression Scale (Sherrill & Kovacs, 2000).
[a]Primarily mixed European American and African American.
[b]Questionnaire not completed for 1 child.
[c]Interviews not completed for 3 children. Range = 0-37.

described in the Data Analytic Strategy section below, the non-independence of participants in the COD group was taken into account in data analyses.

Materials

Demographic questionnaires. Data on family demographic characteristics (such as child ethnicity, child age, parent education level, and family composition) were collected from a parent using questionnaires. Data on the child's medical history, developmental milestones, and behavior problems were also collected through parent report.

Handedness. Because previous research on anterior EEG asymmetry has focused on right-handed participants or on offspring of right-handed parents (e.g., Fox & Davidson, 1988), child handedness was measured using an 11-item version of the Edinburgh Handedness Inventory (Oldfield, 1971) that has been adapted for use with children. This questionnaire has sufficient reliability and validity (Oldfield, 1971). Handedness was determined using scoring methods that yield a laterality quotient and was included in analyses as a dichotomous variable (i.e., left or right). Most of the children in the sample (86%) were right-handed.

Parent psychiatric diagnoses. Parent history of depression was determined through the administration of structured clinical interviews and a review of medical records. Parents in the COD group received diagnoses before the age of 15 years and were evaluated during childhood using the Interview Schedule for Children and Adolescents (ISCA; Sherrill & Kovacs, 2000). Parents in the control group were evaluated using the Structured Clinical Interview for DSM-IV (SCID; First, Spitzer, Gibbon, & Williams, 1995). SCIDs were administered to controls at the time of recruitment to confirm the absence of psychopathology in the control group. Parent history of depression was coded as present or absent for each child.

Parent depressive symptoms. Current parent depressive symptoms were measured using the semi-structured Follow-up Depression Scale (FDS) of the Interview Schedule for Children and Adolescents (Sherrill & Kovacs, 2000). The FDS has acceptable reliability and validity (Sherrill & Kovacs, 2000). Each of the 21 items corresponds to a symptom of major depressive disorder (e.g., dysphoric mood), and the response to each item is rated on a 4-point scale from 0-3. The interview was administered by Masters-level clinicians who were trained to be reliable with clinicians who had extensive experience with the interview. The total FDS score was used to index parents' depression severity. Current parent depressive symptoms were missing for three participants, all siblings, because the parent who accompanied the participants to their assessments declined to complete the interview. Depression symptoms were low for parents in the control group (M = 2.69, SD = 2.68, range = 0-7) and ranged from low to moderate for parents in the COD group (M = 11.74, SD = 9.82, range = 0-37).

Recording of brain electrical activity. Brain electrical activity was measured from scalp sites using EEG with electrode-containing caps manufactured by Electro-Cap International (ECI). The caps allow efficient attachment and recording, and they are designed with electrode leads placed to measure activity in scalp sites described in the 10-20 International System (American Electroencepalographic Society, 1994). The caps, which are available in different sizes, were placed according to standard skull landmarks. This practice ensured that the recording sites were consistent across participants. Circular tin electrodes sewn into the cap facilitated preparation of the skin so that low resistive contacts could be established between the electrode recording surface and the scalp.

In the current study, EEG was recorded at the following 6 pairs of sites: mid-frontal (F3, F4), lateral frontal (F7, F8), central (C3, C4), anterior temporal (T7, T8), mid-parietal (P3, P4), and occipital (O1, O2). Activity at each region was measured with two electrodes, at homologous locations over the left and right hemispheres of the brain. These sites were chosen because they are appropriate for testing hypotheses generated from the approach-withdrawal model of emotion regulation. Several other studies have used these sites to test hypotheses about frontal asymmetry and emotion processes in children (e.g., Calkins, Fox, & Marshall, 1996; Fox et al., 2001). On-line recordings were referenced to an electrode located at the vertex site (Cz), with the mid-frontal site (Fz) as the iso-common ground. After data collection, re-referencing was performed to a common average reference.

Vertical and horizontal electrooculogram (EOG) activity was recorded from two channels using tin cup electrodes placed on the face. Vertical EOG was recorded from surface electrodes placed over the suborbital and supraorbital areas around the right eye, and horizontal EOG was recorded from the left and right outer canthi. EOG data were used to identify and manually remove eye movement artifact.

Pentium computers were used for data acquisition, experimenter control, and video time code generation. EEG, stimulus presentation, and video recordings had precise time synchronization through software that integrates physiology data, stimulus presentation files, and video time code.

The EEG signal was amplified and filtered by an SA Instrumentation bioamplifier set so that output signals represented 50 μV peak-to-peak with a gain of 5000. Bandpass filter settings for EEG channels were 1 Hz (high pass) and 100 Hz (low pass). Data were digitized on-line using a Pentium computer running customized acquisition software. The EEG data were digitized at a sampling rate of 512 Hz per channel.

Disappointment task. The disappointment task involved the presentation of eight toys to the child, four of which were appealing and in good condition, and four of which were unappealing or visibly damaged. Appealing toys included a disposable camera and a colorful yoyo, and damaged toys included a broken crayon and a balloon with a hole in it. Toys were varied based on the age of the child, so that each child had a selection of developmentally appropriate toys. A subsection of a measure of cognitive ability was used to generate materials for the filler task that the child completed after ranking the toys. The child's responses to the cognitive measure were not recorded or used in analyses.

Videorecording of behavior. To record the child's behavior, a camera was placed inside a glass case directly in front of the child and focused on the child's face and upper body. A videocassette recorder (VCR) in an adjacent room recorded from the camera, and a Horita VITC generator was used to generate video time code and record it on the image. Using software from the James Long Company, the time code was synchronized with acquisition of physiology data. VCRs equipped with shuttles to regulate viewing speed were used to code behavior offline after the sessions were completed.

Procedure

A parent accompanied each child to the assessment session and provided informed consent for the child's participation. During the recording of physiology data, the parent completed the depression symptom interview and questionnaires on the child's demographic and other characteristics. The parent waited in an adjacent room from which the experimental room could be viewed on a monitor, except in one case, where the child's mother remained in the experimental room because the child would not proceed without her presence.

Upon arrival, each child was acquainted with the lab staff and the experimental room, which was decorated with a space theme to help the child become comfortable with the equipment and procedures of the study. During the assessment, the child was seated in a comfortable chair. A member of the staff sat next to the child throughout the assessment session in order to give instructions, answer questions, and help the child comply with procedures. All of the children participated in a series of emotion-eliciting tasks, one of which was the disappointment task.

Preparation for acquisition of EEG data. EEG recordings followed standard guidelines for procedure (see Pivik et al., 1993). Electro-gel (from ECI) was inserted into each electrode site to establish contact between the scalp and the electrode. Impedances were checked during cap preparation, and sites were further abraded as needed to obtain impedances below 5 kOhms. Impedances for homologous sites were within 0.5 kOhms of each other. Impedances were checked and recorded at the end of the preparation period and at the end of the assessment session. Five children had pre-session impedances greater than 5 kOhms at midfrontal sites, but in all cases the two midfrontal electrodes were within 0.5 kOhms. A MANOVA for midfrontal and parietal sites with region (frontal or parietal) and hemisphere (left or right) as within-subjects factors revealed no main effect for region or hemisphere and no region X hemisphere interaction ($F(1,56) = 1.29$, $p = .26$; $F(1,56) = 0.39$, $p = .54$; $F(1,56) = 0.34$, $p = .56$, respectively).

Resting condition. EEG was recorded both during a resting condition and during the disappointment task. After preparation for EEG recording was completed, the experimenter told the child that they would blast off for a trip to outer space. The experimenter who sat with the child led the child in a countdown and then explained the procedure for the resting recording condition. There were six resting segments, three in which the child sat quietly with eyes open, and three in which the child sat quietly with eyes closed. The eyes-open and eyes-closed conditions alternated. During eyes-open segments, the child was instructed to look at a small model of a spaceship in order to minimize the presence of EEG artifact related to eye movements and gross motor movements. During eyes-closed segments, the child was instructed to sit with eyes closed and pretend to sleep. If the child had difficulty completing a segment, the segment was repeated at the end of the resting condition. An inspection of videotapes and raw EEG data indicated that the participants complied with instructions and thus had valid data for eyes-open and eyes-closed segments. At the end of the resting condition, the child received a small reward.

Disappointment condition. The emotion regulation task was based on the disappointment paradigm developed by Saarni (1984) and Cole (e.g., Cole, 1986), in which children are led to believe that they will receive a wanted toy but instead are given an undesirable toy. The task contained three segments: a *social bad toy* condition, in which the child received her least-favorite toy; a *nonsocial bad toy* condition, in which the child was left alone with the undesired toy; and a *good toy* condition, in which the child received an apology and her most-favorite toy. Because it places the greatest number of demands on the child's regulation of negative emotion, involves an interpersonal context, and elicit emotion regulation behavior in children of this age (Cole, 1986; Saarni, 1984) the social bad toy condition was the focus of the current study.

After the resting condition was completed, the child was presented with eight small toys and instructed to rank the toys in order of preference. Four of the toys were desirable and age-appropriate, and four were broken or inappropriate. The child was told that she would receive a prize after completing a task, creating the expectation that the first-choice toy would be given. With a second experimenter, the child then completed a brief cognitive task involving picture vocabulary items. The cognitive task was designed to fill the time so that the child's anticipation of the toy could build. After the cognitive task, the second experimenter left the room, promising that to return with the child's first-choice toy.

Instead, the second experimenter returned with the child's last-choice toy concealed from view. The experimenter placed the toy in front of the child and said, "Here is the toy you wanted." Without further explanation, the experimenter sat down next to the child and maintained a neutral facial expression for 60 s. The experimenter interacted minimally with the child, and if the child spoke to the experimenter, the experimenter responded by reflecting the child's statement in a neutral tone of voice. The experimenter then exited the room, leaving the child alone with the undesirable toy for approximately 20 s. This was the nonsocial bad toy segment of the task.

After the nonsocial segment, the first experimenter entered the room and interviewed the child briefly about her response to receiving her last-choice toy. The experimenter explained that there had been a mistake and left the room, then the second experimenter returned with the child's first-choice toy, offered the toy, and apologized to the child for the error.

EEG was recorded throughout the disappointment task.

Data Processing, Coding, and Reduction

EEG data processing. After EEG data were collected, offline transformations were used to derive an average reference, and EEG data were re-referenced to the average reference. Data files were inspected visually for artifact related to eye movement, gross motor movement, and muscle tension in the face or scalp. These types of artifact were manually removed using a computer program designed for editing physiology files. When an epoch was marked as containing artifact, EEG data from all channels during that epoch were discarded from further analysis.

Once artifact was removed, EEG signals were quantified with a discrete Fourier transformation (DFT) using a Hanning window 1 s wide and with 50% overlap. Prior to DFT computation, the mean voltage was subtracted from each data point to eliminate any influence of DC offset. Power (in units of picowatt-Ohms or μV^2) was computed for 1-Hz frequency bins for frequencies between 1 and 30 Hz. Power was clustered into broad bands, with the alpha band as the band of interest in the current study.

The alpha band, which is the dominant EEG rhythm, was selected because it is putatively inversely related to sensory stimulation and cortical activation (see Davidson, 1988). Greater brain activation is defined as the suppression of activity in the alpha band

(Davidson, 1992; Pfurtscheller, Stancak, & Neuper, 1996). Higher power values in the alpha band are assumed to reflect less cortical activity, and lower power values are assumed to reflect alpha suppression and therefore more cortical activity.

In infants and young children, the alpha range is typically defined as 6 to 9 Hz because the peak spectral frequency is approximately 8 Hz. This frequency range has been empirically supported for use with children up to 4 years old (Marshall, Bar-Haim, & Fox, 2002). However, the peak frequency of alpha increases with development (Davidson, Jackson, & Larson, 2000; Marshall et al., 2002). There has been little examination of the peak frequency range for children older than 4 years, and consequently it was not correct to assume that the alpha range defined in previous studies could be applied to children 3-9 years old. Instead, the alpha range definition was determined by quantifying EEG activity for single-Hz bins from 1-30 Hz. The resulting power distribution from 4-12 Hz for each participant's midfrontal electrode sites was inspected visually, and an alpha range was selected in consultation with researchers who have expertise in the change of the alpha range with development. As expected, there was an increase with age in the range of frequencies at which the most EEG power occurred. There did not appear to be a single range that would be appropriate for all children in the study, but it was possible to divide participants into two age groups by their patterns of EEG power. Accordingly, the alpha frequency range was defined as 7-10 Hz for 3–5-year-olds and as 8-11 Hz for 6–9-year-olds.

For the six resting periods, alpha power values (in picowatt-Ohms or μV^2) for each electrode site in each resting segment were averaged across epochs and weighted by the number of artifact-free windows in each epoch, yielding a single resting EEG alpha score. For the disappointment task, the average alpha power for the 60 s of the social bad toy segment was obtained. The average alpha power values were subjected to a natural-logarithm transformation to normalize their distributions for statistical analyses (Gasser, Bacher, & Mocks, 1982).

Frontal asymmetry was computed as the difference of log-transformed power scores for the pair of midfrontal sites. This approach is widely used in research on anterior EEG asymmetry and emotion. As described in detail by Davidson (Davidson, 1988; Davidson et al., 2000), the difference score is the most appropriate form for EEG variables intended for analyses of the relation between EEG power and a criterion variable such as the expression of an emotion. Individual differences in alpha activity result from anatomical variability, especially skull thickness, and these individual differences make the direct correlation of power at a single site with a behavior variable problematic. Difference scores of alpha activity at two homologous sites are equivalent to radiometric scores of the raw data, and computing difference scores removes the effect of individual differences in skull thickness and allows testing of hypotheses about the relation of the balance of EEG activity and a criterion variable.

A drawback of using asymmetry scores is that the method precludes the determination of the source of differences. In other words, greater relative right activity could be the result of right hyperactivation, left hypoactivation, or both. In addition, difference scores can be influenced by the artifactual curvilinear relation that often exists between a difference score and the sum of its two component scores (Chapman & Chapman, 1988). If both scores are high or both scores are low, the asymmetry score will be low. In this way, asymmetry scores could be influenced by total frontal power.

Because asymmetry scores allow the control of individual differences in alpha power and because the *balance* of activity between the two hemispheres is the focus of research on approach-withdrawal and brain activity, however, the difference score approach was followed in the current study.

Asymmetry scores were computed by subtracting the natural logarithm of power at the left recording site from the natural logarithm of power at the right recording site (e.g., lnF4 – lnF3). Because alpha power varies inversely with cortical activation, positive asymmetry values represent greater relative left activation (i.e., left frontal asymmetry) and negative asymmetry values represent greater relative right activation (i.e., right frontal asymmetry) at paired scalp sites.

Using asymmetry scores, dichotomous frontal asymmetry variables were computed for resting and task-related asymmetry. Participants were classified as having either left frontal asymmetry or right frontal asymmetry (n = 26 and n = 32, respectively, during rest; n = 33 and n = 25, respectively, during the task). The rationale for this approach was that the magnitude of asymmetry is postulated to reflect individual differences in characteristics such as skull thickness, and therefore it should not be considered to represent meaningful differences in the balance of brain activation. Direction of asymmetry (i.e., left or right) is considered a better description of frontal laterality and a more appropriate independent variable for testing hypotheses about the relation of asymmetry to behavior (N. A. Fox, personal communication, September 10, 2002).

The variables obtained from the EEG data were (1) frontal asymmetry (left or right) across the six resting periods and (2) frontal asymmetry (left or right) during the social bad toy condition of the disappointment task. The primary sites of interest were the midfrontal (F3/F4) sites.

Coding of emotional behavior. Based on the approach of Cole et al. (1994), the social condition of the task was coded for two types of emotional behavior: emotion expression and self-regulatory behavior. Both types of behavior were coded using a 5-s modified frequency approach. The presence or absence of each behavior was coded during each 5-s interval. In total, 10 emotional behaviors were coded.

The emotion expression categories were defined by facial expressions described in the Facial Action Coding System (FACS; Ekman & Friesen, 1978) and the work of Izard and colleagues (Izard, Dougherty & Hembree, 1983) and by vocal characteristics such a pitch or volume. The expression of the following basic emotions was coded: anger, sadness, worry, disgust, and smiling. Within the *smiling* category, three types of smiles were coded: Duchenne, non-Duchenne, and mixed. Differences in the facial movements that accompany these categories are claimed to reflect the genuineness of the positive affect that is expressed (Ekman, 1992). Because the disappointment task is not considered a context that elicits genuine happiness, there were no hypotheses about the occurrence of the different types of smiles. All three types were coded, however, and the decision about whether to combine them into a single variable was made after examining the data on smiling. Table 2 contains a description of the emotion expression behavior coding categories and the intercoder reliability for each.

Three categories of self-regulatory behavior were coded: active self-regulation, passive self-regulation, and disruptiveness. Each category was based on descriptors of motor and vocal behavior developed by Cole et al. (1994). Active self-regulation was

Table 2

Emotion Expression Behaviors Coded and Corresponding Action Units (AUs) from FACS (Ekman & Friesen, 1972)

Category	Description	AUs
Smiling (.83)	Face • lip corners raised obliquely • cheeks raised Voice • light, lilting quality • higher pitch • laughing, giggling	12
Duchenne (.54)	• smile with crows' feet or gathering of skin around outside of eyes	6 + 12
Non-Duchenne (.68)	• smile without the gathering of skin around the eyes	12
Mixed (.17)	• smile accompanied by wrinkling of nose, raise of upper lip, or tightening or pressing of lips	12 + 9, 10, 23, or 24
Anger (.64)	Face • eyebrows drawn together and lowered • lower eyelids tightened or eyes narrowed • lips tightened or pressed together Voice • harsh, insistent quality • increased vocal pitch and volume	4, 7, 23, 24
Disgust (.62)	Face • skin wrinkled under the bridge of the nose, inner portions of eyebrows drawn down, eyes narrowed • upper lip raised Voice • as if trying to expel something from throat	9, 10
Sadness (.68)	Face • inner portions of eyebrows raised and drawn together • lip corners turned downward • lower lip pouting • chin boss flattened • eyelids drooping Voice • soft or decreasing volume	1+4, 15, 17, 41
Worry (.62)	Face • lip corners pulled downward and outward • inner eyebrows raised and drawn together • upper eyelids raised Voice • strained, not smooth in quality	1+4, 5, 20

Note: Categories and descriptions are adapted from Cole et al. (1994). Intercoder reliability (ê) is reported in parentheses after each category name.

defined as attempts to decrease negative emotion and increase positive emotion by playing with the toy, trying to fix it, or asking the experimenter how the toy was broken. Passive self-regulation involved behaviors in which the child attended to the toy or experimenter but did not actively engage in play or conversation. Examples include sitting quietly and staring at the toy or commenting neutrally that the toy is broken. Disruptiveness was marked by aggressive or socially inappropriate actions such as throwing the toy or speaking angrily to the experimenter. Table 3 contains a description of the self-regulatory behaviors coded and the reliability for each.

Table 3
Self-regulatory Behaviors Coded, with Examples

Category	Description	Examples
Active Self-Regulation (.75)	Approaching and attempting to enjoy toy	• Child plays with toy. • Child makes self-reassuring statements.
Passive Self-Regulation (.67)	Withdrawal from play or neutral stance toward toy	• Child stares at toy but does not play with it. • Child makes neutral statements such as "It's broken."
Disruptiveness[a]	Aggressive or confrontational response to toy or experimenter	• Child throws toy. • Child makes a rude comment to experimenter.

Note: Categories and descriptions are adapted from Cole et al. (1994). Intercoder reliability (ê) is reported in parentheses after each category name.
[a]Kappa statistic could not be computed because behavior occurred once in reliability data set. All three coders agreed on its presence.

Three coders certified in FACS (Ekman & Friesen, 1978) coded behavior from videotape. A FACS-certified coder trained the other coders using videotapes of pilot participants and participants who were missing physiology data. A subset of 15 participants (26%) was coded by more than one coder, and reliability was measured by the kappa statistic. Coders were considered in agreement if both coded the same behavior during the same interval. Kappa values were generally in the acceptable range. The exception to this was the kappa value for mixed smiles, which frequently overlapped with (and was not successfully discriminated from) expressions of negative affect such as disgust.

Behavior data from all 10 categories (7 emotion expression behaviors and 3 self-regulatory behaviors) were reduced to the total count of each behavior. Computing proportion variables was considered, but this would have limited the possible range of values because each social bad toy condition contained 12 intervals. All but one participant had data for all 12 intervals, and thus proportions were not necessary for standardizing the amount of time coded. The participant with missing data moved out of range of the camera for one interval, and the total count for each behavior category was prorated for this participant.

Reduction of behavior data. To reduce the total number of behavior variables, three initial theoretically derived composite variables were created: *approach*, *withdrawal*, and *disruptive anger*. The use of composite variables – and the three particular composite variables created – was novel to the current study. The steps involved in developing the composite variables were as follows: (1) initial composite variables were created based on theoretical considerations; (2) analyses were conducted to validate the composite variables empirically; and (3) composite variables were adjusted based on the results of validation analyses. Steps (2) and (3) are described in the

Results section. The final composite variables were the dependent variables in the primary data analyses.

The basis for the composite variables was the approach-withdrawal model of emotion regulation (Davidson, 1984, 1992; Fox, 1991), which classifies emotions and their accompanying EEG asymmetry as either approach-related or withdrawal-related (please refer to Figure 1 for details). Based on this model, approach behaviors include smiling, anger, and active engagement with the experimenter or toy. Withdrawal behaviors include sadness, fear, disgust, and lack of engagement with the experimenter or toy.

Initially, the approach composite contained Duchenne smiles and active self-regulation and omitted other types of smiles. Duchenne smiles are thought to convey genuine pleasure (Ekman, 1992) and are reported to be related to left frontal asymmetry (Fox & Davidson, 1988). However, as described in the Results section below, Duchenne and non-Duchenne smiles were correlated. Accordingly, all smiles were included in the composite variable. The withdrawal composite contained disgust, sadness, worry, and passive self-regulation. The disruptive anger composite contained anger and disruptiveness. The validity analyses for the three composite variables are reported in the Results section.

Data Analytic Strategy

As an overview, Table 4 lists the main variables in the study.

Table 4
Main Variables in the Study

Variable	Definition
	Primary Hypotheses
Frontal Asymmetry	ln(F4 alpha power) – ln(F3 alpha power)
Resting	average of 6 30-s periods of quiet rest
Task-Related	average over 60-s social bad toy condition of disappointment task
Composite Behavior Variables	
Approach	smiling + active self-regulation
Withdrawal	disgust + sadness + worry + passive self-regulation
Disruptive Anger	anger + disruptiveness
	Secondary Hypotheses
Individual Behaviors	See Tables 4 and 5 for Descriptions
Smiling	
Anger	
Disgust	
Sadness	
Worry/Distress	
Active Self-regulation	
Passive Self-regulation	
Disruptiveness	

The data analytic strategy involved (1) analyses to screen variables for possible inclusion in tests of the study's hypotheses, and (2) random regression (using MIXED in SPSS version 11.0) and logistic regression models to test the primary and secondary hypotheses of the study. Preliminary analyses examined the relation of participant characteristics to resting and task EEG asymmetry variables, composite behavior variables, and individual behavior variables. Random regression models were employed for continuous dependent variables, and logistic regression models were employed for categorical dependent variables. The rationale for logistic regression is discussed in the

Results section below. An alpha level of .05 was used for all statistical tests. Type I error was minimized by limiting the number of tests to that required for hypothesis testing.

Random regression models. Random regression models were selected as the data analytic strategy for primary and secondary analyses because these models are able to account for the nonindependence of cases within the COD group. Multiple children from some COD families were included in the study, and it was expected that family-specific effects would be present and would violate the assumption of independence of cases. For instance, it is possible that there are within-family correlations for emotional behavior. Random regression models address this challenge by treating *family* (or any other participant grouping variables) as a random effect, thereby estimating the correlation among siblings (Gibbons et al., 1993). In the current study, family and the interaction of family X asymmetry were treated as random variables, and the other independent variables (e.g., asymmetry) were treated as fixed variables. The goal of using random regression models was not to test the influence of family on behavior but to develop a model that accounts for the non-independence of cases in the current sample.

For each of the primary analyses, random regression models were used to test the relation of frontal asymmetry and a theoretically defined composite variable. Separate models were tested for resting and task-related frontal asymmetry. In all models, resting or task-related EEG asymmetry score was a fixed independent variable; family was a random variable; and the family X asymmetry interaction was a random variable.

Based on the results of preliminary analyses (see Results below) and on models claiming that risk for depression is related to emotion regulation, parent depression level was included as a covariate in all models. In addition, the full model for each analysis included age group as a main effect and frontal asymmetry X age group as an interaction effect. The rationale for this decision was that no study has tested age-related changes in the relation between frontal asymmetry and behavior. In addition, a previous study with the disappointment task found age-related changes in behavior (Saarni, 1984). Child gender was also included in the full model because previous studies of disappointment have reported gender differences (Cole, 1986; Cole et al., 1994; Davis, 1995; Garner & Power, 1996; Saarni, 1984). A study that included some parents of children in the current sample reported that the interaction of gender and depression group is associated with resting frontal asymmetry in adults with COD (Miller et al., 2002). This provided further reason to include gender as a factor.

Table 5 contains a list of the variables in the full model for testing each hypothesis. For each hypothesis, the most parsimonious model was selected by comparing (1) the outcome of the test of the asymmetry effect and (2) the fit of the model. Model fit was judged by examining scatterplots of the residuals as a function of predicted values for each model (as recommended by Hamilton, 1992). The full model – including the additional variables of gender and age group as independent variables and parent depression as a covariate – was tested first, and independent variables were eliminated in subsequent models until the best model was selected. The final model selected for each hypothesis had the fewest variables and a reasonable lack of relation between residuals and predicted values. The secondary analyses were structured similarly, except that the dependent variable for each model was an individual behavior (e.g., sadness). For all analyses, the first step involved a visual inspection of the data and of the relation between the variables of interest.

Table 5
Variables in the Full Random Regression Model

Variable	Content
Random Effects	
Family	number assigned to each family
Family X Asymmetry	family number X asymmetry
Fixed Effects	
Asymmetry	left or right
Age Group	3–5 or 6–9 years
Asymmetry X Age	frontal asymmetry X age group
Gender	male or female
Parent Depressive Symptoms	total FDS score

Note: FDS = Follow-up Depression Scale of the ISCA (Sherrill & Kovacs, 2000).

RESULTS

Frontal Asymmetry and Behavior Variables

Data distributions. Table 6 contains descriptive statistics for frontal asymmetry and behavior variables. Visual inspection of histograms for frontal asymmetry indicated that the asymmetry variables were normally distributed. Resting and task-related asymmetry were moderately correlated (rs = .38, $p < .005$), and the difference between their means approached statistical significance ($t(57) = 1.75$, $p = .08$).

The disruptive anger composite variable and several individual behavior variables had a high proportion of cases with values of 0. In analyses, these variables were treated as dichotomous and were analyzed using logistic regression. The predictors of these models were the same as those for the random regression models, with the exception of the family variable. Family was omitted for several reasons. In random regression analyses, the inclusion of family as a random effect did not influence the pattern of results. The reduced power of logistic regression relative to analysis of variance (ANOVA) was also an important consideration in this decision. The relation of each independent variable to the individual behavior variable was determined using Wald's test of significance.

Table 6
Mean (SD) of Frontal Asymmetry and Behavior Variables

Variable	Mean (SD)	Range	Proportion > 0
Frontal asymmetry			
Resting	-.02 (.13)	-0.42 – 0.24	N/A
Task-Related	.03 (.24)	-0.56 – 0.94	N/A
Composite Variables			
Approach	9.29 (6.41)	0 – 24	.86
Withdrawal	11.16 (7.40)	0 – 28	.95
Disruptive Anger	.98 (1.82)	0 – 8	.33
Individual Behaviors			
Anger	.86 (1.61)	0 – 7	.33
Disgust	1.64 (2.69)	0 – 12	.48
Sadness	1.71 (2.62)	0 – 12	.52
Smiling	3.22 (4.15)	0 – 15	.57
Duchenne Smiles	.67 (1.55)	0 – 8	.24
Non-Duchenne Smiles	1.86 (2.63)	0 – 11	.48
Mixed Smiles	.69 (1.49)	0 – 6	.24
Worry	1.00 (2.51)	0 – 12	.22
Active Self-Regulation	6.07 (4.57)	0 – 12	.79
Passive self-regulation	6.81 (4.38)	0 – 12	.93
Disruptiveness	.12 (.68)	0 – 5	.05

Note : *N* = 58. Means were derived from the total number of coding intervals for behavior variables. *Proportion > 0* refers to the proportion of participants who exhibited the behavior.

Only individual variables that were not redundant with composite variables were included in logistic regression models. As a result, active and passive self-regulation were omitted because they were redundant with the approach and withdrawal composites, respectively, and anger and disruptiveness were omitted because they were redundant with the withdrawal composite. The individual behaviors analyzed were disgust, sadness, worry, and smiles. The first three of these were predicted to be related to right frontal asymmetry, and the last was predicted to be related to left frontal asymmetry.

Validation of theoretically derived composite behavior variables. To examine the empirical basis for the composite variables, Pearson correlation analyses, data reduction using principal components analysis (PCA), and internal consistency analyses were conducted.

As shown in Table 7, the correlations between behavior variables were low to modest. The exceptions to the level of correlations were the strong negative correlations between Duchenne and non-Duchenne smiles and between active self-regulation and passive self-regulation. Overall, the correlations between variables were in the expected direction, with negative correlations between smiling and the individual withdrawal-related variables, a positive correlation between smiling and active self-regulation, and generally positive correlations between pairs of withdrawal-related variables (e.g., disgust and passive self-regulation).

The correlations reported here may underestimate the true correlations between variables, because correlations can be deflated when variables have nonnormal distributions (Tabachnick & Fidell, 1996). It is possible to estimate actual correlations when the population correlations for pairs of variables are known, but the population correlations of these variables are not known.

Table 7
Correlations among Behavior Variables

Variable	1	2	3	4	5	6	7	8	9	10
1. D Smiles	--	.66**	.13	-.07	-.07	-.21	-.17	.02	.02	.02
2. ND Smiles		--	-.03	-.18	-.25	-.31*	-.23	.13	-.13	.12
3. M Smiles			--	.05	.50**	-.06	-.08	-.02	.08	.00
4. Anger				--	.03	.11	.07	-.15	.14	.13
5. Disgust					--	.00	-.02	-.24	.26*	-.09
6. Sadness						--	-.11	-.22	.25	.06
7. Worry							--	-.16	.21	-.04
8. Active								--	-.97**	-.17
9. Passive									--	.10
10. Disruptive										--

Note: D Smiles = Duchenne smiles, ND Smiles = Non-Duchenne smiles, M Smiles = Mixed smiles. Active, Passive, and Disruptive refer to self-regulatory behaviors; other variables refer to emotion expressions.
**p* < .05. ***p* < .01.

As detailed in Appendix C, the PCA did not strongly support the content of the composite variables. However, the components generated by the PCA also did not explain the variance in the behavior variables clearly or comprehensively. The internal consistency of the 3 composite variables was low: Cronbach's á was .14 for approach, .37 for withdrawal, and .17 for disruptive anger.

Informed final composite behavior variables. The results of correlation analyses, PCA, and internal consistency analyses provided less than ideal support for the composite variables. However, variables can measure the same overarching construct but still not be strongly intercorrelated, and the findings of validity analyses do not definitively rule out the possibility that the three theoretically derived composite variables have construct validity. Therefore, the three theoretically derived composite variables (i.e., approach, withdrawal, disruptive anger) were used in the data analyses for the study.

Table 8 describes the content of the three composite variables. As a result of the correlations and PCA, the approach composite was changed to include all smiles. Duchenne and non-Duchenne smiles were moderately correlated, and they loaded on the same component of the PCA. The validation analyses thus suggested that it would be useful to include both of these types of smiles in the approach composite. Mixed smiles were also included in the composite variable because they can also be considered to represent approach-related emotion regulation. Further, the disappointment task is not likely to elicit true positive emotion, and smiling during the task may represent an attempt to cope rather than an expression of genuine happiness. From this perspective, it did not seem useful to distinguish types of smiles in the current study.

Correlation analyses indicated a strong negative correlation between approach and withdrawal behavior (r = -.71, p = .00), a low negative correlation between approach and disruptive anger (r = -.21, p = .11), and a low positive correlation between withdrawal and disruptive anger (r = .16, p = .25). This result suggests that approach and withdrawal were not orthogonal but were inversely related.

Table 8
Composite Behavior Variables Used in Data Analyses

Composite Variable	Constituent Variables
Approach	smiles + active self-regulation
Withdrawal	disgust + sadness + worry + passive self-regulation
Disruptive Anger	Anger + disruptiveness

Preliminary Analyses

Preliminary analyses with demographic variables. Preliminary analyses examined the influence of child and family characteristics on the primary measures of frontal asymmetry and behavior. Oneway ANOVAs indicated that child ethnicity, parent education level, and child handedness (left or right) were unrelated to composite and individual behavior variables (*F*s = .01 – 2.50, *p*s > .05). Chi square analyses indicated that the demographic variables were also unrelated to resting or task-related frontal asymmetry ($\times^2$ ranged from .02 – 4.23, *p*s > .05).

Preliminary analyses with gender and age. Oneway ANOVAs indicated that child gender was unrelated to composite and individual behavior variables (*F*s = .22 – 3.00, *p*s > .05). A chi square analysis indicated that gender was unrelated to resting or task-related frontal asymmetry ($\times^2(1, N = 58) = .05$, $p = .82$ and $\times^2(1, N = 58) = 1.16$, $p = .28$, respectively). Although asymmetry and behavior did not vary with gender, gender was included in the regression models testing the primary hypotheses. As noted above, previous findings on children's disappointment behavior led to the decision to include gender as an independent variable.

Child age group (3–5 or 6–9 years) was related to the individual emotional behaviors of sadness (for 3–5 years, $M = 2.35$, $SD = 3.13$; for 6–9 years, $M = 0.79$, $SD = 1.18$; $F(1,57) = 5.57$, $p < .05$) and smiling (for 3–5 years, $M = 2.29$, $SD = 2.78$; for 6–9 years, $M = 4.54$, $SD = 5.33$; $F(1,57) = 4.38$, $p < .05$). Younger children displayed more sadness and less smiling during the task than did older children. Age group was marginally related to disgust ($F(1,57) = 3.26$, $p = .08$), with older children tending to display more disgust than younger children. Age group was unrelated to other behavior variables (all *F*s < 1.60, *p*s > .20) and frontal asymmetry ($\times^2(1, N = 58) = 3.02$, $p = .08$ for resting and $\times^2(1, N = 58) = .12$, $p = .72$ for task-related). Additionally, the relation between age and the variables of interest was examined with age (in years) as a continuous variable. Using that approach, age was uncorrelated with behavior variables (Pearson *r*s ranged from -.24–.20, all *p*s > .05) and frontal asymmetry ($F(1,56) = 2.39$, $p = .13$ for resting and $F(1,56) = .15$, $p = .70$ for task-related).

A noteworthy age difference occurred for disruptiveness behavior. This behavior was rare: three children exhibited disruptiveness, and all were in the 3–5-year-old age group. Two of the three participants were boys, and all were offspring of a parent with COD. The parents of these participants had low to moderate levels of depressive symptoms (FDS scores = 10, 14, and 23). Disruptiveness did not differ by COD group ($\times^2(1, N = 58) = 1.24$, $p = .27$) or age group ($\times^2(1, N = 58) = 2.23$, $p = .14$), however. All three participants had right frontal asymmetry at rest, and all displayed anger during the task.

Preliminary analyses with parent depression. To account for the possible influence of children's risk for depression on physiology and behavior, the effects of parent history of depression and current parent depressive symptoms were examined. Oneway ANOVAs with parent history of depression (COD or control) as the independent variable indicated that history of depression was unrelated to behavior variables (all *F*s < 1.67, all *p*s > .20). Chi square analyses indicated that parent history of depression was unrelated to resting and task-related frontal asymmetry ($\times^2(1, N = 58) = .17$, $p = .68$ and $\times^2(1, N = 58) = .37$, $p = .55$, respectively). Parents' current depressive symptoms were modestly correlated with the composite variable of children's disruptive anger ($r = .40$, $p < .01$) and the individual variable of children's anger ($r = .41$, $p < .01$). Children whose parents had high levels of depressive symptoms expressed more disruptive anger and anger during the disappointment task. Follow-up within-group correlation analyses for anger were conducted because this variable was included in the disruptive anger composite and was more frequent than disruptiveness. These within-group analyses indicated that the relation between parent symptoms and child anger held only for the COD group ($r = .40$, $p < .01$) and not for the control group ($r < .40$, $p > .25$). Although parents' depressive symptoms were unrelated to other behavior variables (absolute value of *r*s < .20, *p*s > .10) and frontal asymmetry ($F(1,53) = .49$, $p = .49$ for resting and $F(1,53) = .25$, $p = .62$ for task-related), in light of this pattern of findings and the putative relation between risk for depression and emotion regulation behavior, level of parent depressive symptoms was included as a covariate in the primary analyses.

Primary Analyses

Primary data analyses focused on frontal asymmetry and composite behavior variables. Results are organized by hypothesis.

Hypothesis 1: Approach behavior will be related to *left* frontal asymmetry.

At rest and during the disappointment task, frontal asymmetry was unrelated to approach behavior ($F(1,5.04) = .09$, $p = .78$ and $F(1,4.94) = .18$, $p = .69$, respectively). The asymmetry X age interaction effect was not significant for the resting model or the task-related model ($F(1,5.81) = .02$, $p = .89$ and $F(1,5.71) = .06$, $p = .82$, respectively). Parent level of depressive symptoms was unrelated to approach in either model ($F(1,5.68) = .34$, $p = .58$ and $F(1,5.61) = .39$, $p = .56$, respectively).

Hypothesis 2: Withdrawal behavior will be related to *right* frontal asymmetry.

The interaction of asymmetry and age group was related to withdrawal behavior ($F(1,6.84) = 7.57$, $p = .03$). Figure 3 depicts the mean withdrawal scores for the asymmetry groups at the two ages. Follow-up analyses indicated that in the 3–5-year-old group, children with right frontal asymmetry exhibited more withdrawal than children with left frontal asymmetry (n = 12, M = 6.00, SD = 5.21 for left asymmetry; n = 22, M = 13.73, SD = 8.37 for right asymmetry; $F(1,4.38) = 10.09$, $p = .03$). In the 6–9-year-old group, frontal asymmetry and withdrawal were unrelated (n = 14, M = 12.21, SD = 7.22 for left asymmetry; n = 10, M = 10.20, SD = 4.47; $F(1,2.10) = .97$, $p = .43$). Task-related frontal asymmetry was unrelated to withdrawal behavior ($F(1,3.60) = .13$, $p = .74$).

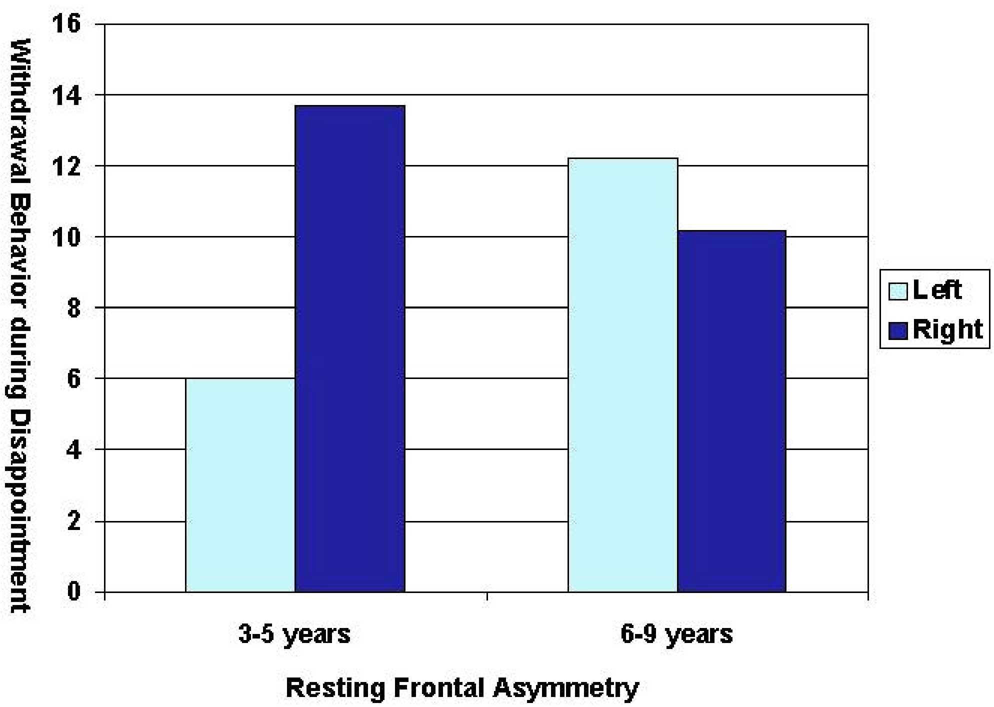

Figure 3. Children's withdrawal behavior during a disappointment task in relation to resting frontal asymmetry and age.

Hypothesis 3: Disruptive anger, which reflects approach motivation, will be related to *left* frontal asymmetry.

At rest and during the disappointment task, frontal asymmetry was unrelated to disruptive anger (Wald (df = 1) = .11, p = .74 and Wald (df = 1) = .00, p = .99, respectively). The asymmetry X age interaction effect, in models for resting and task-related asymmetry, was also unrelated to disruptive anger (Wald (df = 1) = 1.91, p = .17 and Wald (df = 1) = .00, p = .97, respectively). The effect for parent depressive symptoms was not significant in either model (Wald (df = 1) = 1.38, p = .24 for resting and Wald (df = 1) = 2.32, p = .13 for task-related).

Hypothesis 4: Task-related frontal asymmetry will be related to emotional behavior once the influence of resting frontal asymmetry has been accounted for.

Although tests of Hypotheses 1–3 indicated no relation between task-related frontal asymmetry during the task and approach, disruptive anger, or withdrawal behavior, it is possible that when the influence of resting asymmetry was removed, task-related asymmetry would predict behavior. As a result, three simple linear regressions were conducted with continuous asymmetry scores. In these regressions, a composite behavior was the dependent variable and the task-related asymmetry score residualized for resting asymmetry was the independent variable. The residualized scores were obtained by saving the residuals from a linear regression in which task asymmetry was predicted from resting asymmetry. These three models indicated no relation between residualized task asymmetry and approach, withdrawal, or disruptive anger (F(1,56) = .48, p = .49; F(1,56) = .05, p = .83; and F(1,56) = .31, p = .58, respectively).

Secondary Analyses

Secondary analyses were conducted because there was limited support for the study's primary hypotheses. Secondary analyses focused on the relation between frontal asymmetry and individual emotional behaviors rather than composite emotional behavior variables. As described above, the individual emotional behaviors analyzed were disgust, sadness, worry, and smiles. Analyses were conducted using logistic regression models. Based on the results of the primary analyses, frontal asymmetry, age group, and asymmetry X age were included as independent variables. Results are organized by hypothesis.

Hypothesis 5: Individual approach-related behaviors will be related to *left* frontal asymmetry.

The likelihood of smiling was unrelated to frontal asymmetry, age group, or the interaction of asymmetry X age ((Wald (df = 1) values ranged from .02 – .28, all ps > .55).

Hypothesis 6: Individual withdrawal-related behaviors will be related to *right* frontal asymmetry.

Resting frontal asymmetry was related to the likelihood of expressing sadness (Wald (df = 1) = 4.16, p = .04). Children with right frontal asymmetry at rest were more likely to express sadness than were children with left frontal asymmetry. Age group and the asymmetry X age interaction were unrelated to the likelihood of expressing sadness (Wald (df = 1) = 3.76 and 3.78, respectively, ps > .05). Variables in the task-related frontal asymmetry model were unrelated to sadness, and frontal asymmetry, age group, and the asymmetry X age interaction were unrelated to the likelihood of worry and disgust behaviors (Wald values ranged from .01 – 3.76, all *p*s > .05).

Additional Analyses

Additional analyses were conducted to address issues that arose in the course of primary and secondary data analyses. The first set of analyses addressed a concern about the epoch length of EEG and behavior variables in analyses of task-related asymmetry and behavior. The following analyses examined the utility of COD group as a covariate, the utility of resting asymmetry as a covariate for models of task asymmetry, the effect of asymmetry at parietal EEG sites, and the potential sources of the relation between asymmetry and behavior.

The lack of relation between task-related asymmetry and behavior during the disappointment task led to a reconsideration of the lengths of the epochs for which task-related EEG was processed. Originally, power was averaged across the 60 s of the social bad toy condition. Given that fluctuations in frontal asymmetry and behavior might occur more often than once per minute, bar graphs for each behavior across the 12 coding intervals were examined for information on changes in emotional behavior during the condition. Bar graphs for each participant and for the aggregate of all participants indicated that a 30-s interval would be more appropriate. Task-related EEG data were then reprocessed and behavior variables were recomputed so that there were 2 30-s epochs for the task. Random regression models were recomputed for task-related asymmetry and behavior. The results did not differ from those of the original models.

To examine the possibility that COD group was a more appropriate covariate than current parent depression symptoms, random regression models were computed with COD as a covariate. The results did not differ from the results of the original models.

As noted above, resting and task-related asymmetry were moderately correlated. To examine whether task asymmetry was related to behavior when the effect of resting asymmetry was statistically removed, random regression models were conducted with resting asymmetry as a covariate. These models revealed no relation between task asymmetry and behavior.

To examine whether the relation found between frontal asymmetry and the composite withdrawal variable was the result of general laterality in brain activity rather than laterality in the frontal region, random regression models were conducted with dichotomous parietal (P3/P4) asymmetry as an independent variable. Parietal asymmetry was unrelated to withdrawal behavior ($F(1,6.55) = 1.27$, $p = .30$), indicating that the effect for asymmetry was specific to the frontal region.

Because analyses with asymmetry scores do not indicate which hemisphere accounts for the observed effect, random regression models were computed using power on the left side, power on the right side, and the multiplicative interaction term of power at the two sites as independent variables. This approach was adopted in accordance with recommendations by Cohen and Cohen (1983). These analyses were limited to the composite withdrawal variable. For withdrawal behavior, activity at the right site was the only significant independent variable ($F(1,4.95) = 8.01$, $p < .05$; otherwise, Fs ranged from .01 – 4.63, all ps > .05). High levels of withdrawal tended to be associated with greater activity in the right midfrontal site.

DISCUSSION

The approach-withdrawal model of emotion regulation and brain laterality inspired the current study on the correspondence of children's frontal asymmetry and behavior during a disappointment. The central hypotheses of the study were that approach behaviors are related to greater relative left frontal EEG activity and withdrawal behaviors are related to greater relative right frontal EEG activity. The latter hypothesis was moderately supported, but the former was not. Children with right frontal asymmetry at rest exhibited more general withdrawal behavior and were more likely to express sadness than children with left frontal asymmetry. For withdrawal, the effect of frontal asymmetry was evident only in children 3 to 5 years old. Children's resting frontal asymmetry was unrelated to approach behavior. Task-related frontal asymmetry was unrelated to either approach or withdrawal behavior.

Implications for the Approach-Withdrawal Model

These findings provide some degree of support for the withdrawal part of the approach-withdrawal model of emotion regulation. As predicted by the model, right frontal asymmetry was related to a tendency to use a set of emotion regulation strategies that involved passive behaviors and expressions of worry, sadness, and disgust. Importantly, the findings are consistent with the literature on resting frontal asymmetry and emotional behavior in children. Several previous studies have found that frontal asymmetry is associated with withdrawal behavior but not approach behavior (Calkins et al., 1996; Fox et al., 1996; Henderson et al., 2001). For instance, one study reported that infants who exhibited high motor activity and high negative affect at 4 months of age had greater relative right frontal EEG activity at 9 months, whereas infants who exhibited high motor activity and high positive affect did not have left frontal asymmetry (Calkins et al., 1996). A majority of studies with children have focused on withdrawal characteristics such as risk for depression (e.g., Dawson et al., 1999a; Field et al., 1995) or tendencies toward behavioral inhibition (Fox et al., 1992; Fox et al., 1994), but have not considered approach behavior. This pattern suggests that withdrawal behaviors might be a particularly fruitful area for the study of children's frontal asymmetry and emotion.

The association between frontal asymmetry and withdrawal behaviors was present for the younger age group (3 to 5 years) but not for the older age group (6 to 9 years). This finding suggests that the relation between frontal asymmetry and emotional behavior changes with development, decreasing from early childhood to middle childhood. Perhaps, then, the approach-withdrawal model of emotion regulation holds for early childhood but not for middle or late childhood. Studies of frontal asymmetry and emotional behavior in children have focused on the early childhood period, leaving the later childhood and adolescent periods neglected. It will be important to conduct cross-sectional and longitudinal studies to examine whether and how the association between frontal asymmetry and behavior changes with development.

Studies of adults' resting frontal asymmetry present a more complex story, with evidence that both approach and withdrawal are related to resting frontal asymmetry (Tomarken et al., 1990; Tomarken et al., 1992; Wheeler et al., 1993). In one case, asymmetry was associated with approach but not withdrawal (Harmon-Jones & Allen, 1997). An important difference from the current study is that the studies that have found a relation between asymmetry and approach behavior have all relied on self-report questionnaires rather than observations of behavior. Individuals' impressions of their own emotional behavior may be more strongly related to resting asymmetry than is their actual emotional behavior. Alternatively, perhaps approach behavior *is* associated with left frontal asymmetry, and self-report measures are better able to capture stable, cross-context approach tendencies than are single-session laboratory paradigms. The test of either hypothesis would require studies of adults' approach behavior in emotional contexts, ideally using a longitudinal design. The lack of behavioral methods for measuring adults' emotional traits is a gap in the literature on frontal asymmetry and emotion. Indeed, it is a gap in personality research, which traditionally employs by self-report measures.

Together, the current findings and the literature on frontal asymmetry and emotion have the implication that the balance of frontal brain electrical activity might be especially valuable for measuring withdrawal behavior, but less so for measuring approach behavior. Approach and withdrawal behaviors could differ in the strength of their relation to frontal laterality, possibly as a result of differences in the neural circuitry of approach and withdrawal behavior systems. The neural bases of both systems have been defined conceptually (e.g., Davidson, 1994, 1998), but the evidence for an integrated system exists more for the withdrawal system than for the approach system. The central features of the withdrawal system are activity in the amygdala (LeDoux, 1996), a subcortical structure implicated in conditioned fear, and the prefrontal cortex (Davidson, 2002). In particular, descending projections from the medial prefrontal cortex are postulated to inhibit activation in the amygdala (Davidson, 2002). Several different lines of research have addressed the neural substrates of the approach system, and there is not a comprehensive model that includes all of them. The features of the approach system appear to involve the encoding of stimulus reward value in orbitofrontal and ventromedial cortex areas (Davidson, 2002), the integration of stimulus value and goals in the dorsolateral prefrontal cortex (Davidson, 2002), and increased activity in the ascending dopamine pathway from the ventral tegmental area to the nucleus accumbens (Depue & Collins, 1999).

Perhaps the approach system is more heterogeneous than the withdrawal system, involving a more diverse set of behaviors and a variety of neural pathways. This would make the neural basis for withdrawal more straightforward and comprehensible. In the current study, the behaviors defined as *approach* encompassed a variety of functions, ranging from distraction (e.g., playing with the unwanted toy) to social regulation (e.g., smiling at the experimenter with the intention of eliciting her help in obtaining the wanted toy). If there are various types of approach, and if each is associated with a separate neural system, then approach may be a less than unitary construct. Approach in all of its forms may not be easily and consistently associated with the balance of frontal brain activity. Davidson (1994) has addressed this possibility by distinguishing two types of positive affect and postulating that one but not the other is associated with approach and therefore frontal asymmetry. Specifically, approach behaviors are considered those that occur during pre-goal attainment experiences, not those that occur during post-goal attainment experiences.

Limitations of the disappointment task. Admittedly, the emotion regulation task in the current study was not a pre-goal attainment context that would elicit the particular type of approach that Davidson (1994) describes. Further, the emotion regulation task was not designed to elicit genuine positive affect. A disappointment experience, in which a child receives the least favorite toy, is not likely to encourage pleasure and other approach emotions in children. More likely, as in other studies of disappointment (Cole et al., 1994; Saarni, 1984), children will respond with anger or with withdrawal emotions such as worry. If they do smile, they may be masking or suppressing their distress rather then expressing sincere happiness. Thus, the emotion regulation context created two drawbacks. One is that individual differences in approach behavior may not have emerged. The other is that the individual differences that did emerge were not related to pre-goal attainment and were thus unlikely to be associated with frontal asymmetry. This problem could be addressed by future studies using emotion regulation contexts that elicit both pre-goal attainment approach and approach. Candidate tasks for creating such contexts are adaptations of gambling or computer games (e.g., Delgado, Nystrom, Fissell, Noll, & Fiez, 2000; Miller & Tomarken, 2001; Sobotka et al., 1992) that have been used with adults.

From another perspective, the disappointment task in the current study may have been sufficient to elicit individual differences in approach. If approach behavior is considered to encompass *emotion regulation* as well as *emotion expression*, some strategies for regulating negative emotions may include approach. To meet Davidson's criterion of pre-goal attainment positive affect, children – or a subset of children – who display these approach strategies would be considered to display true approach behavior under certain constraints. Namely, they would need to retain the belief that they will obtain the desired toy. For example, a child may experience sadness upon receiving the unwanted toy but may nonetheless smile at the experimenter with the goals of reducing sadness and obtain assistance in attaining the preferred toy. Smiling then could be considered approach behavior. From this perspective, the approach behavior observed in the disappointment task is valid. Instead of concluding that frontal asymmetry was not related to approach because there were methodological problems with eliciting approach, it is possible to conclude that approach behavior is not associated with frontal asymmetry. It is not possible to choose one interpretation or the other without further research, however. The question of whether approach occurs during emotion regulation or only during pure pre-goal attainment can be addressed by comparing children's responses to tasks that reliably elicit pleasure with their responses to tasks that elicit disappointment.

For the sake of simplicity and focus, the social bad toy condition was the focus of the current study. This condition was chosen because it has been shown to elicit a range of emotion expression in children (e.g., Cole et al., 1994). An approach for future work using the same disappointment task would be to consider differences between children's behavior during the social bad toy segment and the behavior during the period immediately preceding it, in which the child is waiting for the experimenter to enter with the toy. The current study did not include such a timed anticipation period, but Davidson's (1994) emphasis on approach as pre-goal attainment behavior makes consideration of the pre-toy period important for understanding the relation between frontal asymmetry and approach. The good toy condition could provide another avenue for examining approach behavior, but it is limited in important ways. First, the displeasure that children experience during the bad toy condition might continue into the good toy condition, thereby contaminating that portion of the task as a context for approach emotions. Second, the good toy condition is generally considered to be more an attempt to repair for the disappointment than a way to elicit valid positive emotions

(Cole, 1986; Saarni, 1984). Third, the good toy condition represents a post-goal attainment context and would not be expected to elicit true approach by Davidson's (1994) definition.

Implications for the view of anger as approach. The current study did not find support for the approach-withdrawal model conceptualization of anger as an approach-related emotion (e.g., Fox, 1991). Anger was uncorrelated with other approach-related behaviors, and it was not associated with left frontal asymmetry. This finding adds to the ambiguity of findings on anger and frontal asymmetry. In previous studies, left frontal asymmetry is associated with self-reported anger tendencies (Harmon-Jones & Allen, 1998) but not with task-related anger (Waldstein et al., 2000). Because the association of laterality and anger was evident when anger was defined as a stable characteristic, frontal asymmetry may be especially important in long-term, cross-context tendencies toward feeling and expressing anger. In contrast, laboratory contexts that elicit anger may bear a weak relation to frontal asymmetry because they are limited to a single occasion or a less intense experience of the emotion. For the current study, the disappointment context was adequate for eliciting anger but did not seem to elicit strong anger. The prosocial demand created by the gift context may have led children to suppress or modulate their anger, thus diminishing the amount of anger expressed. Anger expressions were indeed infrequent. Another possibility is that the limited variability in anger may have attenuated the ability to detect relations with frontal asymmetry. A task that elicits intense, frequent anger in a context in which it is appropriate to express that emotion could provide a better test of the hypothesis that anger is related to greater activity in left frontal areas.

Relation of Resting and Task-Related Asymmetry to Behavior

A second central issue in the current study was whether both resting and task-related frontal asymmetry contribute to emotional behavior. Previous studies have treated resting asymmetry as a trait variable and task asymmetry as a state variable, and the hypothesis in the current study was that each would contribute uniquely to behavior. This hypothesis was not supported because only resting asymmetry was related to behavior. Task asymmetry was unrelated to behavior. Even when resting behavior was included as a covariate in analyses of the relation between task asymmetry and behavior, task asymmetry was unrelated to behavior. These results suggest that frontal asymmetry provides a better index of diatheses for certain emotional responses (as claimed by Davidson, 1994, 1998) than it does an index of ongoing emotional state.

One possibility for this finding is that the 60-second epoch used in the current study is too broad to capture the fluctuations in emotion that occur with emotion regulation. When the association between task asymmetry and task behavior was examined for two 30-second epochs instead of a single epoch, there was still no relation between frontal asymmetry and emotion. An examination of the pattern of emotion expression across the 12 coding intervals did not indicate that another epoch length would be more appropriate for testing this hypothesis, however. A more fine-grained approach used by Fox and Davidson (1988) involves the averaging of EEG asymmetry across discrete expressions of emotion, but the data in the current study were not suited to this approach. Even with the ability to average data across discrete emotion expressions, it is important to question whether the temporal resolution of EEG is sufficient to capture the fluctuations in brain activation that accompany fleeting emotional changes.

Regional and Hemispheric Sources of Asymmetry

Additional analyses indicated that the association of asymmetry and emotional behavior occurred at frontal sites, not parietal sites. This finding supports claims that emotion regulation behavior is associated specifically with the balance of activity in the frontal brain region, rather than with brain laterality in general. Furthermore, when the separate contributions of the left and right frontal sites were examined, it appeared that in general the relation of frontal asymmetry to withdrawal-related behaviors tended to be based on increased electrical activity on the right side or both increased activity on the right side and decreased activity on the left side. Such a conclusion must be made cautiously, though, because individual differences exist for alpha-range EEG activity at individual sites.

Emotion Regulation and Risk for Depression

The sample of the current study contained a group of children (n = 41) who were the offspring of parents with a history of childhood-onset depression. As a consequence of their family history, this group is at risk for developing a variety of behavior problems, especially depressive disorders (Downey & Coyne, 1990). A compelling question is whether these children differ from other children in their emotion regulation physiology and behavior. Unfortunately, there was insufficient statistical power to test this hypothesis because the recruitment constraints of the larger study resulted in a small group of children from control families (n = 16). Based on previous studies of frontal asymmetry and depression (e.g., Field et al., 1995; Henriques & Davidson, 1990) and socioemotional difficulties in children of depressed mothers (Cohn & Campbell, 1992; Downey & Coyne, 1990; Field, 1992; Zahn-Waxler, Cummings, Iannotti, & Radke-

Yarrow, 1984; Zahn-Waxler, Cummings, McKnew, & Radke-Yarrow, 1984), it is possible to predict that the depression group differs in emotion regulation from the control group. Specifically, in the disappointment task, the depressed group would be expected to have greater relative right EEG activity during rest and to display more negative affect, more impulsiveness, and more disruptiveness.

Although depression-related differences were not the focus of the current study, they were examined because the sample included children with a parent history of depression. Children's behavior was related to parents' current level of depressive symptoms: Children of parents with higher symptom levels exhibited more frequent disruptive anger and anger behaviors. A potential explanation for this finding is that the genetic diathesis for depression in children of depressed parents involves temperamental tendencies toward irritability and anger during childhood. Children who are at risk for developing depression may be more likely to respond to events with frustration. The parent-child relationship may also influence children's anger. This may occur through parents' modeling of irritable behavior. If parents tend to respond to disappointing or surprising events with anger, children may do the same when faced with a disappointing laboratory task. Alternatively, the parent-child relationship may influence children's emotional behavior through unusual parent-child social interactions. Mothers with depression have difficulties with reciprocal social exchanges with their children, and their children show corresponding difficulties with emotion regulation (e.g., Cohn & Campbell, 1992). The experience of poor responsiveness, low empathy, or frequent arguments during daily interactions with a depressed parent may lower children's frustration tolerance and increase their likelihood of expressing anger.

Children's frontal asymmetry was unrelated to parent history of depression. The ability to detect a depression group effect was limited by sample size, however, and the possibility remains that children in the depressed group are more likely to have right frontal asymmetry.

The composition of the sample, while providing the potential for increased variability in emotion regulation behavior, is also a drawback of the study. It is important to note that the presence of a group of offspring of parents with COD makes the study an unusual one and limits the generalizability of the findings. The sample was selected not from the general population but from a clinical population and a matched population with no history of major psychopathology, and its findings may not be as relevant to other populations. Populations in which risk for psychopathology is low or average might differ in the behavioral and physiological characteristics of emotion regulation. The sample composition is also a strength of sorts, however, in that it can inform the understanding of emotion regulation in children at risk for emotion dysregulation and psychopathology.

Age and Gender Influences on Emotion Regulation

The cross-sectional design of the current study afforded a chance to examine change with development in children's emotion regulation. As discussed above, the association between frontal asymmetry and withdrawal behavior was moderated by age group, with only the younger group of children evidencing the association. As for emotional behavior, younger children expressed more sadness and older children smiled more frequently during a disappointment experience. These differences could reflect the increasing ability to regulate emotion by modulating some forms of negative affect and employing positive affect. A parallel change in general approach and withdrawal behaviors was not evident. This could indicate that the type of regulatory strategy favored does not change uniformly with age. Instead, the use of approach-related or withdrawal-related strategies might be a stable individual difference. Davidson (1994, 1998) has proposed that such tendencies can reflect a response diathesis, leading to a greater probability for the use of approach or withdrawal in response to an event.

The behavioral differences between the two age groups in the study were similar to those for a previous study with the disappointment task (Saarni, 1982), in which younger children in that study expressed more negative affect and older children expressed more positive affect. That finding was interpreted as reflecting children's increasing ability to use display rules that would dictate the expression of positive affect when receiving a present. Even though the children in the current study were somewhat younger than the children in that study, both samples displayed a similar pattern of age-related changes in behavior. The previous study's findings were qualified by an age-by-gender interaction, however. Higher levels of positive affect were especially evident in older girls, and higher levels of negative affect were evident in younger boys.

This was not the case with the current study, in which there were no gender differences in behavior. The lack of gender differences during a disappointment distinguishes the current study from past studies using a similar task. Gender differences have been reported consistently in the literature on the disappointment task (Cole, 1986; Cole et al., 1994; Garner & Power, 1996; Saarni, 1984). Upon receiving the unwanted toy, boys generally display more negative affect than do girls.

Previous studies with the disappointment task – even the study of children at risk for behavior problems – drew their samples from middle- to upper-middle-class, predominantly European-American populations. A consideration about differences between previous studies and the current study is whether differences in sociocultural standards for behavior are responsible for differences in children's behavior. Specifically, if children in the previous studies were members of a culture that emphasizes compliance and the minimization of negative emotions, they might have experienced more pressure to smile during a disappointing experience. Any developmental effects on the ability to regulate and disguise negative emotions in the context of disappointment would have been evident in those samples. In the current sample, age-related changes in the same skills might not be observed because the sociocultural norms are different.

Resting frontal asymmetry did not change with age, and it was not hypothesized to do so. As with behavioral tendencies that are stable over time, Davidson (1994) has asserted that even during childhood, frontal asymmetry is a marker for stable individual differences in emotion regulation. Indeed, frontal asymmetry in adults is moderately stable (Sutton & Davidson, 1997; Tomarken, Davidson, Wheeler, & Kinney, 1992; Tomarken, Davidson, Wheeler, & Doss, 1992; Wheeler et al., 1993), which supports the claim that resting asymmetry is an index of stable tendencies. Although the current study was cross-sectional rather than longitudinal in design, the finding that children's asymmetry did not change with age lends additional support to the notion of resting asymmetry as a stable emotion regulation characteristic.

An additional developmental issue with frontal asymmetry is whether the frequency range of alpha activity changes with age. The current study was not designed to address this topic, but a visual inspection of the power at various frequencies led to a decision to use different alpha definitions for 3-to-5-year-olds and 6-to-9-year-olds. As expected, the alpha range increased with age.

Conclusions

The current study extends research on the physiology and behavior associated with children's emotion regulation. The study was unique in its measurement of both emotional behavior and frontal asymmetry during the disappointment task, and this feature allowed the examination of the correspondence between behavior and brain electrical activity. Findings suggest that patterns of brain electrical activity at rest are related to individual differences in behavior, especially for withdrawal-related behaviors.

The study is similar to previous studies of emotion regulation but different in important ways. Unlike other studies on frontal asymmetry and emotion regulation, the current study included children who ranged from early childhood to middle childhood. In contrast to other studies of children's disappointment, it included the measurement of physiology. Consistent with studies of children who are prone to be wary of novel circumstances and people, withdrawal, worry, and passive behaviors were associated with resting right frontal asymmetry. Children displayed both positive and negative affect in response to receiving an undesired toy, as have children in other studies of disappointment experiences.

The results of this study indicate several other potentially valuable avenues for research on emotion regulation. Understanding the roles of behavior and brain electrical activity would be enhanced by examining these variables in a variety of emotional contexts and by focusing on questions related to developmental psychopathology. Including contexts in which children tend to respond with positive affect or with anger would improve the ability to test hypotheses about the association between different types of approach behavior and frontal asymmetry. Examining the influence of risk for depression on emotion regulation physiology and behavior may be particularly fruitful because difficulties with the flexible regulation of emotion are hypothesized to be central to depression (e.g., Rottenberg, Kasch, Gross, & Gotlib, 2002). Finally, to extend research to understanding the actual brain regions mediating approach and withdrawal, it will be valuable to investigate emotion regulation using neuroimaging methods as well as electrophysiology methods.

An issue not addressed directly by the current study is the direction of influence in emotion regulation. In some ways, the study was guided by assumptions that physiology influences behavior. But another possibility is that behavior also influences physiology. Changes in behavior may produce changes in brain activation, and longstanding patterns of behavior may cultivate stable patterns of frontal asymmetry. The bidirectional relation between brain activation and emotional behavior is an intriguing idea that suggests an exciting direction for research on the neurobiology of emotion.

In sum, the current study enriches knowledge about the physiology and behavior involved in children's emotion regulation. A compelling question is whether the same relation between resting frontal asymmetry and withdrawal behaviors will emerge in populations other than the ones from which the current sample was drawn. Alternatively, instead of focusing on normal individual differences, an intriguing approach involves including large enough samples to test whether COD and control offspring differ in their emotion regulation. This approach would extend the current research to the topic of developmental psychopathology. The findings of the current study underscore the importance of considering resting and task-related physiology measures and of using the approach-withdrawal model to generate hypotheses about emotion.

APPENDICES

Appendix A

Studies Examining Resting Anterior EEG Asymmetry and Emotion

Study	Behavior	Support for A-W Model? Approach	Withdrawal
	Studies with Infants or Children		
Calkins et al., 1996	• Motor and affective behavior at 4 months	No	Yes
Davidson & Fox, 1989	• Crying during maternal separation	N/A	Yes
Fox et al., 1992	• Maternal separation	N/A	Yes
Fox et al., 1994	• Motor and affective behavior at 4 months • Inhibited behavior at 14 and 24 months	Yes	Yes
Fox et al., 1995	• Social competence and social withdrawal during play with peers at 4 years	Yes	Yes
Fox et al., 2001	• Motor and affective behavior at 4 months • Inhibited behavior at 14, 24, and 48 months	No	Yes
Fox et al., 1996	• Sociability and shyness with peers • Parent report of behavior problems	No	Yes
Henderson et al., 2001	• Parent-rated temperament at 9 months • Sociability and social wariness with peers at 4 years	No	Yes
Schmidt et al., 1999	• Social presentation task at age 7 • Concurrent parent-rated shyness	N/A	No

	Studies with Adults		
Hagemann et al., 1999	• Self-reported trait positive affect and negative affect	No	No
Harmon-Jones & Allen, 1997	• Self-reported trait behavioral activation and behavioral inhibition	Yes	No
Harmon-Jones & Allen, 1998	• Self-rated anger	Yes	N/A
Tomarken et al., 1990	• Self-reported emotional response to pleasant and unpleasant films	No	Yes
	• Change in response between films	Yes	
Tomarken et al., 1992	• Self-reported trait positive affect and negative affect	Yes	Yes
Wheeler et al., 1993	• Self-reported trait positive affect and negative affect	Yes	Yes
	Studies on Depression – Adults		
Henriques & Davidson, 1990	• Rest	N/A	Yes
Henriques & Davidson, 1991	• Rest	N/A	Yes
Miller et al., 2002	• Rest	No	Yes
	Studies on Depression – Infants of Depressed Mothers		
Dawson et al., 1999a	• Rest • Play • Maternal separation • Stranger approach	N/A	Yes
Dawson et al., 1999b	• Rest • Play with mother • Play with experimenter	No	Yes
Dawson, et al., 1992	• Rest • Play with mother • Maternal separation	No	Yes
Field et al., 1995	• Rest	N/A	Yes
Jones et al., 1997	• Rest	N/A	Yes

Note: A-W Model = approach-withdrawal model of emotion regulation.

Appendix B

Studies Examining Task-Related Anterior EEG Asymmetry and Emotion

Study	Emotion Variable	Support for A-W Model? Approach	Support for A-W Model? Withdrawal
	Studies with Infants or Children		
Fox & Davidson, 1987	• Infants' crying during maternal separation • Response to mother's reach	Yes	Yes
Fox & Davidson, 1988	• Infants' Duchenne and non-Duchenne smiles • Sadness expressions with and without crying • Anger expressions with and without crying	Yes	Yes
Schmidt et al., 1999	• Self-presentation task with 7-year-olds	No	Yes
	Studies with Adults		
Davidson et al., 1990	• Adults' facial expressions of disgust and happiness	Yes	Yes
Ekman & Davidson, 1993	• Adults' voluntary smiling expressions	Yes	N/A
Miller & Tomarken, 2001	• Reward (i.e., approach) and punishment (i.e., withdrawal) computer game	Yes	No
Sobotka et al., 1992	• Reward and punishment computer game	Yes	Yes
Waldstein et al., 2000	• Happiness-inducing films and personal event recall task	Yes	N/A
	• Anger-inducing films and personal event recall task	No	

Note: A-W Model = approach-withdrawal model of emotion regulation.

Appendix C

Results of Principal Components Analysis to Validate Composite Variables

In keeping with the recommendations of Tabachnick and Fidell (1996), data reduction was conducted using factor analysis and PCA, several different extraction methods, and both oblique and orthogonal rotations. The analysis that was the most appropriate to the conceptual and empirical relations among the variables was the PCA using varimax rotation. A solution of three components was requested so that the results could be compared to the three theoretically derived composite variables. Table C1 contains the results of the PCA.

Table C1
Results of Principal Components Analysis to Validate Composite Variables

	Component		
	1	2	3
Variance Explained			
Eigenvalue	2.48	1.75	1.48
% Variance	24.88	17.48	14.83
Constituent Variables			
Duchenne Smiles		.85	
Non-Duchenne Smiles		.89	
Mixed Smiles			.83
Anger			
Disgust			.86
Sadness		-.44	
Worry		-.35	
Active Self-Regulation	-.94		
Passive Self-Regulation	.93		
Disruptiveness	.37		

Note: *% Variance* refers to the proportion of variance explained by the component. The values for constituent variables are the variables' loadings on the components. Values are reported only for variables with loadings > |.30| on a component.

The results of the confirmatory PCA were somewhat consistent with the approach-withdrawal model, in that disgust and passive behavior were associated with the same component, active self-regulation was inversely related to passive self-regulation, and worry was inversely related to disruptiveness and smiling. When compared directly, however, the content of the three components was generally dissimilar to the content of the three theoretically derived variables. The approach-related behaviors of smiling and active self-regulation loaded on different components rather than on the same component, and the withdrawal-related behaviors of sadness and worry loaded on a different component than did the other withdrawal-related behaviors of disgust and passive self-regulation. In addition, the three components in the PCA accounted for 57.19% of variance in the 10 variables, which is low for PCA.

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