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Children's affect regulation during a disappointment: Psychophysiological responses and relation to parent history of depression

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Abstract

Psychophysiological responses during affect regulation were examined in 57 children ages 3–9 years, 41 of whom had a parent history of childhood-onset depression (COD). During a structured laboratory task, children were given first a disappointing toy and then a desired toy. Frontal electroencephalogram (EEG) asymmetry, respiratory sinus arrhythmia (RSA), heart period, and heart period variability were measured during resting and task conditions. Affective and self-regulatory behaviors were coded from videotape. In 3–5-year olds, greater relative right frontal activity was associated with withdrawal behavior. High heart period was associated with approach behavior. Compared with children of psychiatrically healthy parents, children of parents with COD exhibited poor heart period recovery after disappointment. For children of parents with COD, greater relative left frontal activity was related to concurrent internalizing and externalizing problems, and low resting RSA was related to internalizing problems. Physiological responses associated with affect regulation may help identify children at risk for depression.
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The regulation of negative affect is critical to children's adaptive social behavior. Through processes that involve reducing the intensity of negative affect, changing the quality of negative affect, or enhancing positive affect (Cole et al., 2004; Dodge and Garber, 1991; Thompson, 1994), affect regulation allows children to achieve goals, such as communicating subjective experience and conforming to sociocultural norms (Campos et al., 1994). Difficulties regulating negative affect can have consequences for behavior problems (Shaw et al., 2001; Silk et al., 2003). One type of situation that demands affect regulation skills is a disappointment experience, such as the receipt of an unwanted gift. A disappointment may provide opportunities for affect regulation, as children endeavor to reduce negative emotions or express gratitude. Structured disappointment paradigms reliably elicit negative affect and regulatory attempts; reveal individual differences in healthy and high-risk children from early to middle childhood; and are ecologically valid because they simulate a social experience likely to occur in children's regular lives (Cole, 1986; Cole et al., 2004, 1994b; Saarni, 1984). During repair of the disappointing event, children encounter further opportunity to apply affect regulation as they attempt to recover from the letdown.

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Two leading complementary models of the physiology associated with children's affect regulation are the approach–withdrawal model of frontal electroencephalogram (EEG) asymmetry (Davidson et al., 2000a,b; Fox, 1991) and the polyvagal theory (Porges, 1997). In the approach–withdrawal model, resting frontal EEG asymmetry, or the balance of left and right frontal brain activity, is expected to be associated with trait-like affective tendencies. *Greater relative left frontal activity* refers to greater left relative to right frontal brain activity, as inferred by lower left EEG alpha power, and *greater relative right frontal activity* refers to the opposite pattern of activity. Greater relative left frontal activity is postulated to be correlated with approach behavior, including anger and positive affect. Greater relative right frontal activity is postulated to be correlated with withdrawal behavior, including sadness and worry.

Both greater relative left and greater relative right frontal activity have been associated with problem behaviors. In adults, greater relative left frontal activity is related to angry and aggressive behaviors (Harmon-Jones and Allen, 1998; Harmon-Jones and Sigelman, 2001), and greater relative right frontal activity has been linked to depression (Henriques and Davidson, 1990, 1991). In infants and young children, greater relative right frontal activity is associated with withdrawal behavior or avoidance, such as crying during maternal separation (Davidson and Fox, 1989), behavioral inhibition (Fox et al., 2001; Kagan et al., 1988) and internalizing problems (Fox et al., 1996). Greater relative right frontal activity is believed to be a marker for affective disorders (Tomarken and Keener, 1998). Accordingly, greater relative right frontal activity may occur in children at risk for depression, as supported by findings with infants and adolescents of depressed mothers (Dawson et al., 1999; Jones et al., 1997; Tomarken et al., 2004). From a developmental psychopathology perspective, frontal EEG asymmetry can also be influenced by experiences that contribute to brain structure and function (Davidson, 1994).

Despite the claim that greater relative right frontal activity may accompany affective disorders, some studies have found instead that affective disorders, particularly anxiety disorders, are accompanied by greater relative left frontal activity. For example, greater relative left frontal activity is associated with anxious apprehension, a component of anxiety, in adults (Heller et al., 1997). Boys with anxiety disorders have been reported to have greater relative left frontal activity (Baving et al., 2002). Among higher-functioning autistic children, greater relative left frontal activity is related to high social anxiety (Sutton et al., 2004).

The polyvagal theory (Porges, 1997), another model of physiology and affect regulation, proposes that parasympathetic control of cardiac output mediates affect regulation. This type of control, indexed by respiratory sinus arrhythmia (RSA), enables children's social engagement. High resting RSA has been postulated to be associated with flexible responses to affective challenges. Correspondingly, low resting RSA has been found to be related to children's behavior problems (Boyce et al., 2001; El-Sheikh et al., 2001; Pine et al., 1998) and risk for depression (Field et al., 1995). Furthermore, effective socioemotional functioning is thought to be characterized by stimulus-relevant flexibility in RSA (Friedman and Thayer, 1998). The expected pattern would be decreased RSA during challenging conditions and increased RSA once challenges resolve (Porges, 1997). Heart period, which is inversely related to heart rate, and heart period variability are also considered measures of autonomic regulation (Fox et al., 2000). Heart period tends to show a similar pattern to RSA across affective contexts. For example, heart period tends to decrease during laboratory affective inductions (Bradley, 2000). Thus, with effective affect regulation, heart period would also be expected to decrease during a challenge and then increase to resting levels after the challenge is no longer present. Infants exhibit the predicted pattern of decreased and then increased RSA and heart period during and after experience of a social stressor (Bazhenova et al., 2001). Patterns of RSA and heart period responding have rarely been examined in older children, however.

Affect regulation may be a particular problem for children of depressed parents. These children are at risk for a variety of adjustment problems (Downey and Coyne, 1990), many of which involve dysregulated mood. Indeed, the development of behavior problems is thought to involve poor affect regulation (Ashman and Dawson, 2002; Field, 1994). One indicator of poor affect regulation associated with depression is reduced physiological flexibility, or failure for physiological processes to vary appropriately with changes in context. Just as flexibility in responding to challenges can be considered the hallmark of adaptive affect regulation in children (Cole et al., 1994a) and of mental health in general (Vaillant, 2003), physiological flexibility is an important component of adaptive affective response. RSA is considered a valuable index of physiological flexibility (Friedman and Thayer, 1998; Porges et al., 1996; Rottenberg et al., 2003) and varies with depression. Notably, depressed adults do not exhibit the typical increase in RSA during the resolution of crying (Rottenberg et al., 2003). Similarly, infants with poor modulation of RSA have higher levels of behavior problems at preschool age (Porges et al., 1996). If *risk for depression* is also associated with poor physiological flexibility, children of depressed parents may exhibit poor flexibility of physiological indices, such as RSA and heart period, during affective contexts. This would be evident, for example, in failure to exhibit decreased RSA during a distressing experience, or, if a decrease in RSA is exhibited, failure to exhibit increased RSA after the distressing experience ends. Furthermore, children of depressed parents may also exhibit poor behavioral flexibility, for instance, by continuing to exhibit negative affect after an unpleasant stimulus is no longer pleasant.

Children of parents with childhood-onset depression (COD), a highly familial form of depression (Kovacs et al., 1997), may be especially prone to affect dysregulation. Emerging evidence supports the influence of early-onset parent depression on children's affect regulation, even very early in life (Forbes et al., 2004). Thus, when children of parents with COD are too young to receive internalizing diagnoses, they may nonetheless exhibit deficits in affect regulation. Studying the affect regulation characteristics of children of parents with COD, especially with respect to physiology, can lead to enhanced knowledge of the relation between risk for depression and behavior problems by describing a possible mechanism for the development of problems.

The current study examined the psychophysiology of children's affect regulation during a disappointment experience. We focused on two sets of issues. First, we investigated the association of baseline physiology with disappointment behavior. Second, we investigated the association between children's risk for depression and (1) their physiological and behavioral flexibility during a disappointment and (2) their behavior problems. This approach allowed us to test hypotheses about general individual differences in the entire sample of children as well as hypotheses about risk for depression. The guiding hypothesis for the first set of issues was that resting physiology reflects affect regulation tendencies. We anticipated that these tendencies would be evident in behavior during an event that demands affect regulation. The guiding hypothesis for the second set of issues was that children at risk for depression exhibit difficulties with affect regulation. To address this hypothesis, we assessed children who were at risk for depression because their parents had a history of COD. We compared these children with children whose parents had no history of psychopathology. Because parents in the COD group were generally not experiencing a depressive episode at the time of the study, we focused on group differences related to history of parent depression rather than current parent depression.

The disappointment paradigm we employed in the study included a condition in which children were given an undesired toy (*bad toy* condition), and then a condition in which children received an apology and a desired toy (*good toy* condition). This allowed us to examine both response to disappointment and recovery from disappointment. Given the task conditions, we expected that children would exhibit more withdrawal behavior during the bad toy condition and more approach behavior during the good toy condition. We hypothesized that children's greater relative right frontal activity at rest would be related to more frequent withdrawal behavior, particularly in the bad toy condition. We hypothesized that high RSA and heart period at rest would be related to better recovery, which was operationalized as more frequent approach behavior during the good toy condition. Because risk for depression is thought to be related to poor physiological and behavioral flexibility, we hypothesized that across task conditions, children of parents with COD would exhibit reduced flexibility of RSA, heart period and behavior. Finally, with respect to behavior problems, we hypothesized that in combination with parent history of COD, greater relative left frontal activity at rest would be associated with externalizing problems, greater relative right frontal activity at rest would be associated with internalizing problems, and low RSA at rest would be associated with both types of problems.

1. Methods

1.1. Participants

Participants were 57 children between the ages of 3 and 9 years, 41 of whom had a parent with a history of COD. The control group was small relative to the COD group because recruitment for the larger study had emphasized the COD group, which was more difficult to obtain, and because there was an objective of recruiting a control group matched for socioeconomic status with the COD group. The COD group included 30 families, with all offspring in the target age range included in the current analyses (18 families had multiple children in the study). Within the control group, one child per family was assessed.

The age range of 3–9 years was selected because it is an important period for the development of affect regulation skills (see Kopp, 1982) and is consistent with the age range included in studies using similar paradigms (e.g. Cole, 1986). The age range includes two important developmental periods: preschool and early school age. This age range is one in which important cognitive and emotional abilities develop to support affect regulation (Posner and Rothbart, 1998). In addition, the peak alpha frequency in the EEG changes with age during this period (Marshall et al., 2002). We did not have specific hypotheses about age-related changes, but we considered such changes by including age group (3–5 years or 6–9 years) in data analyses.

Table 1 presents sample characteristics. Random effects models with COD group as a fixed effect and family as a random effect indicated that children of parents with COD and children of control parents did not differ in age, gender, parent education level, or handedness. Chi square analyses indicated that the two groups also did not differ in ethnicity. Data analyses conducted without left-handed participants indicated that handedness did not exert an influence on the findings reported below.

Participants were drawn from a longitudinal study of affect regulation in adults with COD and their offspring. One parent per child was included in the study, with a total of 4 fathers and 53 mothers participating. Parents in the COD group were recruited either during childhood from referrals to treatment programs ($n = 16$) or during adulthood from studies of childhood psychopathology ($n = 14$) at the Western Psychiatric Institute and Clinic in Pittsburgh,

Table 1
Participant characteristics

	Control group ($n = 16$)	COD group ($n = 41$)
Mean age (years)	5.17 (1.82)	5.32 (1.86)
Age group (%)		
3–5 years old	56	61
6–9 years old	44	39
Sex (female)	44	34
Ethnicity (%)		
European American	69	34
African American	6	17
Asian American or Latino	6	5
Mixed[a]	19	44
Parent education level (high school diploma or above) (%)	88	98
Child handedness[b] (right) (%)	94	85
Parent current depressive symptoms[c]	2.69 (2.68)	11.74 (9.82)
Child behavior problems[d]		
Internalizing (*T*)	45.40 (7.49)	54.92 (8.58)
Externalizing (*T*)	52.13 (11.03)	58.92 (9.99)

Note: COD, parent history of childhood-onset depression. Values for age and parent current depressive symptoms are mean (S.D.).
[a] Primarily mixed European American and African American.
[b] Measure not completed for one COD child.
[c] Interview not completed for parents of three COD children.
[d] Questionnaire not completed for four COD children and one control child.

Pennsylvania. Parents in the control group were recruited through a marketing directory, newspaper advertisements and other studies.

Parents in the COD group who were recruited during adulthood had a history of depressive disorder that was documented in childhood psychiatric records. Thus, diagnoses of childhood depression were not retrospective. Families in the COD group who were recruited when parents were adults did not differ from those who were recruited when parents were children in demographic characteristics, current parent symptoms, child age, child baseline physiology, or child behavior problems.

Parents in the COD group had received diagnoses of major depressive disorder or dysthymia before the age of 15 years. Parent history of depression was determined using structured clinical interviews and a review of childhood psychiatric records. Parents who were recruited into the study during childhood were originally evaluated using the Interview Schedule for Children and Adolescents (ISCA) (Sherrill and Kovacs, 2000). At the time of the current study (but rarely on the day of the child assessment), parents recruited during childhood were evaluated using the Structured Clinical Interview for DSM-IV (SCID) (First et al., 1995). Parents in the COD group who were recruited during adulthood were evaluated with the SCID to confirm childhood depressive diagnoses and to ascertain lifetime Axis I diagnoses. Parents in the control group were administered the SCID to confirm the absence of lifetime Axis I psychopathology. Parents in the COD group had a mean of 1.93 lifetime major depressive episodes (S.D. = 2.11, range = 0–9). Analyses with parents' lifetime diagnosis of anxiety disorder, attention-deficit/hyperactivity disorder, conduct disorder, substance use disorder and lifetime suicide attempt indicated that psychiatric comorbidity and clinical features did not appear to influence the results reported below.

Parents' current depressive symptoms were measured using the Follow-up Depression Scale (FDS). The FDS is a semi-structured interview for depressive symptoms administered by Masters-level clinicians. The FDS was developed from the ISCA (Sherrill and Kovacs, 2000). Clinicians rated each of the 24 FDS items on a four-point severity scale (0 = none, 3 = severe). The FDS yields a continuous measure of depressive symptoms and does not have cut-off scores for clinical depression or severity level. In the larger sample of adults in the COD and control groups, the FDS was strongly correlated with the Beck Depression Inventory (Beck et al., 1988), a widely used self-report scale of depression ($r = .84$, $N = 432$).

Based on the results of the next diagnostic interview that parents completed after the child psychophysiology session, we estimate that eight parents in the COD group were experiencing clinical-level depression at the time of their child's assessment. Because this number is low and because the determination was made using retrospective data from up to 11 mos after the child's assessment, the group of parents who appeared to be in a depressive episode was not examined separately.

1.2. Procedure

The child was seated in a comfortable chair and accompanied by an experimenter (the parent waited in an adjacent room, where there was a monitor with a view of the child). The resting condition involved six 30 s segments, during which the child sat quietly and alternately looked at a small model spaceship and kept eyes closed. The disappointment task was administered in the same order for all participants and followed the paradigm of Cole et al. (1994b). An experimenter asked the child to rank-order eight toys by preference, stated that the child would receive a prize after completing a task, and led the child to expect the most-preferred toy. After the task, the experimenter gave the child the least-preferred toy and sat with the child for 60 s, interacting minimally and maintaining a neutral facial expression (bad toy condition). The experimenter then left the room for approximately 20 s. The experimenter then returned, apologized, and presented the child with the most-preferred toy. After presenting the child with the preferred toy, the experimenter again sat with the child for 60 s and interacted minimally (good toy condition).

The parent completed questionnaires during the assessment. After the assessment, the child was administered a handedness test for children based on the Edinburgh Handedness Inventory (Oldfield, 1971). This test involved demonstration with props (e.g. throwing a ball) and did not require reading skills.

1.3. Data acquisition

1.3.1. Physiology

Physiology data were digitized on-line with a sampling rate of 512 Hz. EEG was recorded at 12 sites (F3, F4, F7, F8, C3, C4, T7, T8, P3, P4, O1 and O2) using an electrode cap (Electro-Cap International) placed according to standard skull landmarks. The isolated-common ground was AFz. Electrode impedances were below 5 kΩ, and impedances for homologous sites were within 0.5 kΩ. On-line recordings were referenced to vertex (Cz), and later re-referenced to a whole-head average. The Cz reference is widely used in research on emotion and psychopathology, but its use is controversial because it often has little relation to other reference schemes (see Allen et al., 2004). Data were re-referenced to an average scheme because in contrast to the Cz reference, the average reference is considered adequate for approximating an inactive reference (Allen et al., 2004). The gain was 5000, and the signal was bandpass filtered at 1–100 Hz. Vertical and horizontal electrooculogram (EOG) were recorded using tin cup electrodes. EOG electrodes were placed on the suborbital and supraorbital areas around the right eye (vertical) and on the left and right outer canthi (horizontal).

ECG was recorded using disposable electrodes placed axially on the left and right sides of the trunk, at approximately heart level. The gain was 250, and the signal was bandpass filtered at 0.1–1000 Hz. Data were resampled off-line at 1000 Hz to increase precision of R-wave detection.

1.3.2. Behavior

Behavior was recorded using a video camera inside a glass case. Video time code was synchronized with physiology data acquisition. Behavior problems were measured by parent report on either the 2–3- or 4–18-year-old version of the Child Behavior Checklist (CBCL) (Achenbach, 1991, 1998), a reliable and valid questionnaire. Standardized (*T*) scores for internalizing and externalizing problems were computed.

1.4. Data processing and reduction

1.4.1. Physiology

EEG and EOG data were inspected visually, and blink, movement, and muscle artifact was removed manually. The COD and control groups did not differ in the quantity of artifact-edited data. All participants had an adequate amount of artifact-free EEG data, which was defined as at least 67% of data for the resting and task conditions. The mean amount of artifact-free data was 77% for the resting condition and 74% for the task condition. The EEG signal was quantified with 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 was computed for 1 Hz frequency bins from 1 to 30 Hz. The alpha band was the focus of analysis because it is putatively inversely related to sensory stimulation and cortical activation (Davidson, 1988; Pfurtscheller et al., 1996). High alpha power values, then, reflect low brain activity, while low power values reflect high activity. Based on inspection of the power distribution at midfrontal sites and developmental findings on EEG (Marshall et al., 2002), we defined alpha as 7–10 Hz for 3–5-year olds and 8–11 Hz for 6–9-year olds.

For resting EEG data, alpha values (in picowatt-Ohms or μV^2) were weighted by the number of artifact-free windows in each segment and then averaged across segments. All resting segments, both eyes-open and eyes-closed, were included. For disappointment task data, average alpha power was obtained for each condition. Values were subjected to a natural-logarithm transformation to normalize distributions (Gasser et al., 1982). With a widely used approach (Davidson et al., 2000a,b), asymmetry scores were computed by subtracting left alpha power scores from right (e.g. $\ln \text{F4power} - \ln \text{F3power}$). Because this technique infers brain activity by the inverse of alpha activity, high power scores indicate low activity. Consequently, positive asymmetry scores imply greater relative left activity by indicating more alpha power at the right site than the left site. Negative asymmetry scores imply greater relative right activity by indicating more alpha power at the left site than the right site.

Asymmetry at midfrontal sites (F3/F4) was the focus of analyses, but asymmetry was also computed for other sites. The midfrontal sites were emphasized because findings on frontal EEG asymmetry in infants and children have generally been associated with those sites (Calkins et al., 1996; Fox et al., 2001; Henderson et al., 2004). Data from these sites also tend to contain less eye movement artifact than do data from other anterior sites. Analyses with significant frontal EEG asymmetry findings reported below were also conducted with asymmetry scores for other anterior sites (i.e. F7/F7 and T7/T8), indicating that asymmetry at those sites was not a source of influence. Similarly, analyses with significant frontal EEG asymmetry findings were conducted with parietal asymmetry scores, confirming that effects were specific to the midfrontal leads.

An automated multi-pass algorithm detected R waves in ECG data and computed interbeat intervals (IBIs). Data were manually checked and corrected after the algorithm was applied. Three variables were obtained from ECG data. *Heart period* was computed as mean IBI. *Heart period variability* was computed as IBI standard deviation. *RSA* was computed by detrending the IBI time series using a high-pass filter and applying fast Fourier transform analyses to compute power within the frequency range of heart rate variability due to respiration. Based on previous developmental findings (Bar-Haim et al., 2000), this frequency range was defined as 0.20–1.00 Hz for 3–5-year olds and as 0.15–0.5 Hz for 6–9-year olds.

To allow adequate data for computing RSA, and following methodological guidelines for research with children (Bar-Haim et al., 2000), 2 s were added to each resting segment (1 s pre- and post-segment) and 4 s were added to each task condition (2 s pre- and post-condition). Viewing videotapes of participants' task behavior during and after task conditions indicated that adding to the task condition times appeared unlikely to alter the affective content of the data.

Values for physiology were averaged across resting segments and within each task condition. RSA data were log-transformed to normalize distributions. Sufficient RSA data were available for 50 (34 in the COD group), 44 (30 COD) and 45 (32 COD) participants; and sufficient heart period data were available for 50 (34 COD), 45 (31 COD) and 46 (32 COD) participants during the resting, bad toy, and good conditions, respectively.

1.4.2. Behavior

Following Cole et al. (1994b), five affective behaviors (anger, sadness, worry, disgust, and smiling) and three self-regulatory behaviors (active, passive, and disruptive) were coded. Affective behaviors involved facial and vocal expression of emotion, and self-regulatory behaviors involved motor actions and engagement with the toy or experimenter. Active self-regulation included playing with the toy or talking to the experimenter about the toy. Passive self-regulation included staring at the toy or sitting still. Disruptive self-regulation included aggressive actions, such as throwing the toy. Using a modified frequency approach, behaviors were coded from videotape as present or absent during each 5 s interval of the task conditions. The three coders were certified in the Facial Action Coding System (Ekman and Friesen, 1978), which ensured that they would have experience in observing affective behavior and would be sensitive to subtle facial movements. A subset of participants (26%) was coded for reliability; kappas were 0.62–0.83.

Based on approach–withdrawal models (e.g. Fox, 1991), composite variables for *approach* and *withdrawal* were created by summing the total intervals in which each relevant behavior occurred for each condition. Approach contained smiling and active self-regulation. Withdrawal contained sadness, worry, disgust, and passive self-regulation. Anger and disruptive self-regulation occurred infrequently (e.g. three children displayed disruptive self-regulation) and were not included in analyses.

1.5. Data analyses

Because the number of children per family varied in the COD group, data were analyzed using random effects models, which account for within-family covariance. Family was a random effect in all models. Child gender was originally included in all models, but because it was unrelated to dependent variables, the results reported are for models without gender.

For analyses of the relation between resting physiology and behavior during the disappointment task, the physiology variable (e.g. frontal EEG asymmetry), age group (3–5 or 6–9 years), and the physiology × age group interaction were fixed variables. The focus of these analyses was general individual differences rather than risk for psychopathology. Accordingly, the entire sample was included.

The remaining analyses focused on differences based on parent history of depression, and thus, those analyses included COD group. For analyses of group differences in physiological and behavioral flexibility across conditions, repeated measures models were employed, with condition as a within-subjects factor. In the repeated measures models, the independent fixed variables were parent COD group, age group, condition and the parent COD group X condition, interaction. Based on findings of reduced RSA flexibility in depressed adults (Rottenberg et al., 2003) and in infants who go on to develop behavior problems (Porges et al., 1996), we defined flexibility as a change in RSA and heart period across resting, bad toy, and good toy conditions. For analyses of behavioral flexibility, we defined flexibility as a change in behavior from bad toy to good toy conditions. For analyses of group differences in behavior problems, independent fixed variables were parent COD group, physiology (e.g. frontal EEG asymmetry), and the group X physiology interaction. Parents' current depressive symptom level was included as a covariate in all models involving parent COD group.

2. Results

2.1. Preliminary analyses

One set of preliminary analyses tested hypotheses about the behavior elicited by the disappointment task conditions. Repeated measures ANOVAs were conducted for the two conditions with affective behavior (approach or withdrawal), age group, and affect X age group as independent variables. As expected, children exhibited more withdrawal than approach during the bad toy condition ($F(1,55) = 26.15$, $p < .001$) and more approach than withdrawal during the good toy condition ($F(1,55) = 27.97$, $p < .001$).

Another set of preliminary analyses examined the influence of demographic variables and current parent depressive symptoms on physiology and behavior. Child ethnicity, child gender, child handedness, and parent education level were unrelated to behavior and physiology. Consistent with typical developmental change (Bar-Haim et al., 2000), younger children had lower RSA and heart period than did older children. This was the case for resting ($F(1,48) = 7.77$, $p < .01$ and $F(1,48) = 34.33$, $p < .001$,

Table 2
Mean (S.D.) or proportion of behavior and physiology variables, by COD group

	Control	COD	All
Physiology			
Frontal EEG asymmetry			
Resting	−.007 (.139)	−.019 (.125)	−.016 (.128)
Bad toy	.036 (.168)	.027 (.240)	.029 (.221)
Good toy	−.025 (.206)	.006 (.168)	−.003 (.178)
RSA			
Resting	6.43 (1.22)	6.71 (1.33)	6.62 (1.29)
Bad toy	5.94 (.91)	6.37 (1.20)	6.23 (1.12)
Good toy	6.28 (.99)	6.46 (1.38)	6.41 (1.27)
Heart period variability			
Resting	.049 (.018)	.057 (.032)	.055 (.028)
Bad toy	.056 (.055)	.047 (.025)	.050 (.037)
Good toy	.044 (.017)	.053 (.032)	.050 (.029)
Behavior			
Approach			
Bad toy	8.31 (5.16)	9.76 (6.90)	9.35 (6.45)
Good toy[a]	13.13 (5.77)	15.10 (6.24)	14.54 (6.12)
Withdrawal			
Bad toy	12.25 (7.65)	10.76 (7.44)	11.18 (.99)
Good toy	5.00 (6.99)	4.78 (5.95)	4.84 (6.20)

Note: COD, parent history of childhood-onset depression. RSA, respiratory sinus arrhythmia. Frontal EEG asymmetry values are difference scores, with positive scores indicating greater relative left midfrontal activity and negative scores indicating greater relative right midfrontal activity. Heart period is not included because it is depicted in Fig. 2.

[a] Data are missing for one COD child.

respectively) and good toy conditions ($F(1,43) = 6.38$, $p < .05$ and $F(1,44) = 26.20$, $p < .001$, respectively). Parents with a history of COD had higher current depressive symptoms than did parents in the control group ($F(1,52) = 13.05$, $p < .005$). Random effects regression analyses indicated that parents' current symptoms were unrelated to children's behavior or physiology but were positively associated with children's internalizing and externalizing problems ($F(1,48) = 12.39$ and 10.91, respectively, $p < .005$). Table 2 contains details on the variables in the study.

2.2. Resting physiology and behavior during a disappointment

To test the hypotheses that (1) greater relative right frontal activity would be related to more frequent withdrawal behavior and (2) high RSA and heart period at rest would be related to more frequent approach behavior during the disappointment task, random effects analyses were conducted separately for each task condition.

2.2.1. Frontal EEG asymmetry and withdrawal behavior

The random effects model for withdrawal behavior during the bad toy condition indicated a significant frontal EEG asymmetry × age group interaction ($F(1,53) = 4.54$, $p < .05$, $\eta^2 = .08$). Follow-up random effects analyses within age groups indicated that in the 3–5-year-old group only, greater relative right frontal activity was associated with more frequent withdrawal behavior ($F(1,32) = 6.39$, $p < .05$, $\eta^2 = .17$). Fig. 1 depicts the relation between frontal EEG asymmetry and withdrawal behavior for this age group. The main effects for frontal EEG asymmetry and age group were unrelated to withdrawal. RSA, heart period and heart period variability were unrelated to withdrawal behavior, as were age group and age group X cardiac variable interactions.

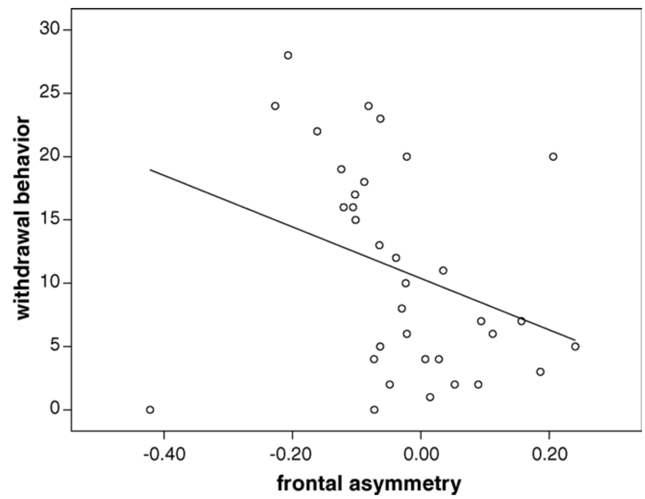

Fig. 1. Scatterplot of the association of withdrawal behavior after receiving a disappointing toy with resting frontal EEG asymmetry in 3–5-year-old children. Positive frontal EEG asymmetry scores reflect greater relative left frontal activity, and negative scores reflect greater relative right frontal activity.

2.2.2. RSA, heart period and approach behavior

Random effects analyses indicated that, as expected, high resting heart period was related to more frequent approach behavior ($F(1,46) = 4.18$, $p < .05$, $\eta^2 = .08$) during the good toy condition. Frontal EEG asymmetry, RSA, and heart period variability were unrelated to approach behavior. Age group and age group X physiology interaction effects were unrelated to approach behavior.

2.2.3. Task physiology and task behavior

In both task conditions, random effects analyses with behavior as the dependent variable indicated that physiology during the task condition was unrelated to approach or withdrawal behavior.

2.3. Risk for depression and flexibility across disappointment conditions

To test the hypothesis that children of parents with a history of depression have less flexible RSA, heart period, and behavior across affective conditions than do control

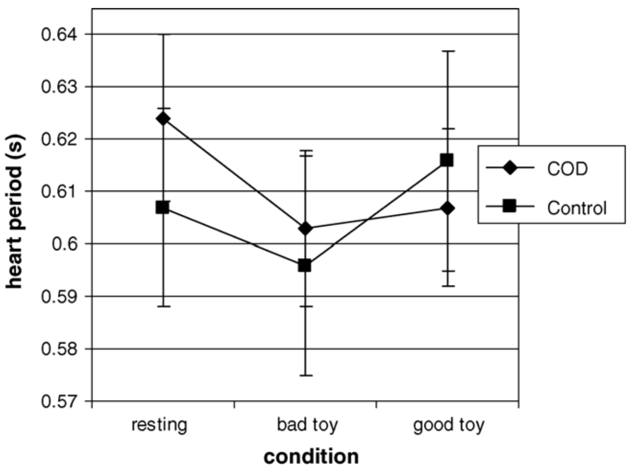

Fig. 2. Mean heart period across resting, bad toy, and good toy conditions for children with a parent history of childhood-onset depression (COD) and children with no parent history of psychopathology (control). Error bars represent one standard error of the mean.

children, repeated-measures random effects analyses were conducted.

2.3.1. Physiological flexibility

As shown in Fig. 2, there was a group X condition interaction for heart period ($F(2,82) = 3.72$, $p < .05$, $\eta^2 = .09$). Follow-up random effects analyses indicated a group X condition interaction for heart period change from the bad toy to the good toy condition ($F(1,41) = 5.67$, $p < .05$, $\eta^2 = .12$) but not from resting to the bad toy condition. Thus, both groups displayed a similar change in heart period from resting to bad toy, but they displayed a different change from bad toy to good toy. Within-group random effects analyses for heart period indicated that, whereas the children in the control group exhibited similar mean heart period during the good toy and resting conditions, children in the COD group exhibited lower heart period during the good toy condition than during rest ($F(1,28) = 5.11$, $p < .05$, $\eta^2 = .15$). This suggests that the control group's heart period after receiving the desired toy recovered to the level of the resting condition, but the COD group's heart period did not.

As in preliminary analyses, the age group main effect was significant ($F(1,43) = 21.29$, $p < .001$, $\eta^2 = .33$). The age group X COD group and age group X condition interaction effects were not significant. Group (COD or control) and the group X condition interaction were unrelated to RSA or heart period variability.

2.3.2. Behavioral flexibility

To investigate whether the COD group displayed less behavioral flexibility, repeated-measures random effects analyses were conducted for approach and withdrawal behavior. The group and group X condition effects were non-significant for both models.

2.4. Risk for depression, resting physiology, and behavior problems

To test hypotheses that in combination with parent history of depression (1) greater relative left frontal activity at rest would be associated with externalizing problems, (2) greater relative right frontal activity at rest would be associated with internalizing problems, and (3) low RSA at rest would be associated with both types of problems, random effects analyses were conducted with internalizing or externalizing *T* score as the dependent variable. Post hoc examination of interaction effects was conducted with the method recommended by Holmbeck (2002). Children in the COD group had higher internalizing problems than did children in the control group ($F(1,42) = 12.16$, $p < .001$, $\eta^2 = .22$). The two groups did not differ in externalizing problems.

2.4.1. Risk for depression and resting frontal EEG asymmetry

For internalizing problems, the group main effect was qualified by a group × frontal EEG asymmetry interaction ($F(1,42) = 10.83$, $p < .005$, $\eta^2 = .20$). Post hoc examination of the interaction effects indicated that the slopes for the relation of frontal EEG asymmetry and internalizing problems were significant for both the COD group ($B = 57.47$, S.E. = 17.49, $t = 3.29$, $p < .005$) and the control group ($B = -36.84$, S.E. = 13.96, $t = -2.64$, $p < .05$). As indicated by the slope for each group and depicted in Fig. 3, the two groups had opposite patterns of association between frontal EEG asymmetry and internalizing problems. For the COD group, children with greater relative left frontal activity had high levels of internalizing problems. In contrast, for the control group, children with greater relative right frontal activity had high levels of internalizing problems. Age group and related interaction effects were unrelated to internalizing problems.

For externalizing problems, there was a group X frontal EEG asymmetry interaction effect ($F(1,42) = 4.69$, $p < .05$, $\eta^2 = .10$). Post hoc examination of the interaction effect revealed that the slope for the relation between frontal EEG asymmetry and externalizing problems was significant for the COD group only ($B = 53.25$, S.E. = 23.44, $t = 2.27$, $p < .05$). For the COD group, children with greater relative left frontal activity had higher levels of externalizing problems (see Fig. 3). Age group and related interaction effects were unrelated to externalizing problems.

2.4.2. Risk for depression and resting RSA

For internalizing problems, there was a significant COD group × RSA interaction ($F(1,36) = 5.12$, $p < .05$, $\eta^2 = .12$). Post hoc examination of the interaction effect revealed that the slope for the relation between RSA and internalizing problems was significant for the COD group only ($B = -4.56$, S.E. = 2.02, $t = -2.26$, $p < .05$). As indicated by the negative coefficient, children in the COD

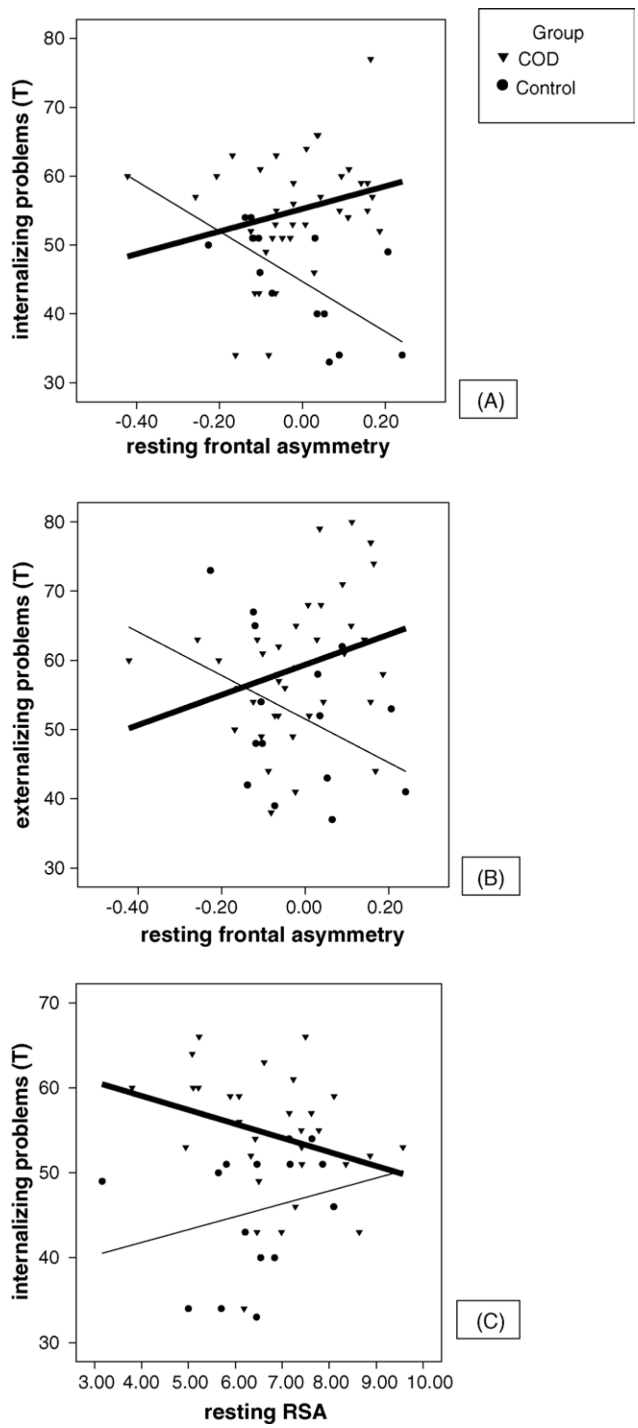

Fig. 3. Scatterplots of the association between behavior problems and resting physiology for children with a parent history of childhood-onset depression (COD) and children with no parent history of psychopathology (control). Total regression line is presented for each group in each scatterplot, with the heavy line corresponding to the COD. (A) Frontal EEG asymmetry and internalizing problems; (B) frontal EEG asymmetry and externalizing problems; and (C) respiratory sinus arrhythmia (RSA) and internalizing problems.

group with low resting RSA had high levels of internalizing problems (see Fig. 3). For externalizing problems, the group × RSA interaction was non-significant. Age group and related interactions were unrelated to either internalizing or externalizing problems.

3. Discussion

The current study extends knowledge of the psychophysiology of children's affect regulation and provides evidence that parent history of depression contributes to children's affect regulation. Children's resting physiology was related to behavior during a disappointment experience. Measures of both central and autonomic nervous system activity were valuable as predictors, with frontal EEG asymmetry and heart period related to withdrawal and approach behavior, respectively. Group differences based on parent history of depression were evident in physiological flexibility across task conditions and behavior problems. Specifically, children with a parent history of COD exhibited less flexible heart period across affective conditions than did children of control parents. Parent history of depression, in combination with resting frontal EEG asymmetry and resting vagal tone, was related to children's behavior problems.

Among 3–5-year-old children, those with greater relative right frontal activity at rest exhibited more frequent withdrawal behavior, such as sadness, worry, and passive response, upon receiving an unwanted toy. This was not the case with 6–9-year-old children. Consequently, we found support for the posited relation of greater relative right frontal activity to withdrawal behavior (Fox, 1991), but only in the younger age group. The relation between frontal EEG asymmetry and behavior has been examined far more often in infants and preschool-age children than in older children. Our results for the younger age group are consistent with findings in children at a similar developmental level (e.g. Henderson et al., 2004). The paucity of studies of frontal EEG asymmetry and affective behavior with older children makes it difficult to place our null findings for the older age group in the context of existing literature.

There are several developmental changes that may, in part, account for the stronger relation between frontal EEG asymmetry and withdrawal behavior in the younger group. First, developmental changes in cognitive abilities critical to affect regulation could account for age-related differences. Specifically, children's effortful control, which allows the self-regulation of affect in challenging situations, undergoes an impressive increase across the preschool years (Posner and Rothbart, 1998). The development of more effective effortful control may have allowed 6–9-year-old children to control the affective expressions or self-regulatory behaviors associated with withdrawal motivation. Children in this age group who have greater relative right frontal activity and experience strong withdrawal tendencies may be more successful at inhibiting or overcoming these tendencies than are younger children. As a result, these children may display similar levels of withdrawal behavior when compared with other children. Second, the introduction of structured education in the 6–9-year-old age group may lead to increased influence of peer and teacher socialization on affective behavior. Thus, socioemotional changes may lead to an attenuated association between greater relative right frontal activity and withdrawal behavior for the older age group in our study.

Our findings for task behavior do not provide support for the approach side of the approach–withdrawal model (Fox, 1991). We had not proposed hypotheses about approach behavior, however, based on previous findings and on the nature of the disappointment paradigm. The literature on frontal EEG asymmetry and children's affective behavior has generally provided more support for withdrawal behavior (e.g. Fox et al., 2001). In addition, the approach behavior elicited by the disappointment task does not correspond to pre-goal-attainment positive affect, which is the form of approach postulated to be related most specifically to greater relative left frontal activity (Davidson, 1994). In order to test the association between greater relative left frontal activity and approach, a more appropriate strategy would be to examine behavior during a different type of paradigm. For instance, a paradigm in which the child waits to receive a valued toy or works to obtain a reward may yield approach behavior that is related to resting frontal EEG asymmetry.

Somewhat consistent with theories of autonomic influence on affective behavior (Porges, 1997), children with high resting heart period displayed more approach behavior, such as smiling, social engagement and playing with the toy, after receiving a desired toy. This suggests that high heart period was associated with affect regulatory response. In particular, children with high heart period may have more effectively recovered from an unpleasant stimulus, so that they could respond appropriately to the desired toy. Because heart period was not associated with behavior during the bad toy condition, it appears not to have played a role in reactivity to an unpleasant stimulus. Our hypothesis that high RSA would be associated with high frequency of approach behavior during the good toy condition was not supported. A possible explanation for this is that children with high RSA did not recover more effectively during this condition. Alternatively, the short duration of the condition and our operationalization of recovery as high approach behavior may have limited our ability to find a relation between RSA and recovery from disappointment.

In support of claims that depression involves poor physiological flexibility (Rottenberg et al., 2003), we found that children at risk for depression (by virtue of a parent history of COD) exhibited difficulty regulating heart period across affective conditions. Children at risk for depression showed a different pattern of recovery from the disappointment experience than did children of control parents. Although children of parents with COD showed a decrease in heart period from the resting condition to the bad toy condition that was similar to the response of the control group, their heart period did not change similarly from the bad toy to the good toy condition. Unlike in the control group, heart period in children of depressed parents failed to return to the resting level. This pattern for the depressed group is similar to findings on physiological recovery in depressed adults (Rottenberg et al., 2003) and in infants who later develop behavior problems (Porges et al., 1996). This reduced flexibility could reflect several processes. The good toy condition involves not only recovering from the disappointment of an undesired event but also responding to a pleasant event. Thus, abnormal affect regulation in children at risk for depression may involve difficulty recovering from distress, difficulty experiencing pleasure, or both. This finding supports claims that depression involves unusually sustained processing of unpleasant stimuli (Siegle et al., 2002) and the experience of a combination of high negative and low positive affect (Clark and Watson, 1991).

Methodological issues or other affect regulation characteristics of children at risk for depression could also explain the group difference in heart period across conditions. The use of the same paradigm for all participants could have introduced order effects, for example. However, testing hypotheses about flexibility in affect regulation physiology response requires examining first the response to an affective challenge and then the response to the resolution of that challenge. Presenting the good toy condition first would not have allowed us to test our hypothesis about flexibility as appropriately. Other possible interpretations of the finding are that the children of COD parents had a longer duration of recovery or did not find the good toy to be a salient stimulus. Unfortunately, we were not able to measure longer-term recovery because we relied on the 60 s good toy condition for recovery data. We do not wish to imply that the children of COD parents did not recover from the bad toy, but rather that they did not recover as effectively as did the children of control parents. Finally, if the children in the COD group have difficulty in the generation and maintenance of positive affect, as posited by motivational and affective models of depression (Clark and Watson, 1991; Depue and Iacono, 1989; Fowles, 1988), they might have found the good toy less appealing.

Internalizing problems were related to resting frontal EEG asymmetry in contrasting ways for children of COD parents and children of control parents. Whereas greater relative right frontal activity was associated with internalizing in children of control parents, greater relative left frontal activity was associated with internalizing in children of parents with COD. These findings for the COD group were the opposite of our predictions, but they were consistent with several other findings in the literature on frontal EEG asymmetry. A study of adults from the larger program project found that men with COD exhibited resting greater relative left frontal activity (Miller et al., 2002). Studies with children have reported greater relative left frontal activity in socially anxious autistic children (Sutton et al., 2004) and boys with anxiety (Baving et al., 2002). Because greater relative left frontal activity is thought to reflect worry and anxious apprehension (Heller et al., 1997), this pattern may indicate that internalizing problems involving worry are higher in children with greater relative left frontal activity and a parent history of depression.

Our predictions about the association of externalizing problems with greater relative left frontal activity in children at risk for depression were supported. This represents one of the first findings with children to parallel reports of anger and aggressive response in relation to greater relative left frontal activity in adults (Harmon-Jones and Allen, 1998; Harmon-Jones and Sigelman, 2001). Taken with the adult findings, this result could indicate that greater relative left frontal activity may predispose children at risk for depression toward externalizing problems that involve approach-related tendencies involving impulsivity, anger or sensation-seeking. This claim is also in line with the perspective that childhood problems related to anger and aggressiveness are approach-related (Beauchaine, 2001).

Given that internalizing and externalizing types of problems frequently co-occur in children (e.g. Hinden et al., 1997), the finding that greater relative left frontal activity was related to both internalizing and externalizing problems in children of parents with COD is not entirely surprising. When considered in the conceptual context of externalizing involving increased approach motivation and internalizing involving increased worry, both of which are postulated to be reflected in greater relative left frontal activity, it is plausible that children with greater relative left frontal activity could exhibit both forms of problems. Furthermore, this pattern of frontal EEG asymmetry may reflect both trait-like affective tendencies and experiences during development (Davidson, 1994). For instance, Fox et al. (2001) reported that 4-year-old children who were consistently behaviorally inhibited tended to have greater relative right frontal activity and were less likely to have experienced non-parental care than were children who changed from inhibited to non-inhibited. Presumably, social experiences, such as non-parental care, could influence both behavioral characteristics and frontal EEG asymmetry. Perhaps children of COD parents who develop a pattern of relative left frontal activity have an initial physiological profile that is then strengthened or maintained by interactions with their parents. Parents' mood, reinforcement of children's affect, or responses to children's affect regulation strategies may all play a role in the emergence or maintenance of this pattern of brain activity.

Consistent with one of our hypotheses about RSA and behavior problems, children in the COD group with low resting RSA had high levels of internalizing problems. Low RSA at rest may thus increase the probability of problems involving dysregulated mood and social withdrawal in children who have increased risk for psychopathology as a result of parent depression. We did not find that low RSA was related to externalizing problems, however. Our findings are therefore not entirely consistent with other reports of low RSA as a factor in both internalizing and externalizing problems (e.g. Pine et al., 1998).

The finding of reduced physiological flexibility in children at risk for depression occurred for heart period, but not RSA or heart period variability. RSA had a similar pattern to that of heart period, however, and we suspect that group differences in RSA were present but difficult to detect given the sample size. It is also possible that group differences in heart period reflect sympathetic rather than parasympathetic differences. Thus, it will be important to include measures of sympathetic activation in future studies. Pre-ejection period (PEP), a measure of the duration of time in which the left ventricle generates force, reflects sympathetic control of the heart (Fox et al., 2000) and would be a good candidate variable for examining sympathetic influence. Low PEP is associated with high-arousal affective conditions in adults (Neumann and Waldstein, 2001). Thus, we would predict that flexibility in PEP during the disappointment task would involve a pattern of decrease and then increase. Heart period variability, thought to indicate one aspect of affect regulation (Fox et al., 2000), may have less relevance than heart period to the type of affective flexibility measured with this paradigm.

We did not find group differences in behavioral flexibility across the disappointment task. Perhaps this was because the task generally elicited withdrawal behavior during the bad toy condition and approach behavior during the good toy condition. However, our finding of group differences in physiological change across conditions echoes a behavioral finding from another study within this program project. In that study, girls with a parent history of COD were more likely than children of control parents to exhibit passive affect regulation strategies while waiting for an appealing toy or snack (Silk et al., in press). It may be that children at risk for depression may become stuck in less than optimal affect regulation patterns. These patterns may be more evident behaviorally in some circumstances and physiologically in others.

Children of parents with COD did not differ from control children in resting frontal EEG asymmetry, RSA, or heart period. Although our hypotheses focused on group differences in physiology and behavior across task conditions and on interactions between risk for depression and physiology, previous studies have found that resting physiology distinguishes children with maternal depression from those without such a parent history (e.g. Dawson et al., 1999). Unlike those studies, which have focused on infants of currently depressed mothers, we focused on middle childhood and parent history of depression. During middle childhood, group differences in resting physiology may be more important in the context of other developmental factors. Just as changes in cognitive, affective and social domains may influence the strength of the association between resting frontal EEG asymmetry and affect regulation behavior, such changes may influence differences in resting physiology.

The limitations of the current study include its cross-sectional design, reliance on a single laboratory paradigm, sample size and use of a 12-site EEG reference. The characteristics and size of the sample were constrained by the use of a longitudinal sample of parents with COD and by recruitment strategies for control families, which resulted in a socioeconomically matched but relatively small control group. As a result, the age-based subgroups were also small. Replication of the current findings in larger samples or in different affect-eliciting conditions will be important. The use of an average EEG reference scheme limited our ability to conclude whether the frontal EEG asymmetry findings were independent of reference scheme and are truly generalizable. To address this issue, future studies should be designed with a goal of comparing results with multiple reference schemes. Furthermore, our average reference falls short of approximating a truly inactive reference because it contained only 12 sites.

Finally, the reliance on parent report to measure behavior problems was another limitation of the study. Although it has been reported that depressed mothers do not have distorted perceptions of their children's behavior problems (Richters, 1992), we found that children's parent-reported behavior problems were high in families with high self-reported parent depressive symptoms. We were not able to compare parent-rated with other-rated behavior problems, so we cannot say whether parents' symptom level influenced their ratings. Ideally, information on children's behavior problems should be obtained from multiple informants.

This study is one of the first to consider parent history of depression rather than solely parents' current symptoms as a factor in children's physiology, behavior and behavior problems. Using a carefully characterized sample of parents who have been studied since childhood, we found that parent history of depression influenced the physiology of children's affect regulation and children's behavior problems. We cannot draw firm conclusions about the role of parent history of depression separately from parents' current symptoms because the two variables were confounded (see Miller and Chapman, 2001). In addition, children of depressed parents had higher internalizing problems than did children of control parents. This group difference in children's psychopathology could also have accounted for some group differences in affect regulation physiology. Nonetheless, we emphasize the importance of measuring both history and current depression in parents and measuring depressive symptoms in children when investigating the children of depressed parents. Both aspects of depression may contribute meaningfully to children's affect regulation and behavior problems.

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