TEMPERAMENT, EXECUTIVE CONTROL, AND ADHD ACROSS DEVELOPMENT

by

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ABSTRACT

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Research examining neuropsychological factors that influence the links between early "difficult" temperaments and later ADHD is limited by a cross-sectional approach and the use of the same informant to assess temperament and psychopathology. In addition, the exact nature of the relationship between temperament, neuropsychological functioning, and ADHD is not clear. This study utilized longitudinal data and objective neuropsychological measures to examine the relationship between temperament, executive control, and ADHD. It was hypothesized that high levels of negative emotionality during the preschool years would be associated with greater ADHD symptom severity in later childhood. However, developing executive control, as measured by tests of working memory and response inhibition, would mediate the relationship between early temperament and later ADHD symptom severity.

Children with and without ADHD were evaluated at three time-points: Parent and teacher ratings of temperament were obtained at ages 3-4, WISC-IV Working Memory Index (WMI) and NEPSY Response Set at age 6, and ADHD symptoms assessed by the Kiddie-SADS at age 7. Pearson correlations examined the relations among parent and teacher ratings of negative emotionality, WMI/Response Set, and ADHD symptom severity at age 7 years. Hierarchical linear regression analyses then examined whether working memory and/or response set mediated the relationship

between early temperament and later ADHD symptoms. Nonparametric bootstrapping procedures were utilized to assess the significance of the mediating effects.

All measures were significantly inter-correlated (all $p<.05$), with the exception of teacher rated negative emotionality and response set. Negative emotionality as rated by parents and teachers significantly predicted ADHD symptoms. Regression coefficients between negative emotionality (parent and teacher) and ADHD severity decreased substantially when controlling for WMI. Similarly, regression coefficients between parent-rated negative emotionality and ADHD severity decreased substantially when controlling for response set.

These findings indicate that early negative emotionality predicts later ADHD severity while development of executive control, as assessed using measures of verbal working memory and response inhibition, mediates this relationship, suggesting that negative emotionality exerts its influence on ADHD severity through its impact on the development of executive control. These findings help support theories that posit that ADHD results from early "bottom-up" dysfunction while persistence of ADHD symptoms reflects poor development of "top-down" control. Early preventative interventions focused on mitigating the harmful influences of negative emotionality or enhancing executive control may help diminish later ADHD severity.

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Introduction

Specific Aims

Individual differences in behavioral functioning are mediated by a number of brain systems and psychological processes. These systems and processes have been conceptualized as being composed of both "bottom-up," automatically-generated emotional reactions, as well as "top-down" effortful self-regulatory processes (Casey, 2005; Eisenberg, Fabes, Guthrie, & Reiser, 2000; Martel, Nigg, Von Eye, 2009). Together these help determine individual outcomes. Recently, much research has focused on the manner in which reactive and effortful systems work independently and together to influence development of psychopathology (Nigg, 2000).

Temperament is generally conceptualized as a biologically-based set of individual differences that appear early in life and remain relatively stable over the lifespan (Thomas & Chess, 1977). Most current theories posit that temperament consists not only of reactive traits, such as emotionality, approach and activity level, but also an active ability to self-regulate and inhibit dominant responses in service of more effective strategies (effortful control) (Rothbart & Bates, 1998). Although effortful control is considered under the rubric of temperament, this regulatory element is thought to emerge later in development than reactive traits; in the second half of the first year of life, and to continue developing throughout childhood and into adolescence (Rothbart, Ellis, Rueda, & Posner, 2003). Furthermore, within the context of normal development, effortful control is thought to increasingly modulate automatic reactive behaviors. The ability of effortful control to exert a regulatory effect on "bottom-up" reactive processes is thought

to be subserved by the anterior cingulate and its projections to the dorsolateral prefrontal cortex and limbic system structures. (Bush, Luu, & Posner, 2000).

Attention Deficit Hyperactivity Disorder (ADHD), a childhood psychiatric disorder characterized by developmentally inappropriate levels of inattention and hyperactivity (Barkley et al., 2002), is often thought of as trait-like in nature with associated functional impairment extending throughout the lifespan. Theoretical models of ADHD propose deficits in approach behaviors, such as response to reward (Sagvolden, Aase, Zeiner, & Berger, 1998), and cognitive and inhibitory control (Barkley, 1997), behaviors that seem to parallel the reactive and effortful control dimensions of temperament, respectively.

Associations between ADHD and temperament have been demonstrated in adult and adolescent samples (Braaten & Rosen, 1997; Nigg et al., 2002; Parker, Majeski, & Collin, 2004; Ranseen, Campbell, & Baer, 1998), and more recently have begun to be explored in children (Nigg et al., 2004). Studies have also examined the differential associations of temperamental constructs to symptoms of inattention and hyperactivity, with findings suggesting a relationship between reactive control and hyperactive-impulsive behaviors, and effortful control with inattention (Martel & Nigg, 2006; Martel, Nigg, & Von Eye, 2009). Furthermore, the nature of the relationship between temperament and ADHD is thought to evolve over the course of development (Martel, Nigg, & Von Eye, 2009).

Research has established a relatively clear pattern of association between high negative emotionality and low effortful control in connection with symptoms of ADHD (De Pauw and Mervielde, 2011). However, while there is evidence to suggest that

reactive and effortful domains work together to influence ADHD symptomatology, the extent to which negative emotionality and effortful control act independently or exert a collaborative influence on ADHD symptoms remains unclear.

Although effortful control is conceptualized as a developmental construct, and there is evidence to suggest that development plays a role in the nature of the relationship between reactive and effortful temperament traits and ADHD outcomes, the majority of research to date is limited by a cross-sectional approach to the study of temperament and ADHD. In addition, the majority of studies examining the relationship between temperament and psychopathology rely upon self or other report ratings of both temperament and ADHD. Not only does this methodology introduce questions of rater bias, but oftentimes there is significant overlap in items on these scales, calling into question the independence of temperament and symptom ratings (Lahey, 2004).

Therefore, the aim of the current study is to examine the relationship between temperament measured at ages 3-4, effortful control assessed at age 6, and ADHD ratings in combination with clinician judgment at age 7 The temperamental concept of effortful control is characteralogically similar to the neuropsychological construct of "executive functions" which are often assessed through cognitive testing rather than rating scales. Neuropsychologically-measured deficits in executive functioning are also often described in relation to ADHD (Barkley 1997, Nigg 2001, Seargent, Geurts, Huijbregts, Scheres, and Oosterlan 2003). To avoid the methodological confound inherent in using ratings to assess both temperament and ADHD symptoms, this study will examine the extent to which top down effortful control influences the relationship between bottom-up temperament and ADHD by examining the relationship between reactive temperamental

traits, executive control (as measured by neuropsychological tests), and ADHD symptom severity.

ADHD

Attention-Deficit/Hyperactivity Disorder (ADHD) is a common childhood disorder characterized by developmentally inappropriate levels of inattention, hyperactivity, and impulsivity that last at least six months and result in functional impairment in more than one setting (American Psychiatric Association, 2000). Children with ADHD may be characterized as primarily inattentive, characterized by behaviors such as "fails to pay close attention to detail," "has difficulty sustaining attention in tasks or play activities," hyperactive-impulsive, characterized by behaviors such as "squirms with hands or feet," "often has difficulty waiting turn," or may exhibit a combination of these features (American Psychiatric Association, 2000).

Externalizing problems, such as ADHD and accompanying impairment, can usually be identified during the toddler and preschool years, and can persist through childhood and into the adult years. Individuals who continue to exhibit symptoms and experience impairment throughout childhood and into adulthood may experience a number of negative outcomes, including school failure (Faraone et al., 1993), relationship difficulties (Maedgen & Carlson, 2000), substance abuse (Kalber & Levin, 2005), and difficulty maintaining employment (Bellack & Black, 1992).

ADHD is a heterogeneous disorder characterized by symptoms of inattention and/or hyperactivity/impulsivity. Therefore, there is much debate regarding the neurobiological origins of dysfunction in ADHD. Multiple pathways to ADHD have been proposed. One such theory suggests that the etiology of symptoms of hyperactivity and

inattention stems from core deficits in executive and inhibitory control (Barkley, 1997). Another, competing theory, proposes that inappropriate response to reward and difficulty tolerating delay underlie dysfunction in ADHD (Sagvolden, Aase, Zeiner, & Berger, 1998). In an attempt to resolve the discrepancy between these competing theories regarding mechanisms involved in ADHD, Sonuga-Barke (2005) proposed that both cognitive and motivational factors contribute to ADHD and help explain the heterogeneous nature of the disorder. Deficits in executive functions are associated specifically with inattention, while incentive based deficits are correlated with hyperactivity/impulsivity. Halperin and Schultz (2006) similarly attempted to integrate theories of dysfunction in ADHD. They proposed that ADHD is a result of early insult in subcortical brain areas that remains relatively static across the lifespan. However, development of prefrontal cortical areas and connections between these areas and subcortical brain structures, facilitates degrees of recovery in overt ADHD symptoms over the course of development. The idea that ADHD represents early and enduring subcortical dysfunction, while symptom improvement reflects increases in executive control over development, was substantiated by findings of a study that compared profiles of performance in individuals diagnosed with ADHD in childhood who continue to meet criteria in adolescence (persisters), those who no longer meet criteria in adolescence (remitters), and normal controls. Consistent with the suggestion that subcortical dysfunction remains static through the lifespan, persisters and remitters performed similarly to each other, but different than controls on measures thought to reflect bottom-up/automatic processes (response variability, perceptual sensitivity, and

subtle motor overactivity). In contrast, only persisters performed significantly worse on measures of executive control (Halperin, Trampush, Miller, Marks, & Newcorn, 2008).

The study of temperament has been proposed as a means of identifying factors that predispose children to externalizing behaviors (Caspi, Henry, McGee, Moffit, & Silva, 1995). Externalizing disorders such as ADHD may be viewed as more trait-like than other psychiatric disorders, with impairment often lasting across the developmental period and into adulthood (Biederman et al., 1996; White, 1999). Adding to this "trait" view of ADHD is the wide variability not only in symptoms, but also in functional impact of behavior and behavioral and emotional comobordities (Wilens, Biederman, & Spencer, 2002). Given this trait-like nature of ADHD, associations with temperament may be an appropriate way to investigate the disorder and its resulting functional impairments. The study of temperament in relation to ADHD may be useful in broadening the understanding of the behavioral manifestations of ADHD symptoms (Martel, Nigg, Von Eye, 2009). Furthermore, temperament traits are proposed to affect the development of psychopathology and therefore may help to explain varying levels of symptom severity in individuals with ADHDand comorbidities. Initial evidence suggests that ADHD is oftentimes associated with extreme affective traits such as high levels of negative emotionality (Martel & Nigg, 2006) and low effortful control. Due to the apparent dysregulation associated with the disorder, the contributions of executive functioning deficits to etiology and trajectory of ADHD is another common avenue of investigation (Barkley, 1997; Nigg, 2001; Sergent, Geurts, Huijbregts, Scheres, & Oosterlan, 2003). Although few studies have examined the combined impact of temperamental traits and higher order cognitive abilities, such as executive functioning, such an integrated

approach may provide useful information regarding ADHD symptomatology and course (Nigg, 2000).

Temperament

It is clear early in development that each child is unique in the manner in which he or she behaves and reacts to the environment. For example, some children tend to be shy, while others are more outgoing, some children may react with anger and frustration in the face of limitations, while others may simply move on. These behavioral tendencies, which tend to remain relatively stable throughout life, are generally referred to as temperament. However, the structure and definition of temperament has been the subject of much debate.

Though the exact nature of temperament has yet to be agreed upon, it is generally accepted that temperament is present in infancy, remains relatively stable throughout the lifespan, has a strong genetic and neurobiological basis, and serves as the basis for later personality (Thomas & Chess, 1977). More specifically, temperament is a set of constructs typically used to describe infants, toddlers, and young children, while personality is generally used to describe the behavior of older children, adolescents, and adults. In addition, most theoretical models acknowledge that temperament includes a variety of traits that influence an individual's behavior (Thomas & Chess, 1977). This multidimensional nature of temperament has generated numerous discussions and theoretical orientations, and has influenced the approach to assessment of temperament.

Several temperament theories have played a prominent role in the research literature. Kagan (1999) and Fox (2005) studied temperament through behavioral

observations rather than utilize traditional approaches such as behavior rating scales. Moreover, they opposed the study of temperament as a multi-dimensional construct, and instead chose to focus on one trait, Behavioral Inhibition, which is assessed by observing a child's reaction to novel situations, and is thought to reflect tendencies to be unusually shy or fearful in unfamiliar environments.

The New York Longitudinal Study conducted by Thomas and Chess was the first large scale study that conceptualized temperament as a set of individual differences that influenced behavior and reactions to the environment. Thomas and Chess (1977) followed the development of 141 children over the course of six years, and based on interviews with parents proposed that temperament is composed of 9 dimensions including activity level, rhythmicity, approach-withdrawal, adaptability to change, threshold of responsiveness, intensity of reaction, emotionality, distractibility and persistence of attention. According to the Thomas and Chess model, these nine dimensions can be reduced to three temperamental types: easy, difficult, and slow to warm-up. Easy children are characterized by regularity, easy adaptations to change, and positive approach to novel situations. On the other hand, difficult children lack rhythmicity, are slow to adapt to changes in the environment and scheduling, withdraw in new situations, and have frequent intense expression of intense mood. Finally, slow to warm-up children tend to exhibit characteristics of behavioral inhibition, including slow adaptability to novel stimuli. Although the Thomas and Chess model provided the foundation for a systematic conceptualization of temperament, critics of this approach argue that the model fails to adequately account for the role that emotion and motivation plays in temperament (Rothbart, 1981; Goldsmith, 1996).

In an attempt to address the criticism of the Thomas and Chess model, Rothbart and colleagues proposed that constitutionally based differences in the dimensions of reactivity and self-regulation exist. This approach to temperament is founded on the belief that individual variability is rooted in psychobiological processes. Reactivity refers to the excitability of brain systems related to responsiveness of emotional activation and arousal (Rothbart, 1989), and is therefore composed of measures of emotionality (positive and negative) and activity level. This system is thought to be served by hippocampal amygdala networks. Self-regulation, otherwise referred to as effortful control, is thought to emerge during the second half of the first year of life, in conjunction with development of frontal executive systems, particularly the anterior attention network, and acts to regulate the reactive aspects of temperament, such as anger, by modulating these more automatic responses (Rothbart, Derryberry, & Posner, 1994). Effortful control is composed of inhibitory and attentional control. Inhibitory control is defined as the ability to inhibit one's behavior when necessary, or more specifically to inhibit a prepotent response in the service of executing a subdominant more adaptive behavior. Attentional control refers to the ability to organize incoming information, delay gratification, and respond appropriately to selected stimuli (Rothbart, Elis, Rueda, & Posner, 2004). Although effortful control exhibits trait like qualities and individual differences in self-regulation have been posited to exist as early as infancy (Kochanska & Knaack, 2003), self-regulatory abilities are influenced by development and the environment (Murray & Kochanska, 2002; Posner & Rothbart, 2000). For example, Murray and Kochanska (2002) studied the development of effortful control from toddlerhood to early school age using a variety of measures thought to evaluate this

construct. Results of this investigation indicated that particular factors such as the ability to slow behavior and suppress dominant responses in the services of subdominant ones remained stable when assessed at both age two and age four. On the other hand, while toddlers showed significant variability on measures that assessed their ability to delay gratification, when those same children reached school age, all of the children were able to wait for the prescribed period of time, suggesting that children develop increasing ability to regulate delay behavior as they grow older.

Reflecting the reactive dimension of temperament encompassed by the Rothbart model, measures of negative emotionality and extraversion were included as additional contributors to temperament, whereas measures of effortful control were added to address the regulatory aspect of temperament (Rothbart, Ahadi, Hershey, & Fischer, 2001). Based on the children's behavior questionnaire (CBQ), a rating scale designed to measure the aspects of temperament included in the Rothbart model, three broad temperament factors can be identified in children. The first factor is referred to as Surgency/Extraversion, and includes items that assess impulsivity, activity level, shyness, and enjoyment of high stimulating activities. The second factor, Negative Affect is defined by a tendency to experience negative emotions most saliently. Individuals who display high levels of negative affect are likely to experience discomfort, fear in the face of novel situations, and can be described as angry, frustrated, and difficult to soothe. Effortful control, the third factor to emerge, is related to the self-regulatory component of the Rothbart model, and as such is primarily characterized by inhibitory and attentional control (Rothbart, Ahadi, Hershey, & Fischer, 2001).

The Eisenberg model is another frequently used approach in temperament research. Although this model is similar to that proposed by Rothbart and colleagues in that it includes dimensions of both emotionality and control, this model includes four higher order traits (Eisenberg et al., 1996). Effortful control as defined by the Eisenberg model is a voluntary mechanism that exacts "top down" modulation of behavior in the service of future goals that are held in working memory. Reactive control on the other hand refers to a more automatic, "bottom up" process that responds to immediate, tangible, incentives. Resiliency, the third factor in this model, involves the flexible use of effortful and reactive control in response to environmental demands, and finally Negative Emotionality refers to the tendency to experience negative affective states (Eisenberg, Fabes, Guthrie, & Reiser, 2000).

Other theorists argue that childhood temperament and later personality constructs can be integrated (Shiner, 2005). According to such approaches, personality features of neuroticism have been linked to negative emotionality, extraversion to high intensity pleasure and surgency, and conscientiousness to effortful control (Shiner & Caspi, 2003).

In an attempt to simplify and integrate temperament and personality models, Martel and colleagues (2008) proposed a two process model of temperament that distinguishes between "top down" and "bottom up" processes. From a neurobiological perspective, top down control is dependent upon activation of cortical structures (i.e., specifically areas of the prefrontal cortex including connections to the anterior cingulate), while bottom up processes are served by subcortical brain areas (i.e., the amygdala). Behaviorally, top down control refers to the deliberate focusing of attention and effort to a specific objective that may not be immediately tangible, but is held in working memory

(Eisenberg, Fabes, Guthrie, & Reiser, 2000). On the other hand, bottom up processing refers to more affective or automatic responses (Casey, 2005) that occur in the face of immediate goals and rewards.

Utilizing "bottom-up" and "top-down" temperament constructs, Nigg (2010) proposed an integrated model of temperament and psychopathology. According to this model, ADHD reflects "difficulty controlling one's behavior." Goal directed behavior can be interrupted by either "bottom-up" subcortically mediated immediate affective incentives (i.e., the need to inspect novel, threatening, or rewarding information). At the same time, goal directed behavior can be maintained through "top-down" prefrontally mediated control. Nigg proposed that ADHD reflects disruption in both "bottom-up" and "top-down" processes. Specifically, hyperactivity/impulsivity reflects oversensitivity of affective responses (i.e., negative emotionality), whereas inattention reflects breakdown in control mechanisms (i.e., effortful control).

Negative Emotionality and Effortful Control

Negative emotionality, also referred to as negative affect, or in the personality literature as neuroticism (Rothbart and Ahadi, 1994), is often thought of as the prototypical reactive/"bottom-up" temperament trait. Developmentally, negative emotionality is one of the first aspects of temperament to emerge and can purportedly be measured as early as one month of age (Rothbart, 1989). The trait of negative emotionality has been found to remain relatively stable across development. Furthermore, there is evidence to suggest that negative emotionality, particularly anger/frustration, measured early on is correlated with other aspects of reactive temperament including activity level, impulsivity, and positive approach measured later in childhood (Rothbart,

Deryberry, & Hershey, 2000), suggesting that high levels of reactive aspects of temperament (i.e., negative emotionality) are present at birth and are thought to be relatively stable by around the end of the first year of life.

In contrast, effortful control, while considered within the construct of temperament, is thought to emerge during the second half of the first year of life and continues to develop throughout childhood. Research indicates that development of effortful control primarily takes place between the ages of two and seven (Rothbart et al., 2003), but continues to increase into adolescence. Furthermore, effortful control is thought to develop in concert with brain development, particularly the executive attention systems (Posner & Rothbart, 1998), but is also influenced by environmental factors. Therefore, while infants exhibit relatively little overt control of behavior and are instead controlled more by reactive traits, over the course of development children's behavior should come under greater influence of developing mechanisms of effortful control.

High levels of negative emotionality (reactive) are thought of as a risk factor for poor developmental outcomes. However, low levels of effortful control (regulatory) have also been linked to childhood psychopathology, particularly behavioral difficulties (Rothbart, 2007). The relationship between both reactive and regulatory aspects of temperament and emergence of psychopathology brings into question the mechanisms by which temperament exerts its effect on behavioral and psychological outcomes.

In addition to the association between negative emotionality and psychopathology, high levels of negative emotionality have also been inversely associated with effortful control (Rothbart & Sheese, 2007). For example, Putnam, Rothbart, & Gartstein (2008) found that high ratings of negative affect during the toddler years were associated with

lower ratings of effortful control, including both attentional and inhibitory control, during early childhood. Similarly, Soderlund and Braungart-Rieker (2007) found that infant reactivity when faced with a novel situation was associated with performance on effortful control tasks in childhood. Specifically, infants who showed greater reactivity performed worse on measures of effortful control. Given evidence of the inverse relationship between negative emotionality and effortful control, it has been suggested that temperamental tendencies toward negative emotions may in some way negatively impact the development of effortful control (Calkins and Degnan, 2006). Consistent with this theory, Stifter and Spinrad (2002) demonstrated that excessive crying measured during infancy hampered development of self-regulatory abilities. In this way extremes of negative emotionality confer even greater risk by interfering with the development of effortful control and thus further weakening the ability to regulate negative affect. Calkins and Degnan (2006) therefore proposed that reactivity/negative emotionality likely exerts its influence on childhood behavioral difficulties through its impact on the development of effortful control.

Parenting may be one mechanism through which negative emotionality influences the development of effortful control. In other words, high levels of negative emotionality in some way alter the nature of the parenting environment. In fact, as part of her temperamental model, Rothbart suggested that parenting will play a particularly important role in adjustment for temperamentally vulnerable children (Rothbart & Derryberry, 1981). There is evidence to suggest that children who display high levels of negative emotionality tend to elicit less adaptive parenting strategies, including lower responsiveness, inconsistency, and restrictive control (Paulussen-Hoogeboom, Stams,

Hermanns, & Peetsma, 2007; Bates 1998). There is also evidence to suggest that parenting practices exert a significant influence on development of self-regulatory abilities such as effortful control (Eisenberg et al., 2005). Kochanska, Murray, and Harlan (2000) found that parenting influenced development of children's effortful control. Specifically, children whose mothers were more supportive, responsive, and accepting showed better effortful control skills compared to children who experienced less adaptive parenting. Furthermore, parenting is not only associated with development of effortful control, but also with externalizing problems. A meta-analysis examined the relationship between parenting and externalizing behaviors utilizing non-clinical samples; a significant inverse relationship was found between parenting characterized by guidance, absence of coercive control, approval, synchrony, and the use of motivational strategies and externalizing difficulties (Rothbaum & Weisz, 1994). Eisenberg et al . (2005) examine the associations between positive parenting and both effortful control and externalizing problems in a longitudinal design. These investigators found that effortful control mediated the relationship between positive parenting and externalizing symptoms. Moreover, they found that while more positive parenting predicted better effortful control, better effortful control did not predict more positive parenting. Thus, there is evidence that high levels of negative emotionality are associated with less adaptive parenting strategies, and more negative parenting is associated with lower levels of effortful control. Therefore, it is possible that negative emotionality exerts its influence on the development of effortful control abilities, and thus externalizing problems, through its impact on parenting. In addition to parenting, Calkins and Degnan (2006) proposed that negative emotionality may impact the development of effortful control by limiting

the child's interaction with the environment, thereby limiting the child's opportunities to develop, refine, and utilize appropriate self-regulatory skills.

Temperament and Externalizing Psychopathology

Until recently, temperament and psychopathology have been studied as distinct domains, with the former generally referring to innate traits, and the latter focusing on the manifestation of behaviors related to psychological impairment. More recently, a link between early childhood temperament and later psychopathology has been suggested. Specifically, a combination of high negative emotionality and low effortful control has been associated with development of psychopathology, particularly externalizing problems (Calkins & Fox, 2002).

Several studies have investigated the relationship between various temperament traits and externalizing behaviors, including ADHD. Using the Kagan (1995) and Fox (2005) approach to temperament described above, several studies have provided evidence that children who show the temperamental extreme of absence of restraint, and behavioral disinhibition may be positively predisposed to develop disruptive behavior disorders, such as ADHD, Oppositional Defiant Disorder (ODD), and Conduct Disorder (CD). Rothbart, Ahadi, and Hershey (1994) found that children who showed high approach behaviors in infancy had higher parent reports of impulsivity at age 7, as well as lower scores on measures of inhibitory and attentional control. Conversely, children who presented as behaviorally inhibited (i.e., tendency to respond to novel situations with hesitancy, fear, reticence, or restraint) as toddlers reported lower rates of delinquent and aggressive behavior at age 13 (Schwartz, Snidman, & Kagan, 1996) and high behavioral inhibition was negatively associated with lifetime reports of disruptive behavior

disorders, including ADHD and ODD (Biederman et al., 2001). Similarly, Becker and colleagues (2002) found that children characterized by behavioral disinhibition as measured in the laboratory at either age 2, 4, or 6 years of age, had higher rates of disruptive behavior disorders than behaviorally inhibited children, and that this relationship was primarily accounted for by symptoms of ADHD. Moreover, children observed to be more behaviorally disinhibited also demonstrated higher rates of placement in special classes, school behavior problems, lower overall functioning, and high rates of psychosocial treatments at age 6. Research employing a multi-dimensional approach, has similarly found links between temperament traits and externalizing symptomatology. For example, Eisenberg et al. (2001) found that children rated higher on externalizing behaviors were also rated as higher in temperamental traits of negative emotionality, particularly anger and irritability, and lower in effortful control, in comparison to children rated high in internalizing problems and normal controls. Olson, Sameroff, Kerr, Lopez, and Wellman (2005) found that ratings of effortful control were negatively associated with children's externalizing problems as reported by mothers, fathers, and teachers. Effortful control measured early in childhood has been shown to predict later development of externalizing problems. For example, lower levels of effortful control during the toddler years have been found to predict higher reports of externalizing problems 2 years later (Rubin, Burgess, Dwyer, & Hastings, 2003). Pitzer, Esser, Schmidt, and Laucht (2009) collected temperament ratings in infancy and early childhood from a sample of at risk children, due to either obstetric or psychosocial complications. Results from this study indicated that controlling for obstetric and

psychosocial risk factors, low regulatory abilities as measured in childhood predicted higher ratings of behavioral and attentional problems at age 15.

Eisenberg et al. (2001) examined differences in temperamental profiles between children with high levels of externalizing, internalizing, and combined internalizing and externalizing behaviors. Children who exhibited high levels of externalizing symptoms, as well as those in the combined internalizing + externalizing group exhibited deficits in all forms of effortful control (i.e., inhibitory and attentional control), and high levels of impulsivity, anger, and sadness. Similarly, Oldehinkel, Hartman, DeWinter, Veenstra, and Ormel (2004) compared temperament profiles of children rated as high on externalizing behaviors and those with high levels of internalizing difficulties. Results indicated that elevated ratings of high intensity pleasure and low levels of shyness, traits that load onto the Surgency factor, were correlated with increased externalizing problems, as were low levels of effortful control. On the other hand, while negative affectivity did not differentiate between externalizing and internalizing symptoms, it did predict severity of reported difficulties. Rothbart and Bates (2006) similarly indicated that negative affectivity predicted both internalizing and externalizing problems. However, within the broad construct of negative affectivity, two distinct pathways can be elucidated, with more fearful aspects predicting internalizing disorders and anger/frustration predicting externalizing disorders. Finally, Rothbart (2007) indicated that effortful control was more closely related to externalizing in comparison to internalizing disorders. Thus, it appears that externalizing problems are most closely related to temperamental profiles characterized by high levels of reactivity and low levels of effortful control.

In addition to research demonstrating a correlation between particular temperament traits and externalizing behaviors, several studies have established connections between personality and specific ADHD behaviors and diagnoses. The relationship between personality constructs and ADHD has been better studied in adolescent and adult populations. Such studies have generally implicated low levels of conscientiousness, thought to be related to the temperamental construct of effortful control, and high levels of neuroticism, theoretically similar to the temperamental constructs of surgency and negative emotionality, in ADHD (John, Caspi, Robins, Moffitt, & Stouthamer-Loeber, 1994; Miller, Miller, Newcorn, & Halperin, 2008; Nigg et al., 2002; Parker et al., 2004; Ranseen et al., 1998). Studies have also suggested a link between ADHD and reduced agreeableness. However, this finding may be more closely related to comorbid diagnoses of ODD (Miller, Miller, Newcorn, & Halperin 2008; Nigg et al., 2002).

The direct link between ADHD diagnoses and specific temperament dimensions in young children has also been studied. Several studies have found patterns of low persistence (effortful control) (Rettew, Copeland, Stanger, & Huziak, 2004) and high activity and impulsivity in children diagnosed with ADHD. Mcintosh and Cole-Love (1996) collected temperament ratings using the Temperament Assessment Battery for Children, from parents and teachers of boys ages 5-8 with and without diagnoses of ADHD. Findings from this study indicated that boys diagnosed with ADHD were rated as high in activity and distractibility, and low in task persistence. On the other hand, typically developing boys exhibited temperaments characterized by relatively lower levels of activity and distractibility and greater task persistence. Similarly, Bussing et al. (2003) found that girls and boys ages 8-10 who met diagnostic criteria for ADHD-

Combined Type were rated as low in task orientation and high in activity level. Foley, McClowry, and Castellanos (2008), collected temperament data from parents and teachers of children ages 6-11 years with and without ADHD using the School-Age Temperament Inventory (SATI) and the Children's Behavior Questionnaire (CBQ). Compared to typically developing children, children diagnosed with ADHD exhibited higher ratings of activity and negative reactivity and lower task persistence as measured by the SATI. Greater impulsivity and less attentional focusing and inhibitory control were endorsed on the CBQ. Martel and Nigg (2006) compared mother temperament ratings in children with and without ADHD and found that ADHD children were rated lower on effortful control and higher on negative emotionality. Consistent with these findings, a review of the temperament and psychopathology literature conducted by De Pauw and Merviedle (2010) suggested that patterns of temperament including high ratings of anger and activity level and low ratings of effortful control were consistent with symptoms of ADHD. A follow-up study comparing children diagnosed with ADHD to a community sample, conducted by De Pauw and Merviedle (2011) similarly indicated that children diagnosed with ADHD were rated as significantly lower in effortful control and higher in emotionality, negative affect, and activity level. In contrast, the groups did not differ on ratings of surgency and shyness. Findings from these studies suggest that both reactive dimensions, such as activity level and impulsivity, and regulatory aspects of temperament, effortful control, contribute to (not necessarily given the overlap and the inherent circularity of the argument) ADHD symptomatology. On the other hand, children with ADHD do not appear to differ from typically developing peers with regard to extraversion (De Pauw and Mervielde, 2011, Martel and Nigg, 2006). These findings

suggest that elevated activity level in children with ADHD is differentially expressed in degree of motor activity, but not with regard to sociability/extraversion. However, it is important to consider results of studies relating temperament traits to ADHD temperament in light of the qualitative overlap between the aspects of temperament studied and externalizing psychopathology. Overall, the current literature suggests a preponderance of evidence to support that ADHD is associated with higher levels of negative emotionality, in particularly anger and frustration (Eisenberg et al., 2005) and low levels of effortful control.

Mirroring theories of top down and bottom up processes in the ADHD literature, several studies have proposed differential contributions of temperamental pathways to ADHD symptom domains of inattention and hyperactivity/impulsivity. Martel and Nigg (2006) examined the contributions of reactive and effortful control, as well as resiliency and negative emotionality, to ADHD symptoms. Results from this study indicated that low levels of reactive control were most closely linked to hyperactive/impulsive symptoms. Resiliency and parent rated effortful control, on the other hand, were associated with symptoms of inattention, while negative emotionality was correlated with comorbid oppositionality. Most recently, Martel, Nigg, and Von Eye (2009), examined the differential contributions of temperament constructs to ADHD symptomatology in children ages 7-12 by creating a two factor model composed of "top down" and "bottom up" factors. In this study, top down referred to effortful forms of control that are goal directed and allow an individual to ignore immediate stimuli in the environment in order to achieve a long term goal held in working memory. In contrast, bottom up refers to less conscious behaviors that are influenced by immediate affective and drive states.

Combinations of temperament ratings and neuropsychological measures of cognitive control were used to create a latent top down factor, whereas only temperament ratings contributed to the bottom up factor. High levels of conscientiousness (conceptually related to effortful control), resiliency, response inhibition, and set shifting fell in the top down control factor. High levels of reactive control and agreeableness, and low levels of neuroticism and negative affect loaded onto the bottom up factor. Using structural equation modeling, negative correlations were found between the top down factor and ratings of inattention alone, while bottom up control was inversely related only to hyperactivity-impulsivity. Similarly, Purper-Ouakil and colleagues (2010) collected temperament ratings from a sample of boys ages 10-18 diagnosed with ADHD and found that while novelty seeking, related to bottom up behavioral activation, was differentially correlated with hyperactivity-impulsivity, low ratings of self-directedness was associated with higher levels of inattention. Thus, these findings seem to at least partially replicate the differential contributions of bottom up and top down processes to inattention and hyperactivity-impulsivity posited by Martel, Nigg, and Von Eye (2009).

In contrast, when this same Martel, Nigg, and Von Eye (2009) model was applied in an adolescent sample, increased top down control was associated not only with lower levels of inattention, but also hyperactivity. Thus, it appears that with development of top down mechanisms, bottom up behaviors, such as impulsivity and overactivity may be influenced by effortful control to impact symptom severity. Although the cross-sectional nature of this study does not permit definitive conclusions to be drawn, these results suggest a role for development, particularly of top down control, in influencing the relationship between temperament traits expressed early in childhood and later ADHD

symptom severity. These findings are, however, consistent with literature suggesting that effortful control, while present in infancy increases over the course of development (Murray & Kochanska, 2002), and that as these abilities increase, effortful control takes on a greater role in modulating bottom up, reactive behaviors (Rothbart, Derryberry, & Posner, 1994). Similarly, findings in the neuroscience literature suggest that significant development of the neural circuitry posited to underlie effortful control, particularly fronto-striatal pathways, occurs throughout childhood and well into adolescence and early adulthood (Giedd et al., 1999; Giedd et al., 1996). These temperament findings relate to neural theories of ADHD that suggest that over development, top-down neural circuitry exacts an increasing influence over subcortical regions thought to mediate bottom up processes, thus allowing for more effective control of emotion and behaviors such as hyperactivity and impulsivity (Halperin & Schulz, 2006).

Overall, research has clearly established a link between temperament and externalizing psychopathology, particularly ADHD. Moreover, differential contributions of top down and bottom up control to inattentive and hyperactive symptoms, respectively, may help account for some of the heterogeneity inherent in ADHD, as well as changes in phenotypical characteristics of the disorder over development. However, these results must be interpreted cautiously in light of qualitative overlap between aspects of temperament correlated with ADHD and symptoms of the disorder itself. For example, is it not surprising that children diagnosed with ADHD, a disorder characterized by high levels of inattention and hyperactivity, are also rated as temperamentally high in activity level and low in attentional control. This issue raises a larger question regarding the extent to which psychopathology and temperament are in essence distinct entities (Frick,

2004; Lahey, 2004). In fact, one predominant view of the relationship between temperament and psychopathology posits that psychopathology simply represents an extreme on the continuum of temperament (Clark, Watson, & Mineka, 1994). The extensive literature establishing linear, one to one, relationships between specific temperament dimensions and corresponding symptomatology seems to lend support to this theory. For example, a child carrying an ADHD diagnosis would logically be rated as higher in activity level than a typically developing child, whether activity level is assessed through use of a temperament measure or a symptom inventory.

Other theorists, however, argue that individual differences in response to environmental stressors suggest that psychopathology is not simply an extension of temperament. Instead, temperament represents an underlying risk factor that helps determine development and type of psychopathology (Murris & Ollendick, 2005). Theorists who argue for the independence of temperament and psychopathology, posit that literature focusing on the direct linear relationships between temperament dimensions and corresponding symptomatology fails to take into account the extent to which levels of multiple temperament dimensions may influence each other. Moreover, investigating these interactions may help to create a framework for understanding the contribution of temperament to the development of psychopathology (Rothbart & Posner, 1995).

Negative Emotionality, Effortful Control, and Externalizing Psychopathology

Research has suggested that while negative emotionality and effortful control are independent traits, negative correlations between temperamental factors of effortful control and reactivity exist. For example, children with higher effortful control ratings

have lower tendencies to react to frustrating situations with anger. Furthermore, over the course of development, reactive behavior increasingly comes under control of regulatory processes. As such, effortful control has been associated with a number of positive outcomes, including social competence. For example, Kochanska, Murray, and Harlan (2000), found that higher levels of effortful control, as measured in the laboratory at age 22 months, predicted greater ability to control anger and exhibit restraint at 33 months of age, and that more successful completion of effortful control tasks was associated with higher parent reports of social competence. In contrast, children described as exhibiting low levels of effortful control have been shown to run a greater risk for developing psychological disorders.

In order to better understand the relationship between conscious control and emotionality in a normative sample, Liew, Eisenberg, and Rieser (2004) investigated the impact of effortful control and negative emotionality on social competence in preschoolers. Parents and teachers completed ratings of child negative emotionality, effortful control, social skills, and externalizing behaviors. Peers were also asked to report on anger, prosocial behavior, popularity, and externalizing behaviors. As part of the study, children were asked to rank five potential gifts from least to most desirable. The children were then given a "disappointing" gift and their reactions immediately after receiving this less desirable gift were observed and coded. Higher levels of effortful control were significantly correlated with a less negative reaction in the face of disappointment. Moreover, children who were rated high on effortful control and exhibited fewer negative reactions in the face of disappointment were also described as more socially competent. In contrast, children's tendencies to verbalize expressions of

disappointment were correlated with lower ratings of effortful control. These results suggest that negative emotionality and effortful control work in concert to impact perceptions of social competence. Several studies have demonstrated that effortful control may influence the relationship between difficult temperaments and adaptive functioning, particularly tendencies toward maladaptive externalizing behaviors. In one such investigation, regulation, negative emotionality, and behavior problems were assessed in children ages 5-8 years and then reassessed two years later in order to test the hypothesis that while effortful control is the strongest inverse predictor of externalizing behavior problems, this relationship would be strengthened in children prone to high levels of negative emotionality (Eisenberg et al., 2000). Structural equation modeling revealed that in the best fitting model, the attentional control component of effortful control exhibited an inverse relationship with externalizing behavior. However, across both time points, this relationship was primarily evident in children who also exhibited high levels of negative emotionality. In other words, in children who exhibited low levels of negative emotionality, attentional control did not exhibit a strong relationship with externalizing symptoms, most likely because this group of children exhibited little variability in degree of externalizing behaviors (i.e., they did not exhibit high levels of behavior problems). However, within the group of children rated as high in negative emotionality there was significant variability in extent of externalizing problems, such that children prone to exhibiting high levels of intense negative emotions in combination with low levels of attentional control had higher ratings of problematic externalizing behaviors. In contrast, children who exhibited high levels of negative emotionality and intact attention control were less prone to externalizing problems, suggesting that the

attentional component of effortful control served to mitigate the risk factor conferred by high levels of emotionality (Eisenberg et al., 2001).

Valiente and colleagues (2003) replicated and extended Eisenberg's et al. (2000) findings of concurrent relationships between effortful control, negative emotionality, and externalizing behaviors by examining the extent to which temperament measured between ages 5 and 8 years predicted behavioral difficulties four years later. Consistent with previous research, the results of this study indicated that parent and teacher reports of greater externalizing problems were significantly correlated with lower ratings of effortful control, particularly in children exhibiting high levels of negative emotionality. Moreover, effortful control and negative emotionality assessed between ages 5 and 8 years predicted later externalizing problems, such that children who initially exhibited high levels of negative emotionality and low levels of effortful control exhibited a greater degree of behavioral difficulties at follow-up. Thus these studies suggest that strong effortful control abilities may play a protective role in the face of high levels of reactive temperament. However, findings regarding the relationship between negative emotionality, effortful control, and externalizing psychopathology are inconsistent. For example, Martel and Nigg (2006) found that high levels of effortful control were associated with lower ratings of ADHD symptoms in combination with low, but not high levels of negative emotionality. Similarly, Healey, Mark, and Halperin (2011) found that effortful control, as assessed using cognitive measures, was associated with lower ADHD severity in combination with low, but not high, negative emotionality. Instead, high negative emotionality represented the greatest risk for ADHD severity.

Overall, research has demonstrated a link between both reactive and regulatory temperament traits and ADHD, with evidence to suggest that ADHD risk is characterized by high levels of emotionality and low levels of effortful control. However, the extent to which these temperament traits act independently or in concert to influence ADHD severity remains unclear. Furthermore, much of the current research should be interpreted cautiously in light of methodological constraints. Currently, the majority of studies examining the relationship between temperament and psychopathology have utilized self or other report rating scales to assess both temperament and psychopathology. Yet, existing measures of temperament contain many items that are very closely related to symptoms of psychopathology (Lahey, 2004). For example, items that assess attentional control on a temperament rating scale closely resemble DSM-IV symptoms of ADHD. Several studies have established correlations between measures of temperament and psychopathology. However, such studies have also demonstrated that after removing overlapping items the relationship between temperament and psychopathology remains (Lemery, Essex, & Smider, 2002; Lenuga, West, & Sandler, 1998). These results suggest that established links between temperament and psychopathology are not simply a result of overlapping items. However, in order to more effectively depict the role that temperament plays in the development of psychopathology, it may be useful to consider alternative methods of assessing this relationship that do not so closely overlap (Lahey, 2004).

Effortful Control and Executive Functioning

Regulatory elements of temperament, such as effortful control, often measured using rating scales, are primarily viewed in terms of one's ability to regulate affective

states (i.e., negative emotionality, surgency). On the other hand, executive functions, typically assessed through cognitive tests, are generally viewed in relation to control of cognitions and behavior. However, these regulatory processes overlap considerably as they both refer to a voluntary, deliberate, and strategic response to a situation.

Executive functioning refers to a set of higher order cognitive capacities that involve the ability to inhibit dominant responses in the service of subdominant, more adaptive behaviors, attend to relevant information in the environment, and plan and sequence complex responses. Similar to the literature documenting correlations between temperament and inattentive and hyperactive-impulsive behaviors, neuropsychologically measured deficits in executive functioning are often described in relation to ADHD (Barkley, 1997; Nigg, 2001; Seargent, Geurts, Huijbregts, Scheres, & Oosterlan, 2003).

In addition, to the qualitative similarities between temperamentally-assessed effortful control and cognitively-measured executive functions (i.e., deliberate control of behavior), as well as joint associations with ADHD, there is evidence to suggest that effortful control and executive functioning may rely on similar or at least partially overlapping brain pathways, specifically the anterior attention networks (Posner & Rothbart, 2000). The anterior attention network includes areas of the prefrontal cortex, including the anterior cingulate gyrus (ACC) and is thought to underlie the ability to actively and effortfully regulate behavior (Posner & Dehaene, 1994). The executive attention network is activated particularly in situations requiring response inhibition and conflict resolution (Posner & Rothbart, 2007). Evidence implicating brain structures associated with the anterior attention network, particularly the anterior cingulate cortex, in both cognitive and emotional/motivational control (Bush, Luu, & Posner, 2000),

suggests that this system may represent the link between executive, cognitive control abilities, and temperamental effortful control. Models of the anterior cingulate cortex propose a cognitive, dorsal region that projects to the dorsolateral prefrontal cortex and an emotional, ventral region with projections to the orbitofrontal cortex. However, there is evidence for a reciprocal relationship between these regions of the anterior cingulate (Bush, Luu, & Posner, 2000). Thus, even the dorsal regions, which are typically associated with executive functioning, are thought to play a role in deliberate regulatory control of emotion (Lewis & Todd, 2007). Consistent with these findings, Perlman and Pelphery (2010) found that as children got older activation of dorsal (cognitive) in comparison to ventral anterior cingulate areas increased when emotion regulation was required in the face of frustration.

Given potential evidence for a shared neural network, several studies have attempted to establish a connection between laboratory based measures of executive function, particularly those thought to measure executive attention, and temperamentally rated effortful control. In an attempt to examine this relationship, Gerardi-Caulton (2000) administered a spatial conflict task, thought to measure executive attention, to typically developing three-year-old children. Results from this study indicated that high parent ratings of effortful control on the Child Behavior Questionnaire (CBQ), was associated with better task performance on the spatial conflict task, as indicated by high accuracy and low reaction time interference effects during conflict trials.

Similarly, Davis, Bruce, and Gunner (2001) examined the extent to which neuropsychological tasks, specifically those that call upon the structures that compose the anterior attention network, would be related to parental ratings of temperament on the

CBQ. Six year old typically developing children were administered a go-no-go task, which examines ability to inhibit a prepotent response, and a forced-choice visual discrimination task that assessed the ability to direct attention away from salient but irrelevant stimuli, tasks thought to be supported by the anterior attention network. Although the investigators expected to find a relationship between accuracy on the measures administered and high levels of Effortful Control, this correlation only trended toward significance. On the other hand, high levels of Extraversion/Surgency were significantly correlated with low accuracy. However, temperamentally assessed measures of impulsivity load onto the Extraversion/Surgency factor, thus these results may reflect a tendency to respond more quickly and therefore less accurately. On the other hand, Wolf and Bell (2004) utilized a day-night Stroop task to assess inhibitory control in children. Unlike the measures used in the study conducted by Davis and colleagues, which involved computer key pressing, responses on the day-night Stroop were provided verbally, thus potentially minimizing the effects of "speedy," impulsive responding. In contrast to Davis and colleagues, Wolf and Bell demonstrated significant correlations between neuropsychological measures of inhibitory control and parent ratings of attentional and inhibitory control on the CBQ. However, similar to Davis et al. performance on the day-night Stroop task was also negatively associated with the approach/anticipation scale on the CBQ, which loads onto the Extraversion/Surgency factor. However, these results are not surprising in light of the fact that Effortful Control itself is negatively associated with reactive dimensions of temperament, such as Extraversion/Surgency (Rothbart, Ahadi, & Hershey, 1994). Furthermore, Geraldi-

Caulton and Wolfe & Bell found that higher scores on cognitive inhibitory control measures correlated with lower ratings on the anger dimensions of temperament.

A link between performance on verbal working memory (digit span) tasks and temperamentally rated inhibitory and attentional control in children has also been established. In contrast, working memory did not correlate with temperamentally rated perceptual sensitivity which is thought to reflect the more automatic and reactive construct of orienting attention (Wang, Deater-Deckard, Cutting, Thompson, Petrill, 2012).

Not only has research demonstrated a link between executive attention and effortful control, there is also evidence to suggest that performance on measures on laboratory based measures of executive attention are influenced by reactive temperament traits. For example, Wolfe and Bell (2007) found that high levels of soothability in infants was associated with higher performance on working memory and inhibitory control measures at age four. Furthermore, both performance on cognitive measures of executive attention and ratings of effortful control are associated with behavioral difficulties and psychopathology. Ellis, Rothbart, and Posner (2004) examined the relationship between adolescent's performance on the Attention Network Task (ANT) and maternal ratings of effortful control. Executive attention, defined as the degree of interference effect during the incongruent condition of the task, was significantly correlated with effortful control. Moreover, the combination of temperamental rated effortful control and executive attention contributed significantly to ratings of problematic behavior. Wiersema and Roeyers (2009) conducted a comprehensive study examining the link between temperamentally rated effortful control, inhibitory control

assessed using a go-no-go task, ERP measured activation of the anterior attention network, and ADHD symptomatology. Results of this study indicated that children rated as low on effortful control were more prone to make errors of commission on the go-no-go task, suggesting difficulties with inhibitory control. In addition, different levels of temperamentally rated effortful control were correlated with components of the ERP thought to reflect activation of the attention network, thus supporting the idea that effortful control like executive attention operates through the attention network. Finally, ADHD symptom severity was associated both with lower ratings of effortful control and lower ERP amplitudes associated with higher rates of commission errors (or worse inhibitory control) during the go-no-go test.

In contrast, Muris and colleagues (2008) assessed the correlations among neuropsychological measures and self report ratings of attentional control and ratings of psychopathology. Although associations between neuropsychological indicators of effortful control and psychopathology were observed, stronger correlations between self report ratings of effortful control and psychopathology emerged. The authors posited that this pattern of results indicate that temperament ratings may be a better index of psychopathology than neuropsychological measures. However, this conclusion must be interpreted cautiously in light of the fact that both temperamental effortful control and psychopathology were assessed using self report ratings, thus increasing the likelihood of these measures correlating to a greater degree than those using performance-based measures of attentional control.

Overall, there is evidence to suggest that temperamentally rated effortful control and cognitively measured executive control are served by similar brain networks.

Furthermore, brain areas typically associated with cognitive control maintain reciprocal connections with emotion related brain structures and thus allow for cognitive control of emotion. The temperamental construct of effortful control suggests that emotion regulation is achieved through attentional (the ability to organize incoming information to achieve a goal) and inhibitory control (the ability to inhibit a prepotent response in the service of a subdominant more adaptive behavior). Cognitively, inhibitory control is often assessed through measures of interference control which refers to the ability to suppress a stimulus that pulls for a competing response so as to carry out another response. The Stroop effect, which relies on training a well-learned response that then competes with a less well-learned response, represents one of the more widely used and perhaps paradigmatic measure of interference control. Imaging evidence suggests that the Stroop effect activates circuitry in the dorsolateral prefrontal cortex and the anterior cingulate gyrus (Cabeza & Nyberg, 1997). This circuitry is associated with the effortful control of attention and behavior and therefore supports the idea that the Stroop effect represents a measure of executive control.

Attentional control is a more complex construct. It has been proposed that working memory not only reflects self-regulatory abilities, but is also reflective of the attentional control component of executive attention (Bell & Deckard, 2007). Working memory is conceptualized as the ability to maintain information mentally and at the same time manipulate that information. The ability to simultaneously maintain and manipulate information is a critical complex cognitive skill that underlies the ability to follow instructions and plan behavior in pursuit of a goal. Therefore, working memory abilities are considered at the core of executive functioning. Working memory is most commonly

assessed via span tasks (e.g., digit span) (Baddely & Hitch 1994). Modern accounts of working memory suggest that it is composed of domain specific storage components that store and rehearse verbal and visual information respectively. The working memory system also contains a central executive which supports the focusing, dividing, and switching of attention (Baddeley, 2007). Kane, Bleckley,Conway & Engle (2001) proposed the controlled attention view of working memory. Consistent with the Baddeley model, this model consists of storage and executive attention components. However, the controlled attention approach proposes that information maintenance in the presence of interference (as opposed to working memory capacity), reflects the control function of working memory. In this view, working memory, much like the attentional control factor proposed by Rothbart, reflects the ability to maintain information and or a goal in an easily accessible state, even in the face of interference, in order to effectively inhibit goal-irrelevant responses (Kane, Bleckley, Conway, & Engle, 2001). Neuroanatomically, the attentional control aspects of working memory are thought to be rooted in functioning of the dorsolateral prefrontal cortex (Kane & Engle, 2002). Poor working memory has been associated with higher level of ADHD symptoms and is thought to be at the core of dysfunction in ADHD (Barkley, 1997, Martinussen et al., 2005). Consistent with the attentional control theory of working memory, research suggests that performance on measures of working memory are specifically associated with inattentive symptoms of ADHD (Lui and Tannock, 2007, Tillman, Eninger, Forssman & Bohlin, 2011).

The Current Study

Overall studies suggest that certain temperamental traits, in particular negative emotionality/anger and effortful control, are associated with ADHD. However, the extent

to which negative emotionality and effortful control exert independent influences on development of ADHD or exert an influence on the disorder through their influence on each other remains unclear. Research examining the connections between reactive temperament processes and effortful control to date has yielded inconsistent results. For example, studies have demonstrated that effortful control acts as a moderator of the relationship between negative affect and ADHD such that in the presence of high levels of effortful control high negative affect is less strongly associated with ADHD symptoms then in the presence of low effortful control. However, other studies have demonstrated that high effortful control only moderates the relationship between negative emotionality and ADHD in the presence of low levels of negative affect, suggesting that in the presence of high levels of negative affect, effortful control does not act to mitigate the severity of ADHD symptoms. Therefore, the aim of the current study is to further investigate the relations between negative emotionality and effortful control, and their influence on ADHD symptom severity.

Several notable limitations exist within the current literature. Effortful control is conceptualized as a developmental construct that evolves in concert with development of the frontal lobes, as well as environmental influences. Furthermore, the nature of the relationship between effortful control and ADHD symptoms is thought to change over the course of development. However, current research is generally limited to cross-sectional examination of these relationships. Longitudinal studies may be able to more specifically examine the extent to which the development of effortful control mechanisms, or lack thereof, influences associations between early temperament ratings and later symptom severity.

Use of temperament rating scales is a second limitation of current studies examining the extent to which control dimensions of temperament affect the relationship between bottom-up factors and ADHD. Qualitatively, items on temperament rating scales closely parallel many items found on symptom checklists and may therefore be confounded with ratings of psychopathology used as outcome measures. Therefore alternative means of assessing temperament, such as objective laboratory measures, is necessary to validate the established relationship between temperament and ADHD, as well as the collaborative effect that temperament traits exert on symptom severity. ADHD has been associated with deficits in both effortful control and executive functioning. A theoretical and neurobiological relationship has been established between temperamentally construed effortful control and executive functioning, specifically with regard to executive attention and the anterior attention network. In addition, correlations between ratings of effortful control and performance on laboratory based measures have been found. Therefore, utilizing neuropsychological measures to assess these higher order cognitive functions may be an appropriate way in which to address this issue. Although temperament has traditionally been associated with emotional and psychosocial functioning, an understanding of the longitudinal relationship between temperament and ADHD may be enhanced by evaluating the role of cognitively mediated executive functions over development. There is neurobiological and theoretical evidence for overlap between cognitively assessed inhibitory control and working memory, and temperamental constructs of inhibitory and attention control. Furthermore, these cognitive constructs are thought to represent core dysfunction in ADHD. Therefore,

neuropsychological assessment of inhibitory control and working memory likely reflects a viable index of temperamentally construed effortful control.

The primary aim of the current study is to elucidate the nature of the relationships between negative emotionality, effortful control, and ADHD symptom severity in a developmental model, as well as to address methodological concerns in the current literature. Therefore, this study was designed to examine the longitudinal associations between temperament rated by parents and teachers at age three to four, effortful control assessed through cognitive measures of inhibitory control and working memory at age six, and ADHD symptom severity as assessed through parent and teacher report and clinician judgment at age seven. With regard to temperament, ADHD has been most consistently associated with reactive traits of negative emotionality (particularly anger/frustration) and activity level. Since temperamental ratings of activity level overlap conceptually with symptom ratings of ADHD, for the purposes of this study, we will focus on negative emotionality as an index of reactive temperament traits. In order to further address methodological confounds inherent in use of rating scales to evaluate both temperament and symptoms, we will utilize objective neuropsychological measures as an index of effortful control.

The current study will utilize mediation models to examine the extent to which negative emotionality acts as a risk factor for ADHD through its negative influence on development of effortful control. Given evidence for the impact of negative emotionality on development of effortful control (measured both using temperament ratings and objective working memory measures), as well as the proposed role of effortful control in persistence of dysfunction in ADHD, we hypothesize that effortful control, as measured

by objective neuropsychological measures will partially mediate the relationship between negative affect and ADHD symptom severity. To test this hypothesis, we address four questions:

1) is early negative emotionality (age 3-4) associated with later ADHD symptom severity (age 7)?

2) is early negative emotionality associated with development of effortful control (age 6)?

3) is effortful control (age 6) associated with later ADHD symptom severity (age 7)?

4) is the relationship between early negative emotionality and ADHD symptom severity reduced when developing effortful control is added into the model?

Methods

Participants

Participants were 161 3- and 4-year-old children (112 boys, 49 girls) who were recruited from local community preschools and clinical referrals from pediatricians, mental health workers, and school psychologists/social workers, as part of a larger longitudinal study on the developmental trajectory of ADHD. At screening, all participants were rated by their parents and teachers on the Attention Deficit/Hyperactivity Disorders Rating Scale-IV (ADHD-RS-IV; DuPaul, Power, Anastopoulos, & Reid, 1998). The ADHD-RS-IV consists of 18 ADHD symptoms listed in DSM-IV, which are rated on a scale from 0 (never) to 3 (very often). A symptom was deemed to be endorsed when a rating of 2 (often) or 3 (very often) was given. Children were classified as typically developing by the endorsement of fewer than three symptoms of hyperactivity/impulsivity and inattention, as rated by both parents and teachers on the ADHD-RS-IV. Children were classified as hyperactive-inattentive based on endorsement of at least six symptoms of hyperactivity/impulsivity and/or inattention across parent and teacher ratings on the ADHD-RS-IV. This design allowed for a sample with a wide range of symptom severity. Of the 94 participants classified as hyperactive-inattentive at baseline, 77 either met full DSM-IV diagnostic criteria for one of the three subtypes of ADHD diagnosis (i.e., predominantly hyperactive/impulsive, predominant inattentive, or combined) or ADHD-NOS (not otherwise specified; a diagnosis given when a child exhibits symptoms from both the inattentive and hyperactive/impulsive domains that are result in functional impairment, but are not sufficient to meet full diagnostic criteria), as determined by the K-SADS-PL semi-structured interview (Kaufman et al., 1997). When

re-evaluated at the outcome time point for this study (3-4 years later) 73 of the children classified as hyperactive-inattentive at screening continued to meet DSM-IV diagnostic criteria for one of the three subtypes of ADHD or ADHD-NOS.

Exclusion criteria at screening included: Full Scale IQ (FSIQ) < 80 (as measured by the Wechsler Preschool and Primary Scale of Intelligence-3rd Edition (WPPSI-III); a neurological or pervasive developmental disorder; not fluent in English; and/or medication use for a chronic medical condition (including for ADHD).

The ethnicity of the sample was diverse. Of the 161 participants 70.2% identified as Non-Hispanic and 29.8% Hispanic. When asked to report child's race, 59.6% of parents described their children as white, 13% Asian, 11.8% Black, and 15.5% mixed or other. Socio-economic status (SES) was measured using the Nakao-Trea Socioeconomic Prestige Index (Nakao and Treas, 1994) where high scores are indicative of higher SES. The SES of this sample was variable (range, 20-97), but most of the children were living in homes with moderate socioeconomic status (Mean= 64.4, SD=17.5).

"*Baseline"/ Initial assessment.* Following screening, children (mean age=4.27, SD=.49) received a comprehensive cognitive, neuropsychological, and psychodiagnostic evaluation. Ratings of child temperament (described below) were collected from parent (n=156) and teachers (n=146).

Six-year-old evaluation. As part of this ongoing longitudinal study, children were evaluated each year following the initial baseline assessment. At age 6 years (two to three years later; mean age=6.56 years, SD = .29) children were administered the Wechsler Intelligence Scale for Children-4th edition (WISC-IV), a measure of general cognitive functioning, and scores from the Working Memory Index (n=154) (described below)

were utilized as an intervening data point in the current study. Children were also administered the NEPSY: A Developmental Neuropsychological Assessment and scores from the Response Set subtest (described below) were utilized as an additional intervening data point in the current study.

Seven-year-old evaluation. Children (mean age=7.58, .32) received a comprehensive neuropsychological, academic, and psychodiagnostic evaluation. For the purposes of this study, K-SADS-PL ADHD symptom severity scores (described below) obtained during this evaluation (n=161) were utilized as an outcome (dependent) variable.

All children were medication naïve at the initial baseline assessment (temperament ratings). At the time of the 6 and 7-year-old evaluations, some children were prescribed medication to address behavioral medications. However, parents of medicated children were asked to withhold children's medication on the morning of the child's evaluation, thus minimizing the impact of medications on working memory performance. In addition, endorsement of ADHD symptoms on the K-SADS-PL was made based on the child's behavior while not medicated.

Measures

Predictor Variables (Baseline Evaluation)

Given that ADHD is a disorder characterized by both "bottom-up" and "top-down" dysfunction, models of temperament that include "bottom-up" and "top-down" factors seem to be an appropriate approach for the study of the relationship between temperament and ADHD. Therefore, we chose to utilize the Rothbart (1989) model of

temperament which includes both reactive (bottom-up) and effortful control (top-down factors).

Children's Behavior Questionnaire (CBQ, Rothbart, Ahadi, Hershey & Fisher, 2001). The CBQ is a well-established, reliable, and valid measure of child temperament. This 94 item questionnaire completed by parents has been found to have good internal consistency (coefficient alpha= .75) and moderate stability over time (r= .63) (Rothbart et al. 2001). Each item was rated on a scale of 1 (extremely untrue of your child) to 7 (extremely true of your child). This measure assesses fifteen dimensions of child temperament: Activity Level, Anger, Approach, Attentional Focus, Discomfort, Falling Reactivity & Soothability, Fear, High Intensity Pleasure, Low Intensity Pleasure, Impulsivity, Inhibitory Control, Perceptual Sensitivity, Sadness, Shyness, and Smiling. These fifteen dimensions can be combined to form three overall domains, namely Surgency (a measure of positive affect and approach), Negative Affect (a measure of fearful and angry emotional reactivity), and Effortful Control (attentional self-regulation). Unlike the items on the Negative Emotionality scale of the TABC-R (described below), which were designed to assess level of frustration in the face of limits, the Negative Affect factor of the CBQ reflects a broad temperamental factor including fear, anxiety, sadness, as well as tendency to become emotionally upset in the face of frustration (anger). High levels of this broad temperamental negative affect have been linked to general stress reactivity (McEwen 2007). However, within this broad construct of negative affect, two distinct pathways to psychopathology have been observed, with the more fearful aspects predicting internalizing disorders and anger predicting externalizing disorders (Rothbart & Bates, 2006). Therefore, the anger subscale of the negative affect

factor was chosen as a predictor variable in the current study, as it seems to more closely reflect the nature of emotional reactivity that is problematic in children with ADHD (Auerbach et al., 2008).

Temperament Assessment Battery for Children – Revised (TABC-R, Martin & Bridger, 1998). Teachers rated each child's temperament on this 29 item questionnaire. Each item was rated on a scale from 1 (hardly ever) to 7 (almost always). This measure generates four dimensions: Inhibition (i.e., tendency to withdraw in novel social situations), Negative Emotionality (i.e., tendency to become emotionally upset when frustrated), Activity Level (i.e., tendency to engage in energetic activity), and Lack of Task Persistence (i.e., effortful control). For this study the Negative Emotionality domain was the main focus in relation to the research question. Of note, the negative emotionality domain of the TABC was designed to assess children's tendency to become upset in the face of limitations and frustration. Therefore, items on this scale most closely mirror items on the anger scale of the CBQ, rather than the negative affect domain of the CBQ, which also includes fearful and sad emotions (more similar to the Inhibition subscale of the TABC and of less interest to this study). As reported in the TABC-R manual, internal consistency (coefficient alpha range.86 to .95) and temporal stability (.47 to .71) have been found to be adequate.

Mediator Variables (6-year-old Evaluation)

Wechsler Intelligence Scale for Children- 4th Edition- Working Memory Index (WISC-IV WMI, Wechsler, 2003) provides a measure of children's working memory abilities. Working memory is defined as the ability to temporarily retain information and perform some operation or manipulation with it. Digit span is a traditional working

memory measure. The digit span subtest on the WISC-IV is composed of Digit Span Forward, which requires the child to repeat aurally presented numbers in the same order, and Digits Backward, which requires the child to repeat the numbers in the reverse order to that presented by the examiner. Each item of Digit Span Forward and Backward is composed of two trials of the same span length. Sample items are provided prior to administration of digits backward to ensure that children comprehended the task demands. Letter-Number sequencing is the second subtest that comprises the working memory index. A series of numbers and letters are presented orally and the examinee is required to recall the numbers first in ascending order and then the letters in alphabetical order. This subtest consists of ten items of three trials each. The WMI composite score (mean=100, SD=10), which is derived from the Digit Span and Letter-Number Sequencing subtests, was used as the mediating variable of interest in this study.

Developmental Neuropsychological Assessment (NEPSY: Korkman, Kirk, & Kemp, 1998) was designed to assess ability across five domains of neuropsychological functioning: Attention/Executive, Language, Memory, Sensorimotor, and Visuospatial. This measure has been found to have good stability over time (r = .68–.90).
The Response Set subtest, a measure that falls on the Attention/Executive domain, was utilized as a mediating variable in this study. The Response Set subtest follows the auditory attention subtest, which trains participants to place a red square in a box upon hearing the word red. The Response Set subtest requires participants to inhibit this over-learned response and place a yellow square in a box upon hearing the word red. In addition, participants are required to place a red square in a box upon hearing the word yellow, but place a blue square in a box upon hearing the word blue. Thus, this subtest

measures aspects of interference/inhibitory control, as well as ability to maintain and shift sets of instructions.

Dependent Variable (7-year-old Evaluation)

Kiddie-SADS - Present and Lifetime Version (Kaufman, Birmaher, Brent, Rao, & Ryan, 1996) is a semi-structured clinical interview that was used during the current study to identify the presence of ADHD. This interview was conducted by Ph.D. level clinicians or trained graduate students under the supervision of Ph.D. level clinicians, who were blind to temperament ratings, as well as participant's performance on measures of working memory and inhibitory control. Information from multiple sources, including the clinical interview with the child's parent; parent and teacher ratings using the ADHD-Rating Scale-IV (DuPaul, Power, Anastopoulus, & Reid, 1998); parent and teacher ratings on the Behavioral Assessment Scale for Children- 2nd Edition (BASC-2; Renolds and Kamphaus, 2002), which assesses a variety of psychiatric symptoms including inattention and hyperactivity; and clinician ratings of behavior during the evaluation, was integrated to determine the presence or absence of each of the 18 ADHD symptoms. DSM-IV algorithms were subsequently applied to determine the presence of ADHD. Children who exhibited 6 or more hyperactive/impulsive symptoms and had significant impairment were classified as meeting criteria for ADHD-Hyperactive/Impulsive subtype. Children who exhibited 6 or more inattentive symptoms and had significant impairment were classified as meeting criteria for ADHD- Inattentive subtype and children who exhibited 6 or more symptoms in both the hyperactive/impulsive and inattentive domains and had significant impairment were classified as meeting criteria for ADHD-Combined Type. For the purposes of the current study, clinical information from the Kiddie-SADS was used in a dimensional format.

KSADS ratings for each of the 18 DSM-IV symptoms (1=not present, 2= subthreshold, 3=clinically significant) were totaled to create a total ADHD severity score. In addition, total scores were separately created for inattentive and hyperactive/impulsive symptoms.

Data Analysis

Pearson product moment correlations were initially used to examine the relations among parent and teacher temperament ratings, the Working Memory Index, Response Set subtest and ADHD symptom severity as assessed through K-SADS-PL interviews. Hierarchical liner regression was used to test for mediating effects of working memory on the relationship between negative emotionality (i.e., independent variable) and ADHD symptom severity (i.e., dependent variable) and the mediating effects of inhibitory control on the relationship between negative emotionality and ADHD symptom severity. Mediation models are generally used to investigate the manner in which the relationship between two variables is influenced by an intervening, or mediating, variable. In order for an intervening variable to be evaluated as a mediator (M), M must be predicted by X, the independent variable, and Y, the dependent variable, must be predicted by both X and M. In order for M to actually serve as a mediator, at least part of the relationship between X and Y must be explained by M. Therefore, mediation is conceptualized as the indirect effect of X on Y, or the effect that X has on Y taking M into account. If M acts as a full mediator, the relationship between X and Y will no longer be significant. However, if the direct effect is reduced relative to the direct effect prior to the insertion of M into the model, but is still significant, partial mediation is said to occur (Baron & Kenny, 1986). In this study, mediation will first be established following the steps outlined by Baron and Kenny 1986. In order to evaluate the significance of the mediating effect, as

recommended by Preacher and Hayes (2004), nonparametric bootstrapping procedures recommended for small, non-normally distributed samples, will be used. This procedure is used to demonstrate that the indirect effect of the mediator on the relationship between the independent and dependent variable is different from zero at the 95% confidence interval (Preacher & Hayes, 2004).

Results

Descriptives

Table 1 presents descriptive statistics for scores on ratings and objective measures that comprise the main study variables.

Table 1. Descriptive statistics for main study variables.

	Mean	SD	Range
Independent Variables			
CBQ: Anger (age 3-4)	4.59	1.12	1.83-6.83
TABC: Negative Emotionality (age 3-4)	3.23	1.65	1.00-7.00
Mediator Variables			
CBQ: Effortful Control (age 6)	20.47	2.88	10.92-25.54
WISC: Working Memory Index (age 6)	102.77	11.85	71.00-138.00
NEPSY: Response Set	29.10	19.75	-56.00-66.00
Dependent Variables			
KSADS: ADHD Total Symptoms (age 7)	34.21	11.88	18.00-54.00
KSADS: ADHD Inattentive Symptoms (age 7)	17.60	6.59	9.00-27.00
KSADS: ADHD Hyperactive Symptoms (age 7)	16.60	5.98	9.00-27.00

Preliminary Analysis

Prior to testing the main study hypothesis, preliminary analyses were conducted to examine the extent to which temperament ratings of effortful control (attentional and inhibitory control) correlated with laboratory measures of working memory and inhibitory control. As indicated in Table 2 parent rated attentional and inhibitory control at age 3-4 correlated significantly with working memory and response set performance at

age 6. Parent ratings of attentional, but not inhibitory control at age 6, were significantly correlated with working memory and response inhibition at age 6.

Table 2. Correlations between temperament ratings of effortful control and working memory and response set performance.

	Baseline: Attentional Control	Baseline: Inhibitory Control	6-year-old: Attentional Control	6-year-old: Inhibitory Control
WMI	.259**	.182*	.216**	.142
Response Set	.339**	.180*	.298**	.118

**p<.01, *p<.05

Subsequently, preliminary analyses were conduced to confirm that data from the current study fits existing temperament models. Therefore, the mediating effect of temperamentally-rated (as opposed to neuropsychological measures) effortful control on the relationship between early negative emotionality and later ADHD severity was examined. Pearson product moment correlations were conducted to assess the relationship between parent and teacher ratings of Anger and Negative Emotionality obtained at ages 3-4 years, parent ratings of Effortful Control obtained at age 6, and ADHD symptom severity measured at age 7. Results of correlations can be found in Table 3. Parent and teacher temperament ratings of Negative Emotionality correlated significantly with parent temperament ratings of Effortful Control and total ADHD symptom severity. Similarly, parent ratings of Effortful Control were significantly correlated with total ADHD symptom severity.

Table 3. Correlations between Anger/Negative Emotionality, parent-rated Effortful Control, and ADHD symptoms.

	CBQ: Effortful Control (age 6)	KSADS: ADHD Total Symptoms (age 7)
CBQ: Anger (age 3-4)	-.368**	.416**
TABC: Negative Emotionality (age 3-4)	-.299**	.452**
CBQ: Effortful Control (age 6)	--	-.536**

**p<.001

Significant correlations between the independent variables (Anger/Negative Emotionality) and the dependent variable (ADHD symptoms), the independent variable and the mediating variable (Effortful Control) and the mediating variable and the dependent variable, suggest that conditions according to the Baron and Kenny (1986) model were met to test for mediating effects. Barron and Kenny (1986) recommend that to test for mediation, the dependent variable be regressed on the independent variable (Anger or Negative Emotionality), the mediating variable (Effortful Control) on the independent variable, and then regress the dependent variable (ADHD symptoms) on both the independent and mediator variables. To detect mediation, the regression coefficient of the relation between the independent and dependent variables is required to drop when the mediator variable is included in the model.

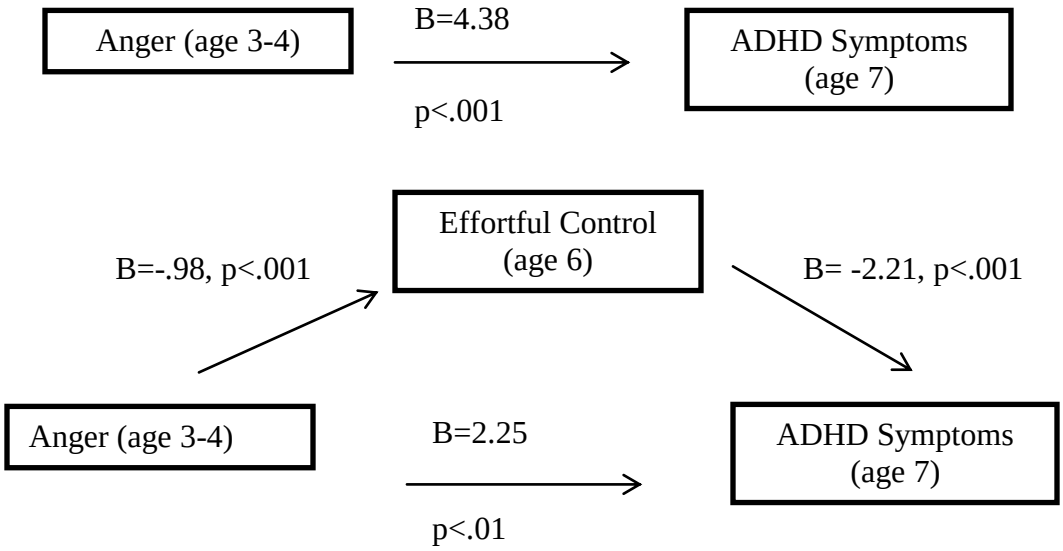
Results of the regression analysis (Table 4) revealed that parent-rated Anger (IV) predicted both effortful control (the mediating variable, M) and ADHD symptom severity (the dependent variable, DV). When parent-rated Anger was entered into the regression together with effortful control, both parent-rated Anger and Effortful Control predicted ADHD symptom severity. Furthermore, there was a drop in the regression coefficient (49%) of parent rated Anger, when Effortful Control was included in the model,

suggesting that Effortful Control acts as a partial mediator in the relationship between Anger and ADHD symptom severity (Figure 1).

Table 4. Effortful control as a mediator of parent-rated Anger and ADHD symptoms.

	B	SE	P
IV-M	-.98	.205	<.001
M-DV	-2.21	.286	<.001
IV-DV (Direct Effect)	4.38	.771	<.001
IV-M-DV (Indirect Effect)	2.25	.785	<.01

Figure 1. Effortful control as a mediator between parent-rated Anger and ADHD symptoms.



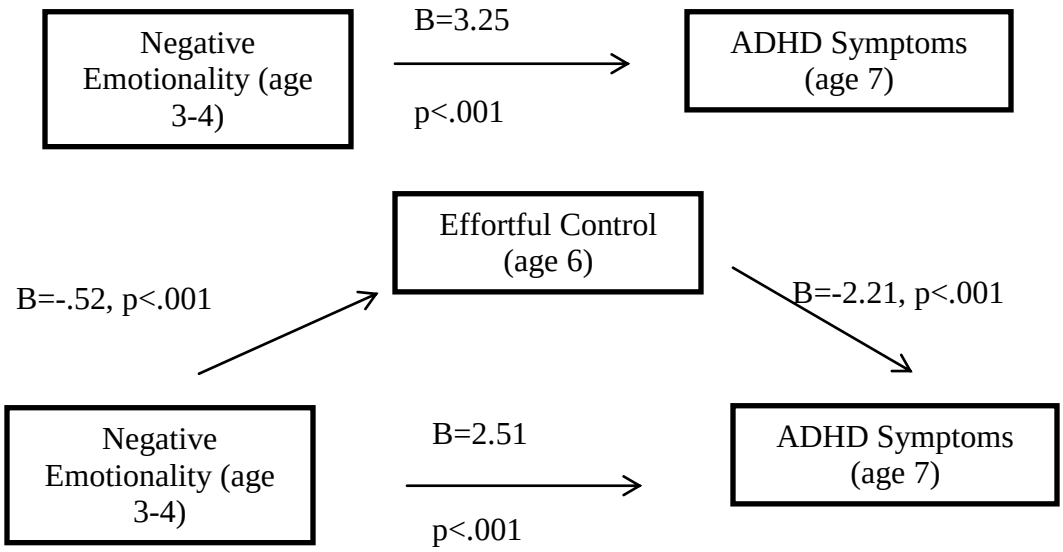
Similarly, teacher-rated Negative Emotionality significantly predicted both Effortful Control (the mediating variable) and ADHD symptom severity (the dependent variable) When entered together into the regression, teacher-rated Negative Emotionality and parent rated Effortful Control predicted ADHD total symptoms. Furthermore, there was a

drop in the regression coefficient (30%) for teacher rated Negative Emotionality when Effortful Control was included in the model, suggesting that Effortful Control acts as a partial mediator in the relationship between Negative Emotionality and ADHD symptom severity (Table 5, Figure 2).

Table 5. Effortful control mediates teacher-rated Negative Emotionality and ADHD symptoms.

	B	SE	P
IV-M	-.52	.143	<.001
M-DV	-2.21	.286	<.001
IV-DV (Direct Effect)	3.25	.534	<.001
IV-M-DV (Indirect Effect)	2.51	.518	<.001

Figure 2. Effortful Control as a mediator between teacher-rated Negative Emotionality and ADHD symptoms.



As recommended for small samples, we used nonparametric bootstrapping analyses (Preacher & Hayes, 2004) to test the significance of the mediating effect of Effortful Control on both the relationship between parent-rated Anger and teacher-rated Negative Emotionality and ADHD symptom severity. In these analyses, mediation is significant if the 95% Bias Corrected and accelerated confidence intervals for the indirect effect do not include 0 (Preacher & Hayes, 2004). Results based on 1,000 bootstrapped samples indicated that Effortful Control was a significant partial mediator of the relationship between parent rated Anger and ADHD symptoms (lower CI= 1.06, upper CI= 2.80). Since zero is not in the 95% confidence interval, the indirect effect is significantly different from zero at $p < .05$ (two tailed). Similarly, bootstrapping analysis indicated that Effortful Control was a significant mediator of the relationship between teacher-rated Negative Emotionality and ADHD symptom severity (lower CI=.429, upper CI=1.680). Since zero is not in the 95% confidence interval, the indirect effect is significantly different from zero at $p<.05$ (two tailed).

Working Memory as a mediator of early Anger/Negative Emotionality and later ADHD symptom severity.

The second set of analyses focused on addressing the hypothesis that objective neuropsychological measures of executive control would provide a means of assessing the mediating effects of effortful control on the relation between early temperament and later ADHD symptom severity while avoiding the methodological confounds of overlap between items on temperament ratings and symptom inventories as well as rater effects. The WISC-IV Working Memory Index (WMI) was utilized as a proxy for the attentional

control component of effortful control. Pearson product moment correlations were conducted to assess eligibility of WMI as a mediator variable. As demonstrated in Table 5, all measures correlated significantly.

Table 6. Correlations between Anger/Negative Emotionality, WMI, and ADHD symptoms.

	WMI	KSADS: ADHD Total Symptoms
CBQ: Anger	-.171*	.416***
TABC: Negative Emotionality	-.172*	.452***
WMI	--	-.254**

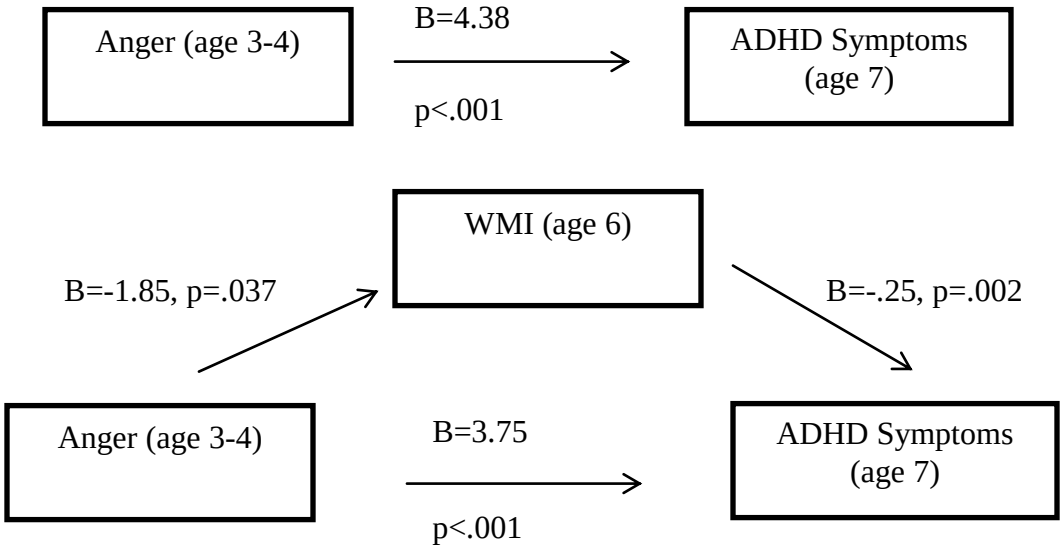
*p<.05, **p<.01, ***p<.001

Following the Baron and Kenny (1986) steps outlined above, the extent to which WMI mediates the relationship between Anger and ADHD symptoms was examined. Results of the regression analysis can be found in Table 7 and revealed that parent-rated anger (IV) significantly predicted both WMI (the mediating variable, M) and ADHD symptom severity (the dependent variable, DV). When entered together into the regression, both parent rated Anger and WMI predicted ADHD total symptoms. Furthermore, there was a drop in the regression coefficient (14%) for parent rated Anger when WMI was included in the model, suggesting that WMI acts as a partial mediator in the relationship between Anger and ADHD symptom severity (Figure 3).

Table 7. Working Memory mediates the relationship between parent-rated Anger and ADHD symptoms.

	B	SE	P
IV-M	-1.85	.875	.037
M-DV	-.25	.078	.002
IV-DV (Direct Effect)	4.38	.771	<.001
IV-M-DV (Indirect Effect)	3.75	.785	<.001

Figure 3. WMI as a mediator between parent-rated Anger and ADHD symptoms.

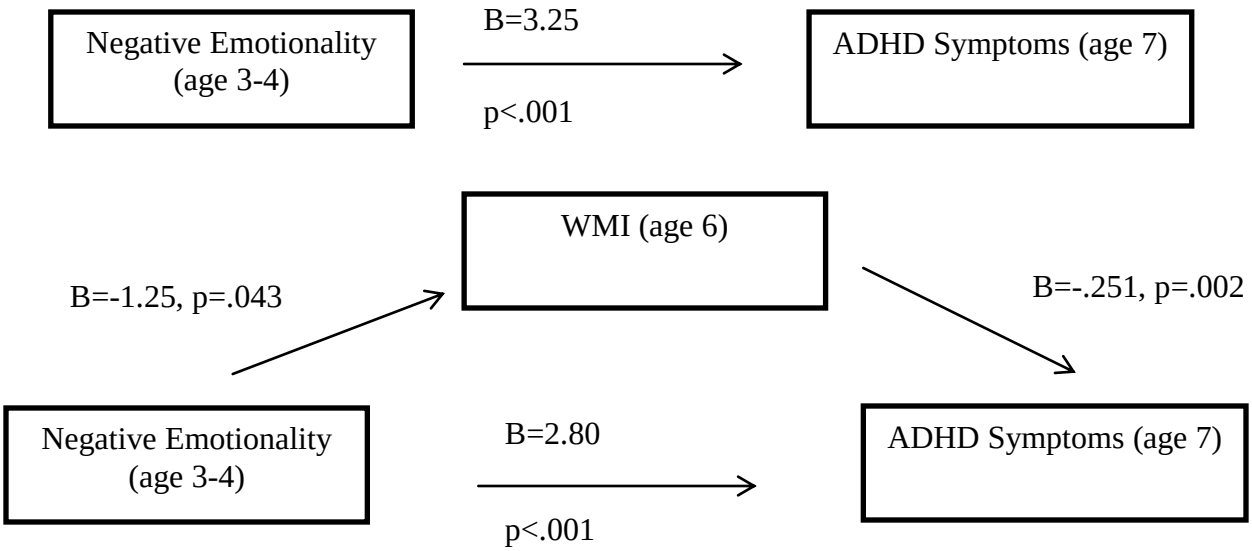


Similarly, teacher-rated Negative Emotionality (IV) significantly predicted both working memory (mediating variable, M) and ADHD symptoms (dependent variable, DV). When entered together into the regression equation, both teacher-rated Negative Emotionality and WMI predicted ADHD total symptoms. Furthermore, there was a drop in the regression coefficient (14%) for teacher rated Negative Emotionality when WMI was included in the model, suggesting that WMI acts as a partial mediator in the relationship between Negative Emotionality and ADHD symptom severity (Table 8, Figure 4).

Table 8. Working Memory mediates the relationship between teacher-rated Negative Emotionality and ADHD symptoms.

	B	SE	p
IV-M	-1.25	.612	.043
M-DV	-.25	.078	.002
IV-DV (Direct Effect)	3.25	.534	<.001
IV-M-DV (Indirect Effect)	2.80	.561	<.001

Figure 4. WMI as a mediator between teacher-rated Negative Emotionality and ADHD symptoms.



Using the nonparametric bootstrapping approach described above WMI is a significant partial mediator of the relationship between parent rated Anger and ADHD symptoms (lower CI=.025, upper CI= .533). Similarly, bootstrapping indicated that WMI acts as a partial mediator in the relationship between teacher-rated Negative Emotionality and ADHD symptoms (lower CI=.018, upper CI=.370). Since zero is not in the 95% confidence interval, the indirect effect is significantly different from zero at $p<.05$ (two tailed).

Working Memory as a mediator of early Anger/Negative Emotionality and later Inattentive and Hyperactive/Impulsive symptoms of ADHD.

ADHD is a heterogeneous disorder composed of both inattentive and hyperactive/impulsive symptoms. Therefore, the WMI index was examined differentially as a mediator of inattentive and hyperactive/impulsive symptoms of ADHD. As depicted in Table 8, all measures correlated significantly.

Table 9. Correlations between Anger/Negative Emotionality, WMI, Inattention, and Hyperactivity/Impulsivity.

	WMI	KSADS: Inattentive Symptoms	KSADS: Hyperactive Symptoms
CBQ: Anger	-.171*	.392***	.393***
TABC: Negative Emotionality	-.172*	.392***	.466***
WMI	--	-.271**	-.204*

*p<.05, **p<.01, ***p<.001

Following the Baron and Kenny (1986) steps outlined above, the extent to which WMI mediates the relationship between Anger and Hyperactive/Impulsive Symptoms of ADHD was examined. Results of the regression analysis can be found in Table 10 and revealed that parent-rated anger was a significant predictor of both WMI (the mediator variable, M), and Hyperactive/Impulsive symptoms of ADHD (the dependent variable, DV). However, when parent-rated Anger and WMI were entered together into the equation only Anger, but not WMI (B= -.060, SE= .039, p=.122) predicted ADHD symptom severity, suggesting that WMI does not mediate the relationship between Anger and Hyperactive/Impulsive symptoms of ADHD.

Table 10. WMI as a mediator of the relationship between parent-rated Anger and Hyperactivity/Impulsive symptoms.

	B	SE	p
IV-M	-1.85	.875	.037
M-DV	-.10	.040	.011
IV-DV (Direct Effect)	2.09	.396	<.001
IV-M-DV (Indirect Effect)	---	---	---

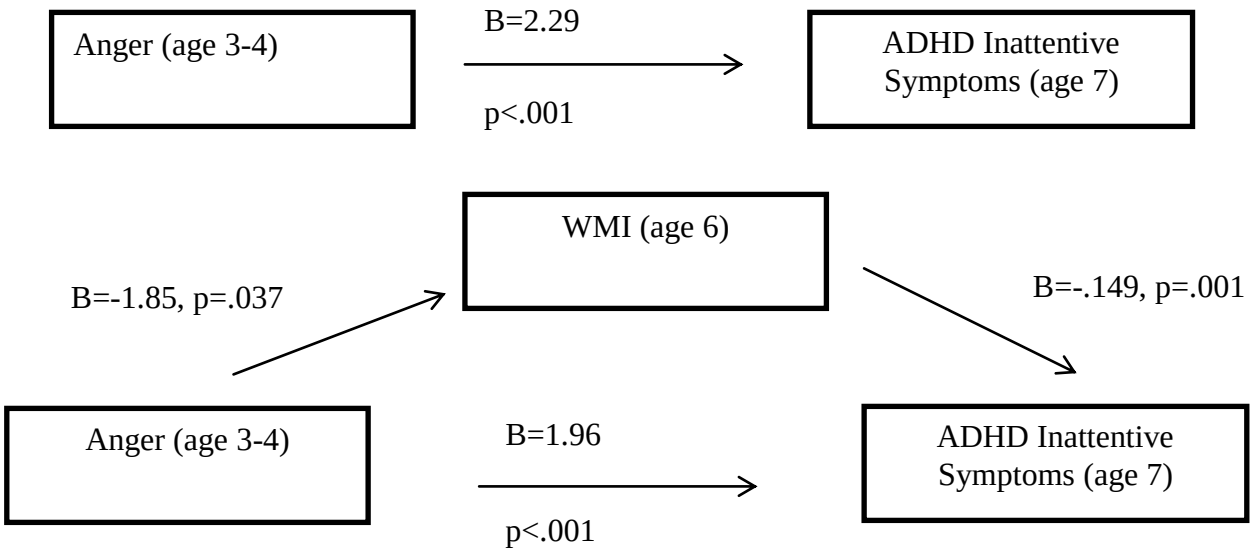
The relationship between parent-rated Anger and Inattentive symptoms of ADHD was also examined. Results of the regression analysis can be found in Tables 11, and revealed that measures of Anger (IV) significantly predicted both WMI (the mediating variable,

M) and inattentive and hyperactive/impulsive symptoms (the dependent variable, DV). When parent-rated Anger and WMI were entered together into the regression, both Anger and WMI predicted Inattentive symptoms of ADHD. Furthermore, there was a drop in the regression coefficient (14%) for parent-rated Anger when WMI was included in the model, suggesting that WMI acts a partial mediator in the relationship between Anger and Inattentive symptoms of ADHD (Figure 5).

Table 11. WMI as a mediator between parent-rated Anger and ADHD Inattentive Symptoms.

	B	SE	p
IV-M	-1.85	.875	.037
M-DV	-.149	.043	.001
IV-DV (Direct Effect)	2.29	.304	<.001
IV-M-DV (Indirect Effect)	1.96	.454	<.001

Figure 5. WMI as a mediator between parent-rated Anger and ADHD Inattentive symptoms.



Similarly, as depicted in Table 12, regression analysis revealed that teacher-rated Negative Emotionality (IV) significantly predicted both WMI (the mediating variable, M) and Hyperactive/Impulsive symptoms of ADHD (DV). However, when entered together into the regression equation only Negative Emotionality and not WMI (B=-.062, SE=.038, p=.108) predicted Hyperactive/Impulsive Symptoms of ADHD, suggesting that WMI does not mediate the relationship between Negative Emotionality and Hyperactive/Impulsive symptoms of ADHD.

Table 12. WMI as a mediator of Negative Emotionality and Hyperactive/Impulsive symptoms of ADHD.

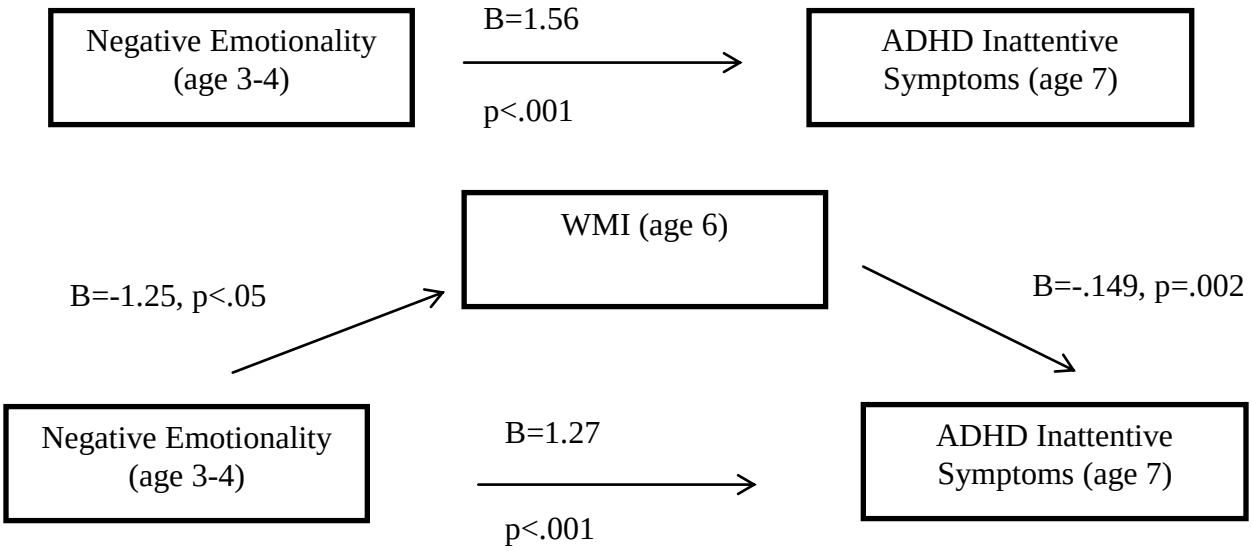
	B	SE	p
IV-M	-1.24	.612	
M-DV	-.10	.040	.002
IV-DV (Direct Effect)	1.69	.268	<.001
IV-M-DV (Indirect Effect)	---	---	---

As depicted in Table 13, regression analyses revealed that teacher-rated Negative Emotionality significant predicted both WMI and Inattentive symptoms of ADHD. When entered together into the regression equation, both Negative Emotionality and WMI predicted Inattentive symptoms of ADHD. Furthermore, there was a drop in the regression coefficient (19%) for teacher-rated negative emotionality when WMI was included in the model, suggesting that WMI acts as a partial mediator in the relationship between Negative Emotionality and ADHD Inattentive symptoms (Figure 6).

Table 13. WMI as a mediator of teacher-rated Negative Emotionality and Inattentive Symptoms of ADHD.

	B	SE	p
IV-M	-1.25	.612	<.05
M-DV	-.149	.043	.002
IV-DV (Direct Effect)	1.56	.304	<.001
IV-M-DV (Indirect Effect)	1.27	.319	<.001

Figure 6. WMI as a mediator between teacher-rated Negative Emotionality and ADHD Inattentive symptoms.



Nonparametric bootstrapping procedures described above indicated that WMI acts as a significant mediator in the relationship between parent-rated Anger and Inattentive symptoms of ADHD (lower CI=.023, upper CI=.533). Similarly, bootstrapping procedures revealed that WMI acts a significant mediator in the relationship between teacher-rated Negative Emotionality and Inattentive symptoms of ADHD (lower CI=.018, upper CI=.370). Since zero is not in the 95% confidence interval, the indirect effect is significantly different from zero at $p<.05$ (two tailed).

NEPSY: Response Set as a mediator between Anger/Negative Emotionality and ADHD Symptoms.

The third set of analyses focused on further addressing the hypothesis that objective neuropsychological measures of executive control would provide a means of assessing the mediating effects of effortful control on the relation between early temperament and later ADHD symptom severity while avoiding the methodological confounds of overlap between items on temperament ratings and symptoms inventories as well as rater effects. The Response Set subtest of the NEPSY was utilized as a proxy for the inhibitory control component of effortful control. Pearson product moment correlations were conducted to assess eligibility of Response Set as a mediator variable. As demonstrated in Table 14, Response Set correlated significantly with ADHD symptoms. While parent-rated Anger correlated significantly with Response Set, teacher-rated Negative Emotionality did not. Therefore, following the recommendations of Baron and Kenny (1986), Negative Emotionality was not examined as a mediating variable.

Table 14. Correlations between Anger/Negative Emotionality, Response Set, and ADHD Total Symptoms.

	NEPSY: Response Set	ADHD Symptoms
CBQ: Anger	-.166*	.416**
TABC: Negative Emotionality	-.045	.452**
NEPSY: Response SET	--	-.355**

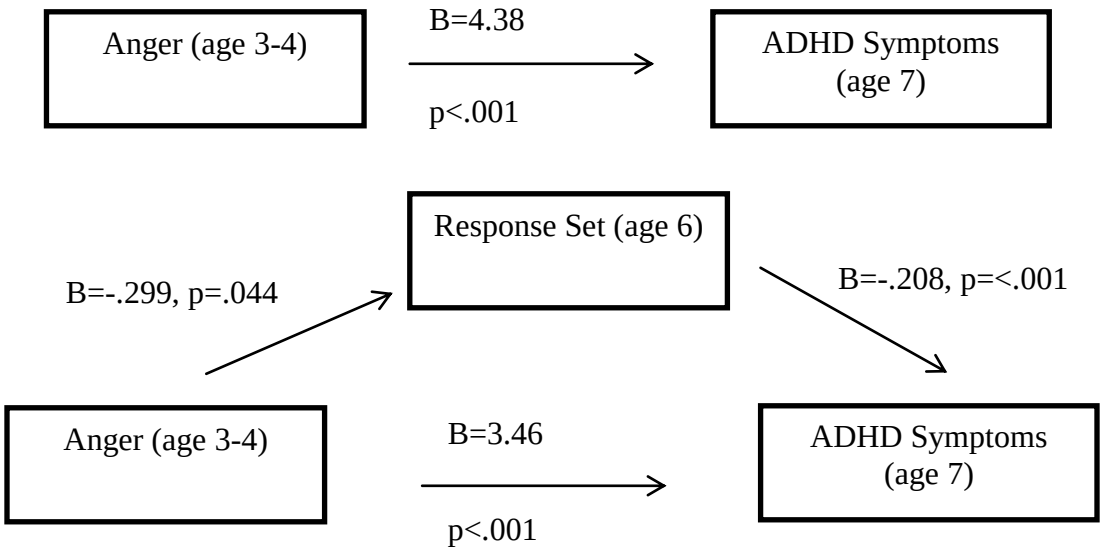
*p<.05, **p<.001

Following the Baron and Kenny (1986) steps outlined above, the extent to which Response Set mediates the relationship between Anger and ADHD symptoms was examined. As depicted in Table 15, results of the regression analysis revealed that parent-rated Anger (IV) significantly predicted both Response Set (the mediating variable) and ADHD symptom severity (the dependent variable). When entered together into the regression, both parent rated Anger and Response Set predicted ADHD total symptoms. Furthermore, there was a drop in the regression coefficient (21%) for parent rated Anger when Response Set was included in the model, suggesting that Response Set acts as a partial mediator in the relationship between Anger and ADHD symptom severity (Figure 7).

Table 15. Response Set as a mediator of parent-rated Anger and ADHD symptom severity.

	B	SE	p
IV-M	-.299	.875	.044
M-DV	-.208	.045	<.001
IV-DV (Direct Effect)	4.38	.771	<.001
IV-M-DV (Indirect Effect)	3.46	.786	<.001

Figure 7. Response Set as a mediator between parent-rated Anger and ADHD symptoms.



The nonparametric bootstrapping procedure described above indicated that Response Set acts as a significant partial mediator of the relationship between parent rated Anger and ADHD symptoms (lower CI=.100, upper CI= 1.034). Since zero is not in the 95% confidence interval, the indirect effect is significantly different from zero at $p<.05$ (two tailed).

Response Set as a mediator of early Anger and later Inattentive and Hyperactive/Impulsive symptoms of ADHD.

Response Set was examined differentially as a mediator of inattentive and hyperactive/impulsive symptoms of ADHD. As depicted in Table 16, all measures correlated significantly.

Table 16. Correlations between Anger, Response Set, Inattention, and Hyperactivity/Impulsivity.

	NEPSY Response Set	KSADS: Inattentive Symptoms	KSADS: Hyperactive Symptoms
CBQ: Anger	-.166*	.392**	.393**
NEPSY: Response Set	--	-.332**	-.335**

*p<.05, **p<.001

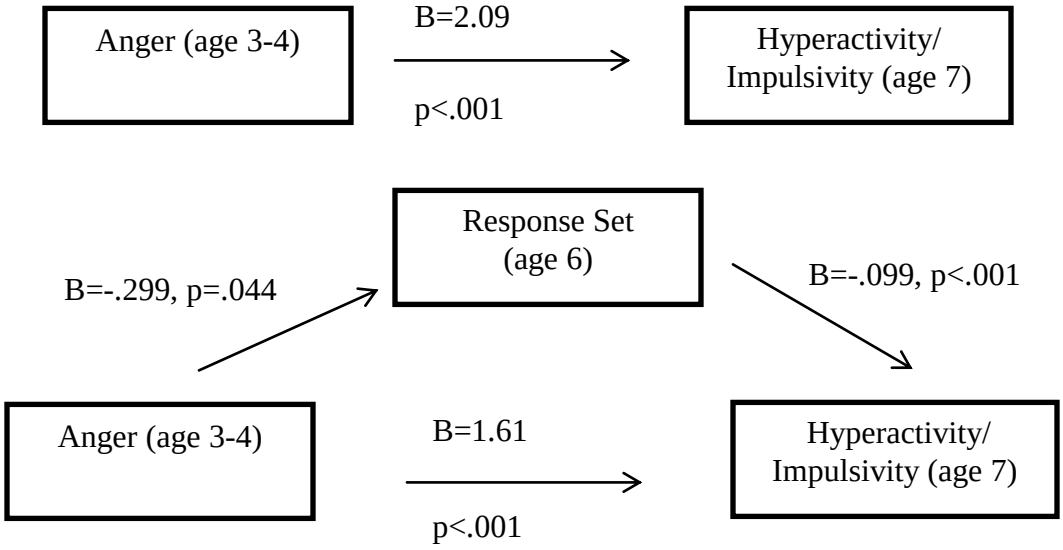
Following the Baron and Kenny (1986) steps outlined above, the extent to which Response Set mediates the relationship between Anger and Hyperactive/Impulsive Symptoms of ADHD was examined. Results of the regression analysis can be found in Table 17 and revealed that measures of Anger (IV) significantly predicted both Response Set (the mediating variable) and hyperactive/impulsive symptoms (the dependent variable, DV). When entered together into the regression, parent-rated Anger and Response Set predicted Hyperactive/Impulsive symptoms of ADHD. Furthermore, there was a drop in the regression coefficient (23%) for parent-rated Anger when Response Set

was included in the model, suggesting that Response Set acts a partial mediator in the relationship between Anger and Hyperactive/Impulsive symptoms of ADHD (Figure 8).

Table 17. Response Set as a mediator of parent-rated Anger and Hyperactive/Impulsive Symptoms of ADHD.

	B	SE	p
IV-M	-.299	.875	.044
M-DV	-.099	.023	<.001
IV-DV (Direct Effect)	2.09	.396	<.001
IV-M-DV (Indirect Effect)	1.61	.406	<.001

Figure 8. Response Set as a mediator between parent-rated Anger and Hyperactivity/Impulsivity.



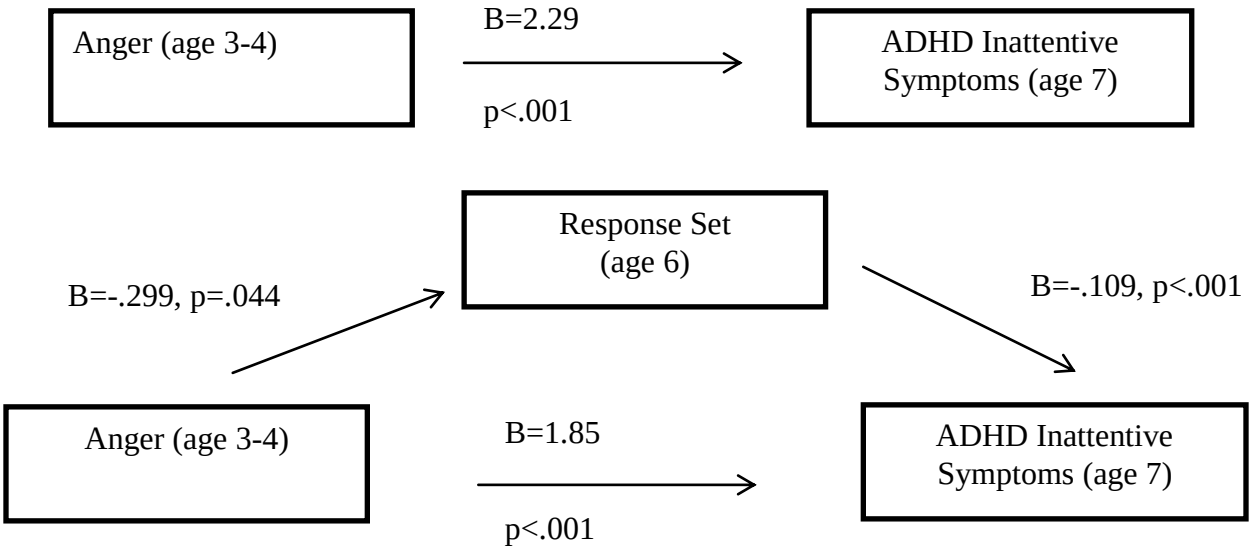
The nonparametric bootstrapping procedure described above indicated that Response Set acts as a significant partial mediator of the relationship between parent rated Anger and Hyperactive/Impulsive symptoms of ADHD (lower CI=.045, upper CI= .546). Since zero is not in the 95% confidence interval, the indirect effect is significantly different from zero at $p<.05$ (two tailed).

Similarly, as depicted in Table 18, regression analyses revealed that parent-rated Anger (IV) predicted both Response Set (M) and Inattentive symptoms of ADHD (DV). When entered together into the regression, both parent-rated Anger and Response Set predicted ADHD Inattentive symptoms. Furthermore, there was a drop in the regression coefficient (19%) for parent-rated Anger when Response Set was included in the model, suggesting that Response Set acts a partial mediator in the relationship between Anger and Inattentive symptoms of ADHD (Figure 9).

Table 18. Response Set as a mediator of parent-rated Anger and Inattentive symptoms of ADHD.

	B	SE	p
IV-M	-.299	.875	.044
M-DV	-.109	.025	<.001
IV-DV (Direct Effect)	2.29	.433	<.001
IV-M-DV (Indirect Effect)	1.85	.446	<.001

Figure 9. Response Set as a mediator between parent-rated Anger and ADHD Inattentive symptoms.



Nonparametric bootstrapping procedures described above indicated that Response Set acts as a significant mediator in the relationship between parent-rated Anger and Inattentive symptoms of ADHD (lower CI=.063, upper CI=.607). Since zero is not in the 95% confidence interval, the indirect effect is significantly different from zero at $p<.05$ (two tailed).

Discussion

This study was designed to examine the hypothesis that reactive temperament acts as a risk factor for ADHD through its negative impact on the development of self-regulatory processes. Specifically, we hypothesized that 1) Negative emotionality measured at age 3-4 would predict later ADHD symptom severity measured at age 7; 2) Early negative emotionality would be associated with development of effortful control at age 6; 3) Effortful control would be inversely associated with ADHD symptoms at age 7; and 4) The relationship between early negative emotionality and later ADHD symptom severity would be reduced when effortful control was added into the model. Given evidence of differential contributions of temperament and control factors to inattentive and hyperactive/impulsive symptoms of ADHD, these relationships were also examined within the distinct symptom domains.

Traditionally, the construct of effortful control has been operationally defined using ratings of temperament. However, recent evidence suggests that effortful control may have cognitive and neural origins. Effortful control requires recruitment of inhibitory and attentional aspects of cognitive control. Inhibitory control, in the Rothbart model, is defined as the ability to inhibit a prepotent response in the service of executing a subdominant more adaptive behavior. Attentional control refers to the ability to organize incoming information, delay gratification, and respond appropriately to selected stimuli (Rothbart, Elis, Rueda, & Posner, 2004). Effortful control is thought to develop in concert with development of frontal executive systems, particularly the anterior attention network (Rothbart, Derryberry, & Posner, 1994), and is thought to rely on neural pathways that have been linked to cognitive control, specifically connections between the anterior

cingulate and the prefrontal cortex (Bush, Lu, & Posner, 2000). Furthermore, laboratory based evidence suggests that ratings of effortful control are correlated with performance on neuropsychological measures of cognitive control as well as activation of the anterior attention network (Gerardi-Caulton, 2000; Davis, Bruce, and Gunner, 2001; Wolf & Bell, 2004). In light of this evidence, effortful control may be best measured utilizing objective neuropsychological measures as opposed to rating scales.

Working memory, frequently measured through digit span tasks (Baddeley and Hitch, 1994), is defined as the ability to simultaneously maintain and manipulate information and is a central aspect of the cognitive control system. The presence of interference can challenge information maintenance and the successful suppression of this interference requires intact cognitive control and may reflect the control function of working memory. Therefore, working memory, much like the attentional control factor (Bell and Deckard, 2007), reflects the ability to maintain information and or a goal in an easily accessible state, even in the face of interference (Kane, Bleckley, Conway, & Engle, 2001). Much like Rothbart's inhibitory control factor, cognitive inhibitory control is often assessed through measures of interference control which refers to the ability to suppress a stimulus that pulls for a competing response so as to carry out another response. Interference control has traditionally been measured utilizing the Stroop paradigm. In this paradigm, a well-learned response competes with the goal of the task which is to successfully endorse a less well- learned response.

One of the limitations of current literature examining the relationship between temperament and ADHD stems from use of rating scales to assess both temperament and ADHD symptoms, often by the same person. This approach introduces the confound of

rater bias. Furthermore, existing measures of temperament contain many items that are very closely related to symptoms of psychopathology (Lahey, 2004). For example, items that assess attentional control on a temperament rating scale closely resemble DSM-IV symptoms of ADHD, thus calling into question whether ratings of temperament and ADHD are measuring distinct or overlapping constructs. In order to address methodological constraints in the current literature, we employed objective neuropsychological measures of working memory and inhibitory control to serve as proxies for temperamentally rated effortful control. This approach allows us to elucidate the relationship between early temperamental factors and ADHD symptoms in later childhood without the above mentioned confounds.

Preliminary analyses indicated that attentional and inhibitory control (scales that make up the effortful control factor) rated by parents at age 3-4 significantly predicted performance on both measures of working memory and inhibitory control at age 6. However, attention, but not inhibitory control rated by parents at age 6 predicted working memory and inhibitory control performance at age 6, suggesting that the relationship between these constructs changes over the course of development.

Consistent with our first hypothesis, results indicated that both parent and teacher rated negative emotionality at ages 3-4 years predicted ADHD symptom severity at age 7, suggesting that early negative emotionality represents a risk factor for ADHD. Similarly, consistent with our third hypothesis, both parent rated temperamental effortful control, as well as performance on objective measures of effortful control (i.e., working memory and response inhibition) at age 6 years were inversely associated with ADHD symptom severity at age 7 years. Associations between higher negative emotionality and greater

ADHD symptom severity and lower effortful/executive control and greater ADHD symptom severity are consistent with findings in the current literature (Pauw and Merviedle, 2010) and confirm the hypothesis that high negative emotionality and low effortful control act as risk factors for ADHD symptom severity. However, our findings are unique in that they examine these associations within a longitudinal model and utilizing specific clinical symptoms of ADHD, rather than externalizing problems more generally, as an outcome measure.

Consistent with our second hypothesis, parent and teacher rated negative emotionality at age 3-4 was inversely associated with parent temperament ratings of effortful control at age 6. Furthermore, both parent and teacher ratings of negative emotionality at age 3-4 were inversely associated with working memory at age 6. Findings with regard to response inhibition were not as consistent, as significant inverse association was found only between parent, but not teacher, rated negative emotionality and performance on a measure of response inhibition at age 6.

These patterns of association are again consistent with literature suggesting that temperamental reactivity is inversely associated with subsequent control mechanisms (Rothbart & Sheese, 2007; Putnam & Rothbart, 2008) and may impact development of executive functions, such as working memory and inhibitory control (Wolf & Bell, 2007). Furthermore, the fact that the associations were present within a longitudinal/developmental model, lends support to the proposal that negative emotionality exerts a harmful effect on the development of self-regulatory abilities (Calkins & Degnan, 2006).

In order to evaluate the fourth hypothesis that the relationship between early negative emotionality and later ADHD symptoms severity would be reduced when effortful control was added into the model, the mediating effect of effortful control on the relationship between negative emotionality and ADHD was examined. Given that parent and teacher rated negative emotionality is significantly associated with effortful control and ADHD, and effortful control is significantly associated with ADHD, conditions were met under the recommendations of Baron and Kenny (1986) to examine mediation effects. As hypothesized, results indicated that when temperamentally rated effortful control was entered into the model the relationship between parent and teacher rated negative emotionality and ADHD was reduced. When neuropsychologically-measured working memory was entered into the model, the relationship between parent and teacher rated negative emotionality and ADHD was similarly reduced. Mediation using teacher rated negative emotionality and response inhibition could not be examined because teacher rated negative emotionality was not significantly correlated with response inhibition. However, when response inhibition was entered into the model the relationship between parent rated negative emotionality and ADHD was also reduced. As predicted, both temperamentally rated effortful control and neuropsychological measures of attentional and inhibitory control measured at age 6 partially mediated the relationship between early negative emotionality and later ADHD symptom severity. Furthermore, nonparametric bootstrapping procedures (Preacher & Hayes, 2004) indicated that all mediation effects were significant. These findings suggest that developing mechanisms of effortful control help to explain the relationship between negative emotionality and ADHD symptom severity. Furthermore, these findings lend support to the hypothesis that

negative emotionality, at least in part, acts as a risk factor for development or persistence of behavioral difficulties through its influence on the development of control mechanisms. Parallel findings between temperamentally rated effortful control and neurocognitively measured executive control (i.e., working memory and response inhibition) suggest that these neuropsychological measures parallel temperamental ratings of attentional and inhibitory control and represent an appropriate means by which to assess these constructs. Although the mediating effect of temperamentally rated effortful control was ostensibly stronger than that of neuropsychologically-measured working memory and response inhibition, this is not surprising given the overlap between temperament ratings of effortful control and ADHD symptoms and the use of observer report to measure both.

The mediating effect of working memory and response inhibition was also examined for symptoms of inattention and hyperactivity/impulsivity individually. Results revealed that parent and teacher rated negative emotionality was associated with both inattentive and hyperactive/impulsive symptoms of ADHD, as was working memory. However, working memory only mediated the relationship between negative emotionality and inattentive, but not hyperactive/impulsive, symptoms of ADHD. In contrast, response inhibition mediated the relationship between parent rated negative emotionality and both symptoms of inattention and hyperactivity/impulsivity. These findings are consistent with evidence that inhibitory control deficits are characteristic of ADHD- Combined Type (i.e., symptoms of both inattention and hyperactivity/impulsivity) (Nigg, 2003), whereas working memory deficits are more strongly associated with symptoms of inattention (Lui and Tannock, 2007, Tillman, Eninger, Forssman & Bohlin, 2011).

The current study replicates findings in the existing literature regarding the relationships between temperament factors and ADHD. In addition, findings from this study extend the existing literature by examining these relationships within a longitudinal design and utilizing objective neuropsychological measures of effortful control. Although patterns of high negative emotionality and low effortful control in association with ADHD have been established in the literature (De Pauw and Merviedle, 2010), the extent to which these temperament traits exert an independent influence on ADHD or work together to influence expression of the disorder has been unclear (Muris & Ollendick, 2005). Results of the current study help shed light on the nature of the relationship between reactive and regulatory temperament traits and their collaborative influence on ADHD symptom severity. Specifically, our findings suggest that tendencies toward negative emotionality place children at risk for ADHD, at least partially, by interfering with the development of effortful control.

Similar to Sonuga-Barke's (2005) model of ADHD, Martel and Nigg (2006) propose that two pathways to ADHD may exist. One "main" pathway reflects disruption of control systems and another "secondary" pathway occurs through negative emotionality. Similarly, Martel, Nigg, and Von Eye (2009) proposed a two trait model of ADHD with "bottom-up" temperament traits, such as negative emotionality, associated with hyperactive/impulsive symptoms and "top-down" control associated with inattention. However, our findings suggest that negative emotionality and executive control do not reflect distinct pathways toward the same disorder, but instead work together to influence expression of ADHD symptomatology. The mediating effect of effortful control on the relationship between early negative emotionality and later ADHD

symptom severity observed in this study suggests that while "bottom-up" factors reflect early risk for development of behavioral difficulties through their impact on "top-down" control, failures of "top-down" control are associated with continued symptom severity. Furthermore, our findings are consistent with the Halperin and Schultz (2006) model of ADHD. This model suggests that "bottom-up" and "top-down" dysfunction do not represent distinct pathway toward ADHD. Instead, they propose that ADHD represents early and enduring ("bottom-up") subcortical dysfunction, while symptom improvement reflects increases in development of prefrontal cortical areas and connections between these areas and subcortical brain structures (top-down control). Thus development of executive functioning is associated with overt symptom improvement, while poor development of these control mechanisms is associated with ADHD persistence. This model is further supported by neuroimaging evidence suggesting that remission of ADHD with age may reflect normalization of initial deficits in cortical brain development (Shaw, Gogtay, & Rapoport, 2010), particularly connections between the dorsolateral prefrontal cortex and anterior cingulate cortex thought to represent the executive functions network (Makris et al., 2007). Moreover, our findings lend support to the idea alluded to in the Halperin and Schultz (2006) model that early subcortical damage is likely to impinge upon optimal cortical development and/or development of cortical-subcortical networks. In other words, "bottom-up" dysfunction is likely to impact development of "top-down" control.

Our findings suggest that negative emotionality may reflect an independent pathway toward the development of ADHD through its impact on effortful control, and temperamental variability may help to explain heterogeneity in symptom expression and

degree of impairment. On the other hand, there is evidence to suggest that temperamental measurements of negative emotionality, particularly the anger component, is associated with other aspects of reactive temperament and therefore may be more generally reflective of strong approach tendencies (Rothbart, et al., 2000), characteristic of children with ADHD. Negative emotionality may therefore reflect disruption of "bottom-up" functioning more generally.

Results from this study add to an understanding of the relationship between temperament and psychopathology. Moreover, findings from this study add to the growing body of literature suggesting that neurocognitive development mediates outcomes in ADHD, and adds support to the idea that with development, brain areas associated with cognitive control begin to play a greater role in emotion regulation (Pearlman & Pelphery, 2010). Growing support for the role of neurocognitive development in mediating outcomes in ADHD has led to an interest in development of novel treatment intervention focused on developing and remediating mechanisms of executive control (Klingberg, et al., 2005; Diamond, Barnett, & Munro, 2007; Halperin et al., 2012). Our findings lend support to the role that cognitive control plays in mediating ADHD severity and thus the potential importance of interventions targeting development of these abilities.

Findings from this study not only add support to the role of "top-down" control in ADHD, but add an understanding of the role that "bottom-up" factors play in this relationship. Specifically, our results suggest that negative emotionality represents an early risk factor for underdevelopment of both temperamentally rated and neurocognitively measured effortful control and thus ADHD. One of the proposed

mechanisms by which negative emotionality exerts its impact on development of effortful control is by limiting the child's interaction with the environment, thereby limiting opportunities to develop and implement self-regulatory skills (Calkins & Denigan, 2006). Interestingly, the neuroscience literature strongly supports this idea that development of executive control is dependent upon environmental input and social interaction (Halperin & Healey, 2011). Furthermore, it is upon this notion of the importance of environmental enrichment that many novel ADHD treatments have been based.

Given the harmful effects of negative emotionality, identifying children at risk (i.e., those high in negative emotionality) may be an important focus for early preventative interventions. Many interventions developed to date target direct development of effortful control mechanisms, such as computer programs designed to enhance working memory abilities (Klingberg et al., 2005). However, given that early negative emotionality appears to confer significant risk for later ADHD symptom severity, interventions designed to directly address early negative emotionality may be warranted. Furthermore, given evidence that negative emotionality impedes development of effortful control, interventions designed to address intervening variables in the pathway between negative emotionality and effortful control may also be helpful. For example, there is evidence to suggest that children high in negative emotionality elicit less effective parenting strategies, which are also associated with poor development of effortful control. Therefore, programs designed to promote parenting strategies thought to support development of effortful control in children identified as at risk due to high levels of negative emotionality, may be an additional possible area of intervention.

Despite evidence that negative emotionality impacts upon development of effortful control, the mechanisms through which this effect occurs have not yet been clearly elucidated. Future research should therefore focus on developing a better understanding of the manner in which negative emotionality influences development of temperamental and neurocognitive control in order to help inform development of additional novel interventions. Effortful control in this study acted only as a partial mediator between negative emotionality and ADHD. Thus, it remains unclear if negative emotionality also exerts a direct effect on ADHD symptom severity or if additional variables mediate this relationship.

This study has several notable strengths. The majority of studies to date have utilized cross-sectional models to investigate relationships between temperament and psychopathology. However, a longitudinal design allows for a better understanding of the developmental trajectory of this relationship. Furthermore, effortful/executive control abilities are thought to develop over childhood (Rothbart et al., 2003) and the nature of their relationship with ADHD symptomatology may evolve over the course of development (Martel, Nigg, & Von Eye, 2009). Therefore, examining these constructs within a cross-sectional study may not allow for full appreciation of their developmental course. Our study examined effortful control at age 6. Although effortful control is thought to be reasonably well developed by around the ages of six or seven years, development of the executive function networks thought to subserve these abilities takes place throughout childhood and into adolescence. Therefore, despite the longitudinal design, our results are limited by the somewhat restricted age range, and should be replicated in older samples. Use of objective neuropsychological measures of cognitive

control as a proxy for effortful control represents another area of strength in this study, as it helps to address the confound introduced by use of rating scales to assess both temperament and psychopathology. Although negative emotionality in this study was assessed via rating scales, we specifically chose to focus on this aspect of reactive temperament because in addition to being consistently associated with ADHD items on this subscale do not at face value overlap with items on ADHD symptom rating scales. In addition, ratings of negative emotionality were obtained at different time points from those of ADHD and also by different raters. Furthermore, with the exception of response inhibition, findings were replicated using both parent and teacher ratings of negative emotionality. However, future studies can focus on replicating our results utilizing more objective, laboratory based, measures of negative emotionality. Finally, an additional strength of our study was the use of clinical criteria to make determinations about ADHD symptomatology and the integration of multiple sources of information to make decisions regarding symptom endorsement. However, it should be noted that although parent, teacher, and clinician information was utilized to make decisions about ADHD symptomatology, the semi-structured interview (K-SADS) utilized in our study is predominantly parent driven. Therefore, it is possible that there is some overlap between parent ratings of negative emotionality at age 3-4 and ADHD symptoms at age 6.

Despite some limitations as noted above, the results of this study add to an understanding of the relationship between temperament and behavioral difficulties and the process by which temperament acts as a risk factor for the persistence of ADHD symptom severity. Furthermore, these findings highlight the important influences of emotionality on the development of neurocognitive control and thus expression of ADHD

symptomatology. The findings also have important implications for future treatment approaches in ADHD. Given increasing evidence of the role that neurocognitive development, and particularly executive functioning, plays in mediating outcomes in ADHD, there has been increased focus on development of treatments focused on remediating these areas of dysfunction. For example researchers have begun using working memory training programs as an intervention for ADHD (Klingberg, et al., 2005). However, given the central role of negative emotionality in the development of effortful control and ADHD symptoms (both directly and indirectly through effortful control) it may be necessary to further elucidate the mechanisms by which negative emotionality exerts its harmful effects in order to help inform additional treatment options.

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