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Affective Decision-Making and Externalizing Behaviors: The Role of Autonomic Activity

Jennifer L. Bubier and **Deborah A. G. Drabick**
Department of Psychology, Temple University, Weiss Hall, 1701 North 13th Street, Philadelphia, PA 19122-6085, USA

Jennifer L. Bubier: jbubier@temple.edu

Abstract

We tested a conceptual model involving the inter-relations among affective decision-making (indexed by a gambling task), autonomic nervous system (ANS) activity, and attention-deficit/hyperactivity disorder (ADHD) and oppositional defiant disorder (ODD) symptoms in a largely impoverished, inner city sample of first through third grade children (N=63, 54% male). The present study hypothesized that impaired affective decision-making and decreased sympathetic and parasympathetic activation would be associated with higher levels of ADHD and ODD symptoms, and that low sympathetic and parasympathetic activation during an emotion-inducing task would mediate the relation between affective decision-making and child externalizing symptoms. In support of our model, disadvantageous decision-making on a gambling task was associated with ADHD hyperactivity/impulsivity symptoms among boys, and attenuated sympathetic activation during an emotion-inducing task mediated this relation. Support for the model was not found among girls.

Keywords

ADHD; ODD; Psychophysiology; Decision-making

Both attention-deficit/hyperactivity disorder (ADHD), which is characterized by problems with attention, hyper-activity, and impulsivity, and oppositional defiant disorder (ODD), which is defined by a pattern of negativistic, hostile, and oppositional behaviors toward adults, are relatively common in childhood (American Psychiatric Association 2000), and are associated with numerous negative correlates and sequelae. These correlates include deficient social problem-solving skills and impaired social functioning (Frankel and Feinberg 2002; Matthys et al. 1999), poor academic achievement (Drabick et al. 2004; Rapport et al. 1999), and co-occurring internalizing disorders (Drabick et al. 2004; Jensen et al. 2001). In addition, ADHD and ODD are related prospectively to substance use, poor academic achievement, conduct disorder (CD), and antisocial behavior (Masten et al. 2005; van Bokhoven et al. 2005), though the association between ADHD and CD may be accounted for by co-occurring ODD (Lahey et al. 2002; van Lier et al. 2007).

Despite some similar correlates and outcomes, research has shown significant differences among children with ADHD vs. ODD in terms of cognitive functioning and academic performance (Carlson et al. 1997; Keenan and Wakschlag 2000), prenatal/perinatal complications (Harvey et al. 2007), family functioning and parenting (Cunningham and

Correspondence to: Jennifer L. Bubier, jbubier@temple.edu.

Boyle 2002; Drabick et al. 2004), and family psychiatric history (Drabick et al. 2004; Harvey et al. 2007). Similarly, the ADHD-predominantly inattentive (ADHD-I) and ADHD-predominantly hyperactive-impulsive (ADHD-H) subtypes differ in terms of correlates. For instance, the ADHD-I subtype is associated with higher levels of academic difficulties and internalizing problems, whereas the ADHD-H subtype is associated with social impairment, motor inhibition deficits, and externalizing symptoms (Eiraldi et al. 1997; Gadow et al. 2000, 2004; McBurnett et al. 1999; Nigg et al. 2002). Despite these differences, most studies compare ADHD-I and the combined subtype of ADHD (ADHD-I + ADHD-H), likely because of the relatively lower base rates of pure ADHD-H. Given these adverse outcomes and distinct correlates among ADHD subtypes and ADHD vs. ODD, identification of processes associated with ADHD and ODD is critical.

Biosocial models suggest several likely candidate markers of vulnerability for externalizing problems, including attenuated autonomic nervous system (ANS) activity, as well as altered orbitofrontal and amygdala functioning (Beauchaine et al. 2001; Blair 2004, 2007). Concurrent examination of these processes may aid in identification of subtypes of individuals with externalizing problems that have distinct etiologies and may provide indices of treatment response (Beauchaine 2001). Accordingly, our goal in the present study was to test a conceptual model linking ADHD and ODD symptoms with ANS and affective decision-making (shown to be partially dependent on orbitofrontal and amygdala functioning; Bechara et al. 1999) to examine whether differential processes underlie symptoms characteristic of ADHD subtypes and ODD. This conceptual model is based on three lines of work and includes research conducted by Beauchaine and colleagues examining ANS functioning among children with ADHD and ODD (Crowell et al. 2006), by Blair and colleagues examining decision making and reversal learning among individuals with psychopathy (e.g., Blair 2005; Fisher and Blair 1998), and by Damasio, Bechara, and colleagues investigating the somatic marker hypothesis (Bechara and Bar-On 2006; Damasio 1994). The present study can be distinguished from previous work in two primary ways: (1) we applied our conceptual model to both ADHD subtypes and ODD symptoms in children, and (2) we relied more specifically on the somatic marker hypothesis (Bechara and Bar-On 2006; Damasio 1994) rather than reinforcement expectancy models of amygdala-orbitofrontal interaction (Blair 2004).

The first component of the model involves associations between decision making and ADHD and ODD symptoms. Recently in the developmental psychology literature, a distinction has been made between “cool” and “hot” cognition (Kerr and Zelazo 2004). Cool cognition includes executive functioning (EF) abilities, such as planning, working memory, and the ability to inhibit prepotent responses, whereas hot cognition refers to the affective aspects of decision-making. In the present study, we were primarily interested in hot cognition, which can be assessed through various strategies (e.g., gambling and response reversal tasks) that are at least partially dependent on the functioning of the amygdala and orbitofrontal cortex (OFC; i.e., the brain area occupying the ventral portion of the frontal lobe; Blair 2004). Numerous studies have examined the relations between EF (cool cognition) and ADHD (e.g., Clark et al. 2000; Nigg et al. 2002), ODD and CD (Clark et al. 2000), and aggression (Seguin et al. 1999). In addition, research supports links between decision making (hot cognition) and ADHD and CD among adolescents (Ernst et al. 2003) and psychopathic traits among children and adolescents (Blair et al. 2001; Fisher and Blair 1998). Nevertheless, there has been little examination of relations between affective decision-making (hot cognition) and ADHD and ODD among children, despite more recent suggestions that hot and cold cognition may play separate and important roles in the development of ADHD (Sonuga-Barke 2003).

In addition to these findings, several lines of evidence from research examining OFC and amygdala functioning among children provides indirect evidence for a link between affective decision-making and ADHD and ODD symptoms. First, children with OFC damage exhibit impulsivity, attentional difficulties, and aggression, each of which is associated with ADHD or ODD (Eslinger et al. 2004). Second, decreased cerebral blood flow in the OFC has been reported in children with ADHD (Lee et al. 2005). Third, individuals in late childhood and early adolescence with psychopathic traits make more errors on response reversal tasks, which are associated with OFC and amygdala functioning (Blair et al. 2001). Fourth, given that the amygdala is important for processing negative emotions (e.g., sadness, fear), underactive amygdala functioning could lead to difficulties in processing sad and fearful expressions, potentially fueling externalizing behaviors and poor decision-making (Bechara et al. 1999; Blair et al. 1999, 2001). Indeed, Blair et al. (1999) was the first to document a relation among the amygdala, processing of negative facial expressions, and increased risk for antisocial behavior. Moreover, because the amygdala is necessary for establishing conditioned fear and recognizing threat cues (Davidson 2002), an underactive amygdala may contribute to difficulty learning stimulus-incentive associations, which has been implicated in the development of impulsivity and aggression (Patterson and Newman 1993). Taken together, these findings suggest that various externalizing behavior symptoms, including ADHD and ODD, may be related to affective decision-making and other abilities dependent on the OFC and amygdala.

Currently, however, there is a dearth of research examining abilities dependent on the OFC and amygdala in children with ADHD and ODD, which may have stemmed from limited time-efficient and cost-effective methodological approaches. One promising, non-invasive methodology involves gambling tasks, which are designed to evaluate affective decision-making as they simulate real-life decisions including uncertainty, reward, and punishment, and index both OFC and amygdala functioning among other areas (Bechara et al. 1994, 1999). Research involving gambling tasks suggests that young children perform similarly to individuals with OFC and amygdala lesions, and affective decision-making abilities continue to develop throughout childhood and adolescence (Bechara et al. 1999; Crone and van der Molen 2004).

The second component of our model posits that the ANS is associated with ADHD and ODD symptoms. The ANS controls basic visceral functions of the body (e.g., cardiovascular activity, metabolism) and is composed of the parasympathetic (PNS) and sympathetic (SNS) nervous systems. Generally speaking, the SNS regulates involuntary reactions to stress (e.g., increased heart and breathing rates) and prepares the body for action in the context of stressors, whereas the PNS promotes growth and restorative processes. Sympathetic activation is indexed by pre-ejection period (PEP), and shorter PEPs are associated with sympathetic activation. Parasympathetic cardiac influences are indexed by respiratory sinus arrhythmia (RSA), or the waxing and waning of heart rate across the respiratory cycle (Porges 1995). RSA typically is used as an estimate of vagal tone because it is a proxy for regulatory processes that cannot readily be measured non-invasively. In terms of the relation between RSA and vagal tone, RSA results from *decreases* in vagal efference during inhalation, which increase heart rate, and *increases* in vagal efference during exhalation, which decrease heart rate (Beauchaine 2001).

Externalizing behaviors are related to decreased SNS and PNS activity (e.g., Beauchaine et al. 2007; Calkins and Dedmon 2000; Pine et al. 1998), though associations differ depending on the type of externalizing behaviors and age period considered. For instance, preschool children with ADHD and ODD exhibit attenuated SNS, but not PNS activity (Beauchaine et al. 2007; Crowell et al. 2006). In middle childhood and adolescence, ODD and CD are associated with attenuated SNS and PNS activity (Beauchaine et al. 2001, 2007), which suggests that PNS activity may come “online” during middle childhood and SNS deficiencies may emerge before reductions in PNS activity. The relation between attenuated PNS activity and externalizing problems that has been reported among middle class children and adolescents (e.g., Beauchaine et al. 2007) also has been demonstrated among urban boys at risk for delinquency; moreover, this relation remained significant even after controlling for age, ethnicity, and socioeconomic status (SES; Pine et al. 1998). The similarities among these findings suggest that the relations between ANS activity and externalizing symptoms may generalize to different SES groups.

The third component of the model suggests a link between ANS functioning and affective decision-making. One specific model that describes the relations among autonomic arousal and affective decision-making is the somatic marker hypothesis, which was developed to account for findings of impaired decision-making in individuals with OFC (and specifically, ventromedial prefrontal cortical; VMPC) lesions (Damasio 1994; Damasio et al. 1996). According to Damasio and colleagues, decision making requires accessing and relying on emotions, which are associated with changes in bodily states (i.e., somatic markers). The amygdala triggers somatic markers (physiological arousal) when an individual is presented with emotional stimuli, whereas the VMPC triggers somatic markers when an individual recalls a memory associated with a specific emotion (Bechara and Bar-On 2006). For instance, the first time that a child is faced with punishment (e.g., the child misses part of recess for interrupting the teacher), the amygdala would trigger somatic states associated with the feelings of fear and/or sadness. If a child subsequently encounters a situation in which he or she was previously punished (e.g., the child is considering interrupting the teacher), the VMPC would be responsible for connecting the memory of the previous situation to a physiological representation of the emotion associated with the punishment (e.g., sadness, fear). Thus, the amygdala induces emotion in an automatic way, whereas the VMPC induces emotion by coupling memories with physiological representations of what it “felt like” to be in a given situation (Bechara and Bar-On 2006). Therefore, dysfunction in terms of the ANS, amygdala, or OFC could result in externalizing symptoms.

In sum, there is evidence for each of the three components of the proposed model, including links among (1) affective decision-making (dependent on the OFC, amygdala, and other brain areas) with ADHD and ODD symptoms, (2) ANS functioning with ADHD and ODD symptoms, and (3) ANS functioning with affective decision-making. Based on this model, we expected that impaired affective decision-making would be associated with a child’s ability to generate physiological representations of emotion, as measured by ANS activation. Attenuated autonomic arousal during affective situations would limit a child’s ability to learn from punishment and to develop physiological “memories” that could help to navigate complex social situations while controlling impulses and refraining from aggression. Furthermore, we expected that impaired affective decision-making would be related to the behavioral manifestations of ADHD and ODD symptoms, and attenuated ANS activation would mediate this relation.

We also examined whether these processes differed based on child sex. The little research that has examined sex differences in autonomic activity among children is inconsistent. Calkins and Dedmon (2000) demonstrated that boys have lower resting heart rates than girls; however, Alkon et al. (2003) found no significant sex differences with regard to heart rate, RSA, or PEP during a series of challenging tasks. Previous research examining sex differences in affective decision-making in preschool-age children also has found no significant sex differences (Kerr and Zelazo 2004; Overman 2004), though males perform more favorably in affective decision-making tasks than females in adolescence (Overman 2004). To date, sex differences in ANS and affective decision-making in middle childhood have not been examined. Although there are no a priori reasons to expect physiological differences in pre-pubertal children, boys exhibit higher levels of ADHD and ODD symptoms in childhood (APA 2000; Gaub and Carlson 1997), suggesting that there may be some sex differences related to the processes (e.g., ANS functioning) that confer risk for ADHD and ODD (e.g., different prevalence rates, sensitivity to, or prediction from these processes to externalizing symptoms).

There is also a limited body of work examining relations among ANS, affective decision-making, and ADHD and ODD symptoms among impoverished samples. This is unfortunate given that poverty is associated with detrimental effects on IQ, cognitive development, and child psychological adjustment, and these effects are likely exacerbated for children who live in impoverished neighborhoods (Attar et al. 1994; McLoyd 1998). Children residing in disadvantaged neighborhoods are more likely to be exposed to physical and psychosocial stressors, witness violence, and experience maltreatment (Attar et al. 1994; Evans and English 2002; McLoyd 1998; Wandersman and Nation 1998). Moreover, these neighborhoods are often characterized by high levels of crime, residential mobility, environmental stressors (e.g., noise, overcrowding), and delinquent peer groups; poor social cohesion; and low quality schools (Leventhal and Brooks-Gunn 2004; Sampson 1997; Wandersman and Nation 1998), each of which has been linked to physical and psychological adjustment, including psychophysiological factors (Evans and English 2002; Kliewer et al. 2002; Wilson et al. 2000). Children of ethnic minority descent are disproportionately affected by these issues given that ethnic minority (especially African-American) children are particularly likely to reside in impoverished, segregated neighborhoods in urban areas (Leventhal and Brooks-Gunn 2004). One of our goals in the present study was to identify physiological processes associated with ADHD and ODD symptoms that may be malleable in childhood. Given the adverse impact of living in an impoverished and segregated neighborhood, testing the relations among these processes and psychological symptoms among children residing in an inner-city environment could be particularly fruitful for informing early intervention and prevention efforts among children at higher risk for poor outcomes based on these contextual factors.

In the present study, we sought to address these gaps in the literature by evaluating the relations among affective decision-making, SNS and PNS activity, and ADHD and ODD symptoms in a predominantly impoverished sample of children residing in the inner city. We chose to examine these relations among young children as our goal was to identify factors that are associated with and may exacerbate externalizing problems at a point when these processes may be malleable to intervention and prior to the development of additional negative sequelae. In terms of developmental processes, childhood is an important period for the development of connections between the amygdala and OFC and myelination of the prefrontal cortex (Derryberry and Rothbart 1997; Raine 2002), and likely represents the time period during which the relation between PNS attenuation and externalizing problems occurs (Beauchaine et al. 2007). Moreover, given that puberty onset occurs ever earlier and is accompanied by a host of biological, hormonal, and brain changes (Susman and Rogol 2004), we included children in first through third grade in an effort to limit puberty-related maturation.

We hypothesized that impaired affective decision-making and decreased sympathetic and parasympathetic activation would be associated with higher levels of ADHD and ODD symptoms in this school-aged sample. We hypothesized that ADHD-H, in particular, would be associated with affective decision-making, as opposed to ADHD-I symptoms, given that social impairment co-occurs with ADHD-H (Gadow et al. 2004), and results, in part, from impaired affective decision-making (Bechara and Bar-On 2006). We also hypothesized that low sympathetic and low parasympathetic activation during an emotion-inducing task would mediate the relation between affective decision-making and child symptoms. In terms of sex differences, we hypothesized that boys would be rated as exhibiting higher levels of ADHD and ODD symptoms than girls, but would not differ in terms of affective decision-making. Given inconsistencies in the literature, no hypotheses were made for sex differences in sympathetic and parasympathetic activity.

Method

Participants

Participants were 63 children (*M*=7.79±1.08 years old; 54% male, 95% African-American, 5% Latino/a; 38% first grade (58% male), 35% second grade (50% male), 25% third grade (50% male)) and their primary caregivers (86% biological mothers) drawn from three elementary schools in North Philadelphia. The neighborhoods from which families were drawn can be characterized as an inner city area, with high levels of crime, poverty, and homogeneity in terms of ethnic minority status. In terms of family configurations, 47.6% of children lived in single-parent households, 31.7% lived in intact (i.e., two-biological parent) households, 9.5% lived in blended homes, and 8% lived in other family configurations (grandparental, adoptive). In terms of annual family income, 62% of families earned less than $20,000, 21% earned from $20,000–$30,000, and 17% earned over $30,000. Sixty-nine percent of the children lived in families receiving public assistance. Fifty-one percent of the primary caregivers had completed high school, 31% less than high school, and 19% beyond high school. Thus, families were predominantly impoverished and resided in impoverished neighborhoods as well.

Procedure

The study was approved by a University Institutional Review Board. After obtaining permission to recruit families from the school principals, a description of the study and consent form were sent to primary caregivers (hereafter "parents") of all first- through third-grade children in three local elementary schools. The study description stated that we were interested in understanding children's social, physical, and emotional adjustment, as well as what might place children at risk for emotional or behavioral problems. Interested families either returned a self-addressed stamped postcard or called to make an appointment. Approximately 21% of families responded to the information sent, which is consistent with other research using high-risk samples with similar ethnic and SES compositions (e.g., Sessa et al. 2001; Silk et al. 2004). The sample characteristics (i.e., ethnicity, sex, family SES) reflect the schools from which the families were drawn; nevertheless, due to confidentiality requirements, no information was available to compare those who self-selected into the project and those that did not. Parents and their children were invited to our research lab for two visits, each lasting approximately 2.5 h. Parents and children provided consent and assent, respectively, prior to participation. After consenting to participate, parents were asked to complete several questionnaires related to the child, their families, and themselves. While parents were completing questionnaires, children participated in a variety of activities designed to measure autonomic activity and affective decision-making. Parents were paid for their participation and reimbursed for transportation and children received a small gift. A donation was made to the school for each family that participated.

Measures

ADHD and ODD Symptoms—Parents rated child ADHD and ODD symptoms using the Child Symptom Inventory-4 (CSI-4; Gadow and Sprafkin 1994, 2002), which contains the behavioral symptoms of most childhood disorders described in the *Diagnostic and Statistical Manual of Mental Disorders-Fourth edition* (*DSM-IV*; APA 1994). Individual items bear one-to-one correspondence with *DSM-IV* symptoms (i.e., high content validity). Because the goal of the present study was to examine processes associated with ADHD and ODD symptoms, as opposed to the diagnostic categories, we examined these symptoms dimensionally. Items were scored on a scale from 0 (*never*) to 3 (*very often*). Responses to individual items were summed to create a Symptom Severity score for three symptom categories: ADHD-Predominantly Inattentive subtype (ADHD-I; nine items, α=0.91); ADHD-Predominantly Hyperactive-Impulsive subtype (ADHD-H; nine items, α=0.94); and ODD (eight items, α=0.92).

Compared to scores derived from the community-based samples used to norm the CSI-4 (Gadow and Sprafkin 2002), the present sample of inner-city children was consistently rated as exhibiting higher levels of ADHD and ODD symptoms. Specifically, boys in the current versus normative sample, respectively, were elevated on ADHD-I (10.7 vs. 6.7), ADHD-H (9.7 vs. 5.3), and ODD (6.3 vs. 5.4). Similarly, girls in the current versus normative sample, respectively, were elevated on ADHD-I (5.9 vs. 4.8), ADHD-H (7.0 vs. 4.0), and ODD (5.5 vs. 4.4). An ancillary way to facilitate comparisons between the present sample and other samples is to use the CSI-4 to derive Symptom Count (categorical) scores, 0=*never/sometimes*, 1=*often/very often*. For Symptom Count scores, a specific symptom is considered to be a clinically relevant problem if it is rated as occurring "often" or "very often." When the total Symptom Count score equals or exceeds the number of symptoms specified by *DSM-IV* as necessary for a diagnosis, the child receives a Screening Cutoff score of "yes." The number of children who received Screening Cutoff scores for ADHD-I ($\geq$6 symptoms), ADHD-H ($\geq$6 symptoms), and ODD ($\geq$4 symptoms) compared to the total number of children (n=63) was ADHD-I (n=7, 11%); ADHD-H (n=13, 21%); and ODD (n=9, 14%).

Autonomic Activity—Autonomic arousal was assessed with Bio-Impedance Technology's HIC-2000 (Chapel Hill, NC, n.d.), a noninvasive instrument for detecting and monitoring bioelectric impedance signals. An external electrocardiographic (ECG) cable was added to the HIC-2000 to increase the flexibility for electrode positioning and ease of detecting the ECG signal. The HIC-2000 recorded RSA and PEP with a constant 5 V potential across seven electrodes that were pre-gelled and have a circular contact area with a 1 cm diameter. Disposable spot electrodes were attached to the child's neck, back, stomach, and shoulder (Qu et al. 1986). Cardiac signals were monitored by and interfaced to a PC-based computer.

Both RSA and PEP were measured during tasks chosen to provide a range of stressors (i.e., social, cognitive, physical, and emotional; Alkon et al. 2003). The protocol has been shown to be a reliable and valid method for examining sympathetic and parasympathetic responses to challenge during middle childhood and in children from 3 to 8 years of age (Alkon et al. 2003). The tasks were presented in the same order for each child and took approximately 20 min to administer. The social challenge was designed to engage the child in conversation and included questions about school, family, and interests. In the cognitive challenge, the child repeated a list of two to six numbers presented orally by the experimenter. In the physical challenge, the child was asked to taste and identify several drops of lemon juice that were placed on his or her tongue by the experimenter. The emotional challenge consisted of two brief video clips designed to evoke fear and sadness. Age-appropriate books were read to the child before and after the challenge tasks to obtain baseline measures of resting autonomic activity. For all of the tasks, the child's behavior and physiological reactions (i.e., heart rate, RSA, and PEP) were monitored.

Sympathetic-linked cardiac activity was indexed by PEP, measured as the time between the ECG Q wave (onset of ventricular depolarization) and the impedance cardiographic B wave (onset of left ventricular ejection). Waveforms were collected using the spot electrode configuration described above (Qu et al. 1986). PEP data were ensemble-averaged in Cop-

Win 6.0 H software, in 30 s epochs. Parasympathetic cardiac activity was assessed using spectral analysis via Nevrokard's Long-Term Heart Rate Variability (LT-HRV) software (Ljubljana, Slovenia, n.d.), which separates heart rate variability time series into component frequencies using fast-Fourier transformations (Berntson et al. 1997). High frequency spectral power (>0.15 Hz) was extracted to measure RSA. This high frequency band is believed to better index cardiac vagal control than low frequency (<0.04 Hz) or midfrequency (0.04–0.15 Hz) variability (Houtveen and Molenaar 2001; Mezzacappa et al. 1994). Spectral densities were calculated in 30 s epochs. The log of RSA was used to index parasympathetic functioning, which is a common transformation used to normalize spectral analytic data (Crowell et al. 2006).

Mean scores for PEP and RSA were calculated for baseline (pre- and post-challenge listening to books), across each of the four tasks (social, cognitive, physical, emotional), and individually for the emotional task (see Alkon et al. 2003). We examined the emotional task separately because we hypothesized that arousal during this task could be a proxy for arousal during affectively charged situations, and thus would increase the external validity of the findings. Participants were included in the analyses if they had at least 50% scorable epochs within each task and during baseline. This decision was made to maximize the number of participants included while maintaining an adequate number of epochs. A difference score between the mean task and mean baseline scores for both RSA and PEP was used to measure parasympathetic and sympathetic activation, respectively. Individual variables (and *ns* for complete data) included RSA at baseline (n=40), RSA during the tasks (averaged across all four challenges; n=42), RSA emotional task (n=44), RSA change (difference between mean task and mean baseline; n=39), PEP at baseline (n= 47), PEP during the tasks (averaged across all four tasks; n= 50), PEP emotional task (n=48), and PEP change (difference between mean task and mean baseline; n=47).

Affective Decision-Making—We used a developmentally appropriate analogue of the Iowa gambling task to assess affective decision-making, which has been shown to be sensitive to individual differences in children as young as 3-to 4-years-old (Kerr and Zelazo 2004). Instead of using monetary gains and losses as in the adult version of the gambling task (Bechara et al. 1994), children played for candies (i.e., mini M&Ms). Children played with two decks of cards (50 cards each) that displayed happy and sad faces, which corresponded to rewards (candies) won and lost, respectively. Cards in one deck offered more rewards per trial, but were disadvantageous across trials due to occasional large losses. Cards in the other deck offered fewer rewards per trial but losses were minimal, and thus were advantageous over time. In both decks, the number of gains was constant but the number of losses varied across trials (see Kerr and Zelazo 2004). Children selected 50 cards. For scoring purposes, trials were divided into five blocks of ten trials each (Kerr and Zelazo 2004). Difference scores were calculated for each block (i.e., the proportion of advantageous choices minus the proportion of disadvantageous choices per block) and ranged from −1 to 1. Difference scores for the first and last blocks and the mean of the difference scores across blocks were examined. The first block was included to obtain a baseline measure of individual differences in affective decision-making, and the last block to obtain a measure of learning. No a priori hypotheses were made regarding blocks 2, 3, or 4, and given power issues, these blocks were not examined individually.

Statistical Analyses

To examine sex differences, independent sample *t*-tests were conducted for each variable. To test our a priori conceptual model, we conducted separate multiple regression analyses for boys and girls. Tests of mediation were conducted using the ordinary least squares regression procedure suggested by Baron and Kenny (1986) and a bootstrap procedure

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(Shrout and Bolger 2002). Given that we expected the emotional challenge to be a proxy for "real" affectively driven situations, mediation analyses examined whether RSA and PEP measured during the emotional task accounted for the relation between affective decision-making and ADHD and ODD symptoms. For these analyses, affective decision-making was entered into two equations, predicting (1) the outcome variable (e.g., ADHD-H symptoms) and (2) the hypothesized mediating variable (e.g., PEP emotional task). Next, the mediating variable (e.g., PEP emotional task) was entered simultaneously with affective decision-making to examine whether the mediator accounted for the relation between affective decision-making and the outcome variable (e.g., ADHD-H symptoms). If the mediator was significant and affective decision-making was non-significant when entered simultaneously, this finding would suggest that the purported mediator was the mechanism through which affective decision-making was related to externalizing symptoms (Baron and Kenny 1986). The present study also used the bootstrap procedure described by Shrout and Bolger in AMOS 4.01 (Arbuckle 1999) to determine the significance of the indirect effects and whether the direct effect was equivalent to zero, after controlling for the proposed mediator. Bootstrap procedures have been used to develop more accurate estimates of the indirect and direct effects when testing mediation, and may be more powerful when using smaller sample sizes (Shrout and Bolger 2002). Last, we conducted supplementary analyses to examine whether our findings could be better accounted for by family income, child EF, or IQ.

Results

Bivariate correlations, means, and standard deviations are presented separately for boys and girls in Table 1. Although the bivariate correlations are intended to provide an overview of the relations among study variables, these correlations were not interpreted as part of the study's primary hypotheses. Nevertheless, to minimize issues associated with Type I error, we used a more conservative p value of 0.01 to mark significant correlations in Table 1. Independent sample t-tests indicated few significant sex differences, with two exceptions. Girls had higher RSA baseline than boys, $t(38)= 2.07$, $p<0.05$, Cohen's $d=0.67$; and boys were rated as exhibiting higher levels of ADHD-I symptoms than girls, $t\,(57)=3.56$, $p<0.05$, Cohen's $d=0.94$. However, many effect sizes (Cohen's d) fell in the suggested low (0.2) to medium (0.5) effect size range (Cohen 1988), suggesting that these group differences may have reached significance with a larger sample. In particular, effect sizes for ADHD-H symptoms ($d=0.36$; boys>girls) and RSA change from baseline to task ($d=0.33$; boys>girls) approached the suggested medium range. Thus, as predicted, boys tended to exhibit higher levels of ADHD symptoms than girls, though the findings did not attain significance. In addition, consistent with preschool-age samples, we found no sex differences for affective decision-making.

Multiple regression analyses examining the relations among ANS activity during the emotional task, ADHD and ODD symptoms, and affective decision-making revealed several significant findings. Specifically, multiple regression analyses testing mediation (see Table 2) indicated that among boys, the proportion of advantageous choices predicted sympathetic arousal during the emotional task (regression 1: $\beta=-0.42$, $p<0.05$). Consistent with our hypothesis, the proportion of advantageous choices predicted ADHD-H symptoms (regression 2: $\beta=-0.38$, $p<0.05$). In addition, sympathetic arousal during the emotional task predicted ADHD-H symptoms when entered simultaneously with the proportion of advantageous choices (regression 3: $\beta=0.49$, $p<0.05$), and the relation between the proportion of advantageous choices and ADHD-H symptoms became non-significant when sympathetic functioning during the emotional task was entered into the equation (regression 3: $\beta=0.02$, $p>0.05$). Mediation analyses examining ODD symptoms and those including girls were not significant.

Results from the bootstrap samples (Shrout and Bolger 2002) indicated that choosing disadvantageously was related to decreased sympathetic arousal during the emotional task, indirect effect=−0.44, $p<0.05$, 95% CI (−0.72, −0.07). Decreased sympathetic arousal during the emotional task was related to increased ADHD-H symptoms, indirect effect=0.48, $p<0.01$, 95% CI (0.16, 0.94). Last, the proportion of disadvantageous choices was unrelated to ADHD-H symptoms after controlling for sympathetic arousal, direct effect=0.02, $p>0.05$, 95% CI (−0.49, 0.36). These results indicate that sympathetic arousal mediated the relation between disadvantageous choices and ADHD-H symptoms; however, given the wide range of values provided by the CIs, it is unclear whether the mediation was partial or full. Mediation analyses for girls were not significant.

Supplementary tests indicate that the findings of the present study are not better accounted for by child age, EF, IQ, or by family income. Specifically, age was not significantly correlated with any indices of ANS activity among boys or girls (absolute values of *r*s ranged from 0.01 to 0.35, all *p*s>0.05) or affective decision-making (*r*s= −0.22 and −0.08 among boys and girls, respectively). Furthermore, among boys and girls, respectively, affective decision-making was not significantly correlated with EF, which was assessed by the number of problems solved using the minimum number of moves on the Stockings of Cambridge task (from the Cambridge Neuropsychological Test Automated Battery; Luciana and Nelson 2002; *r*s= 0.19 and 0.08); IQ (assessed by the Wechsler Abbreviated Scale of Intelligence; Wechsler 1999; *r*s=−0.09 and 0.25); or household income (*r*s=−0.13 and −0.01). Controlling for IQ and household income did not change the above mentioned findings.

Discussion

The present study hypothesized that impaired affective decision-making and decreased sympathetic and parasympathetic activation would be associated with higher levels of ADHD and ODD symptoms, and that low sympathetic and parasympathetic activation during an emotion-inducing task would mediate the relation between affective decision-making and child externalizing symptoms. In addition, we hypothesized that impaired affective decision-making would be associated with ADHD-H symptoms. Last, we hypothesized that boys and girls would not differ in their performance on the affective decision-making task, but boys would be rated as exhibiting higher levels of ADHD and ODD symptoms than girls. The proposed conceptual model, which extended the work of Blair and colleagues (Blair 2005; Fisher and Blair 1998), received preliminary support among boys, but not girls. Among boys, attenuated sympathetic activation and disadvantageous decision-making were related to increased ADHD-H symptoms. Furthermore, decreased sympathetic activation during exposure to emotion-inducing stimuli mediated the relation between affective decision-making and ADHD-H symptoms. The relations between impaired affective-decision making and ADHD-H, but not ADHD-I, symptoms, provide further support for continued differentiation among ADHD subtypes (Eiraldi et al. 1997; Gadow et al. 2000, 2004; Gaub and Carlson 1997). Moreover, the associations among attenuated sympathetic activation during exposure to emotion-inducing videos, disadvantageous decision-making, and ADHD-H symptoms among boys suggest that boys who are unable to generate somatic markers related to fear and sadness may be more impulsive, perhaps because they lack the physiological representations of emotions (provided by the OFC and amygdala) that are important for guiding and learning socially appropriate behavior. Our results did not support the hypothesis that parasympathetic arousal would be related to ADHD and ODD symptoms or mediate the relation between affective decision-making and externalizing symptoms. It is possible that the children in the present study had not yet evidenced the relation between attenuated parasympathetic activity and externalizing behaviors that appears to come “online” in middle childhood (Beauchaine et al. 2007).

Consistent with hypotheses and previous research (Kerr and Zelazo 2004), boys and girls in middle childhood did not differ in terms of their affective decision-making. However, given that sex differences in affective decision-making likely emerge in adolescence (Overman 2004), future research examining sex differences in affective decision-making should take age and developmental period into account. Boys exhibited higher ADHD-I symptoms than girls, as expected, but contrary to prediction and previous research (APA 2000; Gaub and Carlson 1997), boys did not exhibit higher levels of ADHD-H and ODD symptoms than girls. However, further analysis indicated that the effect size of ADHD-H symptoms approached the suggested medium range, which suggests that with a larger sample size this sex difference may have been significant. The reason for a lack of sex differences in ODD symptoms is unclear and may stem from the self-selected nature of this sample. Although boys and girls in this inner-city sample evidenced higher levels of ODD symptoms than a normative sample, compared to their peers, participating boys may have exhibited lower levels of ODD symptoms and/or participating girls may have exhibited higher levels of ODD symptoms than their peers. Future research among inner-city and more heterogeneous samples will be necessary to test these possibilities.

Importantly, our results do not appear to be explained by differences in age, EF, IQ, or SES. The lack of association with age supports previous work demonstrating that abilities dependent on the OFC and amygdala are distinct from the child’s cognitive and problem-solving abilities (Eslinger et al. 2004). The lack of association between EF and affective decision-making further supports the distinction between cold and hot cognition (Kerr and Zelazo 2004) and suggests that these abilities may rely on different areas of the prefrontal cortex. Last, given that controlling for IQ and family income did not change the findings, the child’s ability to understand the tasks and family SES likely did not unduly influence the results.

The strengths of the study include the examination of affective decision-making and sex differences in relation to ANS activity and externalizing behaviors, and an evaluation of the generalizability of findings involving autonomic correlates of ADHD and ODD symptoms to impoverished, inner-city children, which can inform intervention efforts aimed at potentially malleable risk factors (Crowell et al. 2006; Raine et al. 2001). For instance, it is likely that the alteration of one’s environment (e.g., contextual disadvantage, parental stress, marital conflict) can shape and modulate psychophysiological processes and subsequent behavior problems. Indeed, Raine et al. (2001) found that children enrolled in enriched preschool environments with an intervention component when 3- to 4-years-old exhibited enhanced psychophysiological arousal at 11 years of age. This finding suggests that some autonomic markers may be malleable in young children and that further examination of environmental influences that have long-term effects on the ANS is warranted.

The inclusion of affective decision-making is particularly important given the associations among disadvantageous choices, attenuated ANS activation, and impulsive/aggressive behavior seen in adults that to date have remained untested among children exhibiting ADHD and ODD symptoms (Anderson et al. 1999). Tying affective decision-making to ANS activity can further theories of the development of externalizing behaviors by providing specific hypotheses regarding the brain mechanisms (e.g., OFC and amygdala) that underlie various developmentally relevant manifestations of externalizing behaviors, including not only ADHD and ODD, but also CD, aggression, and psychopathy (Blair 2007). However, to develop ecologically valid biological models of externalizing behaviors, it is essential to examine children of varying ages, ethnicities, and SES. It also may be beneficial to examine separate models for boys and girls, as research indicates important sex differences with regard to prevalence of and risk factors related to externalizing behaviors (Drabick et al. 2006; Gaub and Carlson 1997). Last, the use of objective indicators of autonomic activity and affective decision-making minimizes concerns related to mono-rater and mono-method biases.

Despite these strengths, the present study has several limitations. First, the study was cross-sectional. It is not clear whether the various patterns of autonomic and affective decision-making were mechanisms, risk factors, correlates, or sequelae of externalizing problems. Indeed, it is likely that the influence among these factors is bidirectional and transactional, given evidence of the malleability of ANS processes and the anatomical connections among the amygdala, OFC, and ANS (Bechara et al. 1999; Raine et al. 2001). Prospective research is necessary to tease apart these alternative explanations. In addition, factors that may alter autonomic activity should be included in future research (e.g., parent–child interactions, neighborhood), which could facilitate identification of at-risk children and suggest vehicles for intervention (Beauchaine 2001). Externalizing symptoms were defined using a rating scale, not a diagnostic interview; thus, the *DSM-IV* symptoms examined were not equivalent to the diagnostic categories of ADHD and ODD. This study provides a first step to linking these processes to ADHD and ODD, and future research can determine whether these patterns of physiological functioning map onto these diagnostic categories. Nevertheless, in the case of ADHD, structured interviews do not increase the validity of ADHD diagnoses over and above what can be obtained with a psychometrically validated ADHD-rating scale (Pelham et al. 2005) and the *DSM*-referenced rating scale used in this study has been included in numerous studies of ODD (e.g., Drabick et al. 2004, 2007). The relatively small sample size suggests that we may have been underpowered to detect effects, particularly in the mediation analyses.

Although the merits of examining these processes in an inner city sample are notable, the sampling method (i.e., self-selection) introduces the possibility of sampling biases. For example, the method of self selection may have biased our sample to higher functioning families (e.g., families that were able to organize transportation and child care, experienced lower levels of stress or parental psychological difficulties, etc.). Therefore, we might expect that the children in our sample meet developmentally appropriate milestones and have lower levels of psychological symptoms than their peers living in similar contextual disadvantage. Nevertheless, compared to normative samples, the children in the present investigation exhibited higher mean levels of ADHD and ODD symptoms. Thus, future work must examine the generalizability of our findings. If the results generalize to varying SES and ethnic groups, this would suggest that the findings of the present study are generally characteristic of children with ADHD and ODD symptoms (also see Crowell et al. 2006). If the findings do not generalize, these results may suggest that contextual factors (e.g., poverty, neighborhood characteristics) may exert an important influence on ANS functioning and affective decision-making (Evans and English 2002). If the latter account received more support, future research could identify distinct subgroups of children with varying biological markers at a young age. These children could be prospectively followed to evaluate what environmental factors serve to increase risk or protection of children from later externalizing problems and whether there are sensitive periods in the development of pathological traits (Beauchaine 2003). Furthermore, this knowledge could contribute to information regarding the mechanisms underlying child × context interactions.

In sum, the inclusion of affective decision-making and autonomic activity contributes to conceptualizations of the maintenance and exacerbation of ADHD and ODD symptoms. In particular, affective decision-making and sympathetic activation in emotion-inducing circumstances likely contribute to ADHD-H symptoms among boys in high-risk, impoverished environments. Given that our model was not supported among girls, sex differences also should be examined in research evaluating biological models of affective decision-making, ADHD, and ODD symptoms. Future research examining ANS and specific brain processes (e.g., OFC and amygdala functioning) related to different externalizing behaviors can speak to whether these processes confer risk across time and thereby represent a common underlying pathology or if certain processes are specific to particular outcomes (e.g., impulsivity vs. oppositionality). Such knowledge can inform etiological models and early intervention efforts for ADHD and ODD, and thus potentially limit the exacerbation of ADHD and ODD symptoms and the negative sequelae associated with these conditions.

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Table 1

Bivariate correlations, means, and standard deviation for study variables among boys and girls

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
RSA Baseline	–	0.49	−0.64*	−0.02	−0.15	−0.19	−0.26	−0.24	0.08	0.09	0.03	0.25	0.13	0.11
RSA Task	−0.04	–	0.37	0.51	−0.00	0.02	0.08	−0.06	−0.28	0.03	−0.39	0.14	0.00	−0.12
RSA Change	−0.78*	0.66*	–	0.40	0.19	0.26	0.40	0.24	−0.35	−0.06	−0.41	−0.19	−0.18	−0.22
RSA Emotional Task	0.14	0.37	0.13	–	0.05	0.04	−0.04	−0.08	−0.03	−0.17	−0.16	−0.04	0.01	0.01
PEP Baseline	−0.07	−0.04	0.06	0.32	–	0.98*	0.67*	0.97*	−0.11	0.16	−0.21	0.41	0.31	0.20
PEP Task	−0.05	−0.04	0.02	0.34	0.98*	–	0.78*	0.98*	−0.18	0.12	−0.27	0.34	0.23	0.15
PEP Change	0.13	0.01	−0.18	0.13	−0.11	0.08	–	0.69*	−0.37	−0.03	−0.43	0.01	−0.09	−0.07
PEP Emotional Task	0.01	0.06	0.05	0.33	0.98*	0.98*	0.04	–	−0.14	0.08	−0.16	0.39	0.31	0.21
Mean of Blocks	−0.40	0.37	0.52	0.12	−0.10	−0.16	−0.28	−0.23	–	0.54*	0.93*	−0.05	0.23	0.33
Difference score for block 1	−0.52	0.25	0.60*	0.22	0.03	−0.05	−0.23	−0.08	0.37	–	0.34	0.16	0.25	−0.04
Difference score for block 5	−0.16	0.13	0.16	−0.02	−0.32	−0.32	−0.15	−0.42	0.87*	0.10	–	−0.19	0.13	0.31
ADHD–I (CSI) Symptoms	−0.11	−0.12	0.11	0.32	0.41	0.28	−0.45	−0.42	−0.16	0.25	−0.31	–	0.82*	0.51*
ADHD–H (CSI) Symptoms	−0.03	0.07	0.12	0.25	0.42	0.35	−0.16	−0.47	−0.35	−0.02	−0.38	0.81*	–	0.76*
ODD (CSI) Symptoms	−0.02	−0.12	−0.01	−0.15	0.29	0.19	−0.31	0.22	−0.15	−0.04	−0.14	0.55*	0.59*	–
Boys: *M*	3.86 [a]	4.33	0.43	3.71	99.25	101.13	1.44	101.24	0.31	−0.04	0.50	10.70 [b]	9.65	6.34
SD	0.65	0.53	0.84	0.80	13.90	13.30	2.67	13.80	0.37	0.36	0.59	5.60	7.35	4.60
Girls: *M*	4.25 [a]	4.50	0.20	3.89	97.88	97.92	0.04	96.78	0.22	−0.11	0.43	5.93 [b]	7.07	5.48
SD	0.56	0.45	0.52	0.66	8.87	10.70	2.50	10.31	0.50	0.54	0.64	4.58	7.46	5.92

Correlations for boys are below the diagonal. Correlations for girls are in italics and above the diagonal.

RSA Respiratory sinus arrhythmia, *PEP* pre-ejection period, *Task* mean across all four challenges, *Change* change from baseline to task, *Mean of Blocks* mean of difference scores across decision-making blocks, *CSI* Child Symptom Inventory-4

* $p<0.01$

[a] Girls>boys ($p<0.05$)

[b] Boys>girls ($p<0.05$)

Table 2

Multiple regression analysis summary for sympathetic arousal during the emotional task, decision making, and ADHD-H symptoms among boys

Step and variable	*B*	*SE B*	β	R^2	ΔR^2
Regression 1: Outcome=PEP emotional task				0.17*	0.17*
Affective decision-making	−11.65	5.40	−0.42*		
Regression 2: Outcome=ADHD-H symptoms				0.14*	0.14*
Affective decision-making	−4.85	2.34	−0.38*		
Regression 3: Outcome=ADHD-H symptoms				0.23**	0.23**
PEP emotional task	0.24	0.11	0.49*		
Affective decision-making	0.22	3.04	0.02		

PEP Emotional Task pre-ejection period during the emotional task, *ADHD-H* attention-deficit/hyperactivity disorder—predominantly hyperactive-impulsive subtype

* $p<0.05$,

** $p<0.10$