UNDERSTANDING AND PREDICTING THE EARLY COURSE OF SYMPTOMS OF ATTENTION DEFICIT HYPERACTIVITY DISORDER

by

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B. A., New York University, 1999

Submitted to the Graduate Faculty of

Arts and Sciences in partial fulfillment

of the requirements for the degree of

Masters of Science

University of Pittsburgh

2006

UNIVERSITY OF PITTSBURGH

ARTS AND SCIENCES

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Using data from the NICHD Study of Early Child Care, we examined whether: 1) attention deficit hyperactivity disorder (ADHD) symptoms remain stable from preschool (54 months) through early school age (1st grade); 2) preschool behavioral inhibition moderates the relationship between preschool and first grade ADHD symptomatology; and 3) deficits in behavioral inhibition at preschool age mediate the relationship between ADHD symptomatology assessed at preschool and first grade. Modest stability in ADHD symptoms from 54 months to 1st grade was found. Two out of three measures of inhibition predicted later teacher ratings uniquely. However, no evidence of moderation or mediation was found. Results are discussed in terms of executive and motivational facets of inhibition that may be related to early signs of ADHD.

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PREFACE

I would like to thank Susan B. Campbell, Daniel S. Shaw, and Brooke S. Molina for their comments on earlier versions of this article. In addition, Emily Moye Skuban must also be mentioned for the invaluable formatting advice that she provided. Finally, I would like to thank the investigators who designed the larger study, the site coordinators and research assistants who collected the data, and the children, parents, and teachers who participated in this longitudinal investigation. This research was supported by the National Institute of Child Health and Human Development (Grant HD25420). Correspondence concerning this article should be addressed to Camilla von Stauffenberg, Department of Psychology, University of Pittsburgh, 3215 Sennott Square, 210 South Bouquet Street, Pittsburgh, PA 15260 or by e-mail (cav5@pitt.edu).

1.0 INTRODUCTION

Over the past two decades Attention-Deficit/Hyperactivity Disorder (ADHD) has become one of the most commonly diagnosed and studied childhood disorders (see for review, American Academy of Pediatrics, 2000; Swanson, Lerner, & Williams, 1995; Tannock, 1998). Major questions still remain, however, about its etiology, developmental course, and early indicators (Rowland, Lesesne, & Abramowitz, 2002).

Historically, ADHD has been defined by core behavioral symptoms of excessive inattention, hyperactivity and impulsivity (Barkley, 1997; Campbell, 2000). In the DSM-IV (Diagnostic and Statistical Manual of Mental Disorders (4th ed.), American Psychiatric Association, 1994) this definition was modified somewhat and ADHD is now diagnosed by the presence of deficits in two primary areas: hyperactivity-impulsivity and inattention. Childhood ADHD is associated with maladjustment in many domains of functioning over the course of development (American Academy of Pediatrics, 2000). For instance, "hard-to-manage" preschool-age children exhibiting ADHD symptomatology have been found to be at significant risk for later behavioral, social, familial, and academic difficulties relative to their normal counterparts (Campbell, Pierce, March, Ewing, & Szumowski, 1994). ADHD in school-age children has been found to increase the likelihood of later violence, delinquency, driving accidents, impaired social relationships, poor academic achievement, risky sexual behavior, smoking and substance abuse (Barkley, 1997; Rowland et al., 2002; Tannock, 1998; Taylor, Chadwick, Heptinstall, & Danckaerts, 1996). Overall, children with ADHD disproportionately use medical and mental health services compared to children without ADHD (Rowland et al., 2002). Given the costly toll that ADHD takes on individual adjustment, family life, schools and social services, the benefits associated with understanding the developmental course and underlying mechanisms of ADHD, which may eventually lead to early identification and treatment, are immeasurable.

Clarifying the early developmental course of ADHD involves three fundamental tasks. First, the longitudinal stability of ADHD symptoms must be established. Second, potential underlying mechanisms of, or early contributors to, ADHD must be identified. This search should be guided by theoretical models of ADHD, which, based on some empirical data, have identified possible underlying mechanisms. Third, the predictive power of these underlying mechanisms must be tested in a community sample across time. The credibility and utility of the proposed underlying mechanisms rely on their ability to either predict the emergence of ADHD symptoms, or explain the continuity in ADHD symptoms over time, in a non-clinical sample. The current study aims to identify cognitive or behavioral factors in the preschool period that act as predictors and also possible underlying mechanisms of ADHD symptomatology at school entry in a large community sample. Furthermore, the results of this study may be used to inform our understanding of the early development of ADHD, and subsequently to guide future early identification and treatment efforts.

Based upon a review of the empirical and theoretical research on ADHD, I propose that a deficit in behavioral inhibition in preschoolers may be an early contributing factor to the development and maintenance of ADHD symptoms. Behavioral inhibition has been measured using a variety of tasks. In the current study behavioral inhibition will be operationalized by three measures often used to index this construct: a preschool version of the Continuous Performance Task (CPT), the Day-Night Stroop Test, and a Delay of Gratification Task (DGT). Specifically, I will examine whether children's performance on these tasks at 54 months predicts "attentional problems" in first grade, and whether performance then also moderates or mediates the relation between "attentional problems" at 54 months and first grade, as rated by teachers on the Teacher Report Form (TRF). In addition, because the focus is on "attentional problems" and ADHD symptoms including both inattention and impulsivity, an early marker of potential attention problems will also be included, CPT omission errors, thought to index lapses in attention (Halperin, Sharma, Greenblatt, & Schwartz, 1991).

In order to establish a clear rationale for this study, I review several theoretical models of ADHD and relevant studies involving preschool and school-age children with ADHD. First, I will review five theoretical models of ADHD that attempt to explain the development and underlying mechanisms of ADHD. Behavioral inhibition is a common factor identified in all five models. Next, I will review the empirical findings linking ADHD to inhibition deficits and argue that problems with inhibitory control may serve as an early indicator of ADHD as well as an underlying mechanism in the development of ADHD. I will then explore possible measures of this construct and provide the rationale for operationalizing behavioral inhibition using the CPT, Delay of Gratification and Stroop tasks noted above. Finally, the need for, and the strengths of, this study will be highlighted by examining the current literature on the development of ADHD in preschool and early school age children.

2.0 LITERATURE REVIEW

2.1 THEORETICAL MODELS OF ADHD AND THE ROLE OF INHIBITION

Over the past fifteen years, five major theoretical models of ADHD have emerged (Sergeant, Geurts, Huijbregts, Scheres, & Oosterlaan, 2003). They are the Behavioral Inhibition / Activation Model (Quay, 1988), the Delay Aversion Hypothesis (Sonuga-Barke, 1994), the Executive Function Model (Pennington & Ozonoff, 1996), the Behavioral Inhibition Model (Barkley, 1997), and the Cognitive-Energetic Model (Sergeant, Oosterlaan, & van der Meere, 1999). Despite different emphases, these models all posit deficient behavioral inhibition as a central feature of ADHD.

Quay (1988) speculated that the fundamental biological and behavioral basis of ADHD could be explained by the neuropsychological theory proposed by Gray in 1982. This theory asserts that there are three systems that underlie instrumental learning, which in turn affect all areas of human behavior: the behavioral inhibition system (BIS), the behavioral activation system (BAS), and the flight-fight system. The Behavioral Inhibition/Activation model postulates that the inability of ADHD children to withhold an inappropriate response is due to an under-active BIS (Quay, 1988). The BIS is responsible for reducing or terminating ongoing behavior in response to signals of impending punishment, pain or novelty. According to this theory, inhibition deficits resulting from an under-responsive BIS constitute the core problems in ADHD (Quay, 1997).

In the Delay Aversion Hypothesis, ADHD symptoms are accounted for by an underlying motivational style (Sonuga-Barke, 1994, 2002; Sonuga-Barke, Houlberg, & Hall, 1994), in contrast to models that identify ADHD symptomatology as a result of a dysfunction in inhibition and/or regulation. More specifically, ADHD children have a primary deficit in their reward processes (a shorter than normal delay-of-reinforcement gradient), which translates into a decreased tolerance for delay (Sagvolden & Sergeant, 1998). As a result, children with ADHD are motivated to escape or avoid delay. The hallmark inattentive, hyperactive and impulsive behaviors associated with ADHD represent strategies children use to minimize delays in the face of valued rewards (Sonuga-Barke, 1994, 2002). Some empirical findings linking ADHD with hypersensitivity to delay are consistent with this central tenet of the Delay Aversion Hypothesis (Sonuga-Barke, 2003). Thus, this model attempts to explain inhibition deficits in terms of motivation rather than regulation.

Based upon a review of the empirical literature, Pennington and Ozonoff (1996) proposed that an underlying combination of executive function and general cognitive deficits account for the symptoms of ADHD. They defined executive function as “the ability to maintain an appropriate problem-solving set for attainment of a future goal,” which includes such domains as inhibition, working memory, planning, and interference control. Their Executive Function Model rests upon the results of 18 studies, which demonstrate that deficits on executive function tasks are consistently found in samples of ADHD children (Pennington & Ozonoff, 1996; Sergeant et al., 2003). Executive function tasks measuring inhibition have been found to be especially sensitive to ADHD, including the Stroop test, Tower of Hanoi, Matching Familiar Figures Test, Trailmaking Test and an assortment of motor inhibition measures (see Table 1).

Table 1: Consistency of Differences and Average Effect sizes of Executive Function Measures in ADHD

Measures	Consistency†	Average *d*
Wisconsin Card Sorting Task		
perseverations	4/10	0.45
TrB time	4/6	0.75
MFFT		
time	4/6	0.44
errors	5/5	0.87
Stroop time	4/5	0.69
Mazes	¾	0.43
Letter Fluency	¼	0.27
Category Fluency	0/3	
Tower of Hanoi	3/3	1.08
Motor Inhibition tasks	6/6	0.85

Notes. †Number of studies finding a significant group difference/number of studies employing the measure. (Pennington & Ozonoff, 1996)

These results, in conjunction with findings showing that executive function deficits are reversed by stimulant medication, led Pennington and Ozonoff to conclude that ADHD children may have a primary executive function deficit, particularly in inhibition.

Barkley's (1997) Behavioral Inhibition Model also identifies executive function deficits as primary. According to Barkley, a behavioral inhibition deficit cascades through the neuropsychological and behavioral substrates. For example, impaired behavioral inhibition interferes with optimal functioning on certain executive tasks, such as working memory, self-regulation of affect/motivation/arousal, internalization of speech and reconstitution (analysis of events or messages through decompositions and then synthesis of component parts in order to reconstruct novel responses or messages) (Barkley, 1997). Deficits arising in these four specific executive functions, as a result of the primary impediment in behavioral inhibition, in turn, lead to decreased control over motor behavior. Barkley concludes that these deficits, spearheaded by behavioral inhibition, working in concert are manifested in the inattentive, hyperactive and impulsive symptoms of ADHD.

Sergeant and colleagues have proposed the Cognitive-Energetic Model, which they argue is the most comprehensive theory of ADHD as it subsumes all of the other models described above (Sergeant, 2000; Sergeant et al., 2003). Instead of identifying one primary deficit responsible for the constituent symptoms of ADHD, the cognitive-energetic model highlights several contributing motivational, neuropsychological and cognitive deficiencies at three levels: lower level cognitive processes such as response output, energetic pools such as activation and effort, and executive functions such as inhibition, set shifting, planning, fluency and working memory (Sergeant et al., 1999). Ultimately, the Cognitive-Energetic model proposes that ADHD symptomatology results from inhibition deficits in combination with the specific state (arousal) of the child and his or her allocation of energy to any given task (motivation) (Sergeant, 2000).

Even though all of the models incorporate inhibition, they differ regarding the precise definition and role that they attribute to it. To some degree, the diversity of definitions of inhibition amongst the ADHD models reflects the amorphous nature of the construct within the broader literature (Nigg, 2000, 2001). Reciprocally, the loose definition of inhibition is perpetuated by the disparate views proposed by the models. Each model incorporates an inhibition deficit in their espoused underlying mechanisms, in their description of ADHD, or, more commonly, in both. The models differ according to their definition and whether they ascribe a primary or secondary role to the underlying inhibition deficit (Nigg, 2001). For instance, the Behavioral Inhibition model asserts that ADHD is primarily driven by an inhibition deficit (Barkley, 1997). An inhibition deficit is relegated to a secondary role in the Cognitive-Energetic Model; it is not considered to be the primary deficit that is ultimately responsible for ADHD (Sergeant et al., 1999). On the extreme end of this spectrum lies the Delay Aversion Model. This model denies that an underlying inhibition deficit accounts for the behavioral problems observed in children with ADHD. Instead, it suggests that a hypersensitivity to delay is responsible (Sonuga-Barke, 1994, 2002) and this delay aversion is partly manifest as impulsive behavior (i.e. difficulty waiting). rarely an absolute or global outcome. Rather, it is circumscribed and may change over time relative to both the course of development and life circumstances (Masten & Garmezy, 1985; Werner & Smith, 1982), as well as the manner in which it is assessed.

2.1.1 Behavioral Inhibition

As noted above, all of the models include deficient inhibition, although, there is little consensus regarding the definition of inhibition and the specific role that it plays in the etiology of ADHD. Despite the lack of agreement in these areas, the fact that inhibition is common to all of the ADHD models, has accepted measurement tools, and is seen in young children recommends it as a underlying mechanism that may contribute to the development and maintenance of ADHD symptoms. However, before inhibition can be examined as an underlying mechanism, it must be more clearly defined.

For the purposes of this paper, I will employ a definition of behavioral inhibition similar to that used by Barkley (1997). Behavioral inhibition will refer to the ability to suppress a dominant response to an event. Suppression of the response may occur before the response is initiated or while the response is on-going. A dominant response is associated with either immediate or prior positive or negative reinforcement. In other words, the failure to withhold dominant responses, despite either threat of punishment or loss of desirable rewards, is defined in this paper as a behavioral inhibition deficit.

Measurement concerns must also be considered when choosing to test a potential contributing factor of ADHD. Fortunately, due to its long history in the research literature, behavioral inhibition can be assessed with multiple measures (Nigg, 2001). Assessments which have been commonly used to measure behavioral inhibition in children include the Continuous Performance Test (CPT), delay of gratification tasks (DGT), Go/no-go paradigm, Matching Familiar Figures Task, Stop-signal paradigm, and the Stroop test (Barkley, 1997; Nigg, 2001; Pennington & Ozonoff, 1996). Specifically, in preschool children behavioral inhibition has been assessed using age-appropriate versions of the CPT, DGT, and the Stroop test (Campbell et al., 1994; Gerstadt, Hong, & Diamond, 1994; Mariani & Barkley, 1997). Therefore, for the purposes of this study, measurement will not be an obstacle to testing whether or not behavioral inhibition acts as a contributing factor to the development and maintenance of ADHD symptoms in young children.

2.2 STUDIES OF INHIBITION AND ADHD SYMPTOMS IN SCHOOL-AGE CHILDREN

The emphasis on executive function deficits, such as behavioral inhibition, in models of ADHD has progressed in tandem with empirical research exploring their interrelation (Barkley, 1997; Nigg, 2001; Pennington & Ozonoff, 1996). To date, the overwhelming majority of studies assessing various aspects of inhibition have demonstrated a concurrent inhibition deficit in school-age children exhibiting ADHD symptomatology compared to children without signs of ADHD (see for reviews, Barkley, Grodzinsky, & DuPaul, 1992; Corkum & Siegel, 1993; Homack & Riccio, 2004; Losier, McGrath, & Klein, 1996; Oosterlaan, Logan, & Sergeant, 1998; Pennington & Ozonoff, 1996; Tannock, 1998). From these studies we can conclude that behavioral inhibition deficits are related to ADHD symptoms. However, the majority of these studies has not examined the nature of this relation over time, and, hence, do not provide answers regarding the development of ADHD symptomatology. Furthermore, these studies have failed to examine behavioral inhibition as a potential mediator and / or moderator of ADHD symptomatology across time. Without conducting such analyses, little insight can be provided into the mechanisms underlying the development and maintenance of ADHD symptoms.

Studies do exist which have examined the longitudinal stability of early ADHD symptoms (Lahey et al., 2004; Lahey, Pelham, Loney, Lee, & Willcutt, 2005; Pierce, Ewing, & Campbell, 1999). However, these studies have not investigated potential mechanisms, which may underlie this temporal stability. More specifically, Lahey and colleagues (2004) examined the three-year predictive validity of DSM-IV ADHD in children diagnosed between 4 and 6 years of age. They found that children who met full diagnostic criteria during their first assessment were likely to continue to meet diagnostic criteria for ADHD over the next 3 years. Pierce et al. (1999) found that symptoms of ADHD identified in hard-to-manage preschool boys predicted continuing problems in middle childhood. The present study aims not only to replicate these findings, but also to advance current knowledge by examining the role played by a potential underlying mechanism: behavioral inhibition. Inhibition deficits at preschool age may underlie the development and maintenance of early ADHD symptoms by exacerbating their later occurrence and intensity. In addition, it is possible that behavioral inhibition may mediate the association between ADHD symptoms in early childhood and ADHD symptoms upon formal school entry by accounting for the initial symptoms at preschool age.

Behavioral inhibition has been operationalized using a variety of measures, such as the Continuous Performance Task (see for reviews, Barkley et al., 1992; Corkum & Siegel, 1993; Losier et al., 1996), Delay of Gratification Tasks, the Matching Familiar Figures Test (Campbell, Douglas, & Morgernstern, 1971; Pennington & Ozonoff, 1996; Weyandt & Grant, 1994), the Stop Task (see for review, Oosterlaan et al., 1998) and the Stroop Test (see for review, Homack & Riccio, 2004). In the current study behavioral inhibition will be measured using CPT commission errors, DGT waiting time and Stroop interference effects for the following two reasons: not only have these three measures been used extensively in research on school-age children, they have also been used successfully with preschool age populations. Finally, CPT omission errors will also be examined. CPT omission errors are thought to index lapses in attention, which, even though they are not the focus of the present study, have historically enjoyed a strong association with ADHD and are, as a result, implicated in the developmental course of the disorder (Epstein et al., 2003; Losier et al., 1996).

A voluminous literature exists that examines inhibition and ADHD symptomatology in school-age children. For the sake of consistency, I will focus on the studies that have operationalized inhibition using the CPT, DGT and Stroop test (Berlin, Bohlin, Nyberg, & Janols, 2004; Collings, 2003; Corkum & Siegel, 1993; Doyle, Biederman, Seidman, Weber, & Faraone, 2000; Epstein et al., 2003; Gorenstein, Mammato, & Sandy, 1989; Grodzinsky & Barkley, 1999; Homack & Riccio, 2004; Losier et al., 1996; McGee, Clark, & Symons, 2000; Nichols & Waschbusch, 2004; Savitz & Jansen, 2003; Semrud-Clikeman et al., 2000). The number, as well as diversity, of studies reporting significant results attests to the robust nature of the concurrent relation between deficient inhibition and ADHD symptomatology in school-age children.

Four out of the five studies mentioned above that employed the CPT as a measure of inhibition found that the ADHD group on average made significantly more errors of commission than the control group (Berlin et al., 2004; Epstein et al., 2003; Grodzinsky & Barkley, 1999; McGee et al., 2000). In their meta-analysis, Losier and colleagues (1996) similarly conclude that children with ADHD make significantly more errors of commission than normal children. However, an earlier review conducted by Corkum and Siegel (1993) reported more equivocal results. For example, out of the 10 studies reviewed which used the more traditional measures derived from the CPT, such as commission errors, only four studies found significant differences in the number of commission errors made by the ADHD group compared to the control group.

Results for the Stroop and Delay of Gratification tests provide even stronger support for the relation between inhibition deficits and symptoms of ADHD. Homack and Riccio (2004) conducted a meta-analysis examining whether performance on the Stroop test is significantly associated with ADHD and other developmental disorders in school-age children. The authors concluded that children with ADHD symptoms consistently exhibit stronger interference effects on the Stroop test, implying that these children have more difficulty inhibiting a dominant response (stating the color of the ink versus reading the word) compared with control children. This finding was replicated by each of the individual studies cited above that used interference effects from the Stroop test as a measure of inhibition (Berlin et al., 2004; Doyle et al., 2000; Gorenstein et al., 1989; Grodzinsky & Barkley, 1999; Savitz & Jansen, 2003; Semrud-Clikeman et al., 2000). Delay of gratification tasks have also demonstrated significant inhibition deficits in children with ADHD in contrast to control children (see for review, Nichols & Waschbusch, 2004). However, the majority of studies of delay of gratification that have been conducted involve preschool children and, as a result, will be discussed later.

The conflicting results that have been reported above may be due to an array of varying sample characteristics, diagnostic criteria, and specific outcome parameters employed across studies (see Table 2). For example, the one study listed above that did not find a significant difference between children with ADHD and control children on the CPT used longer than average interstimulus intervals (ISIs), the duration of time between presentation of the stimuli (Collings, 2003). In their meta-analyses, Losier et al. (1996) reported that group differences in commission errors began to disappear as the length of ISIs increased (typically greater than 1 s).

Collings (2003) noted that his null findings could be due to a ceiling effect produced by the relatively long ISI times that he employed (1-4 s). Varied task parameters are used throughout the literature complicating the interpretation of results.

Table 2: Studies that found deficient inhibition significantly related to ADHD versus school-age controls: Study Characteristics

Study	Sample Characteristics									
	Gender	Experimental	Control	Ethnicity	*N*	Age	Diagnostic Criteria	Subtypes	Comorbidities	Measures
Berlin et al., 2004	Male	Referred	Community Normal	Not specified	63	7-10	DSM-IV	Combined & Hyperactive	Included	Stroop-like, CPT Go/No Go
Collings 2003	Male	Community, some prior diagnoses	Community Normal –	63% Cauc, 21% Hispanic, 6% Af Am, 3% Asian	70	8-10	DSM-IV	Combined & Inattentive	Excluded	CPT
Doyle et al, 2000	Male	Referred	Non-ADHD medical controls	Caucasian, non-Hispanic	260	6-17	DSM-III-R	Not specified	Psychosis & autism excluded. Depression anxiety & CD included.	Stroop, CPT
Epstein et al., 2003	Mixed	Epidemiological ADHD diagnosis	Epidemio -logical No-ADHD diagnosis	37% Cauc. 58% Af Am, 5% other	817	9-18	DSM-IV	All subtypes	Included	CPT
Gorenstein et al., 1989	Mixed	Referred – special classroom	Non-deviant – normal classroom	Not specified	47	8-12	Disruptive Behavior	Emphasized hyperactivity	Included	Stroop
Grodzinsky & Barkley, 1999	Male	Clinical (maternal report)	Community – normal	Not specified	130	6-11	DSM-III-R	Combined type	Excluded RD, LD, autism, psychosis, & language delays	CPT and Stroop
McGee et al., 2000	Mixed	Referred	Clinical controls	Not specified	100	6-11	DSM-IV	Not specified	Included	CPT
Savitz & Jansen, 2003	Male	Clinical – Prior diagnoses	No history of ADHD	Not specified	81	8-12	Not specified	Not specified	Included	Stroop
Semrud-Clikeman et al., 2000	Male	Clinical	Psychopath-ology free	Caucasian	21	8-18	DSM-III & DSM-III-R	ADD/H	Excluded LD and other diagnoses	Stroop

Another influential factor that varies across studies is the nature of the experimental and control groups. It is unclear whether inhibition is specific to ADHD or is also present in other disorders (Barkley et al., 1992). Therefore, if an ADHD group is compared to a control group that does not exclude children with other disorders, the differences found between these groups may be diluted due to the pathology included in the control group (Corkum & Siegel, 1993; Nichols & Waschbusch, 2004). Another sample characteristic that can have a significant effect on the results is the nature of the populations from which the experimental and control groups are recruited (Corkum & Siegel, 1993). If children with ADHD are referred to the study based on their level of symptoms it implies that their symptom picture is more severe than children whose ADHD symptoms have not been targeted for treatment by parents or teachers. In turn, this discrepancy could affect both whether significant differences between groups are found and the magnitude of those differences. For instance, Corkum and Siegel (1993) noted in their review that children included in ADHD groups, identified by multiple informants, displayed greater impairment on cognitive measures. These examples attest to the importance of considering the selection criteria employed in studies when trying to interpret conflicting results.

Overall, the findings from the studies focusing on school-age children buttress the theoretically posited relation between inhibition deficits and ADHD (Campbell, 2000). However, the aim of this study is to explore whether early behavioral inhibition deficits predict later symptoms of ADHD, and also to examine the role that behavioral inhibition plays in the development and maintenance of ADHD symptomatology in preschool children. Therefore, we must refer to the literature examining behavioral inhibition and ADHD symptomatology in our target population, preschool children.

2.3 STUDIES OF PRESCHOOL CHILDREN WITH ADHD SYMPTOMS

Even though a DSM-IV ADHD diagnosis requires the presence of symptoms prior to age seven, the research literature has traditionally focused on school-age children because children are most often diagnosed after they enter school (Barkley et al., 1992; Campbell, 2000). However, it is widely recognized that symptoms are evident prior to school age and that research on preschool samples is important for early identification and to understand the developmental course of the disorder.

Initially stimulated by Campbell and colleagues, a growing body of studies exists that examines ADHD symptomatology and behavioral inhibition in preschool children (Berlin, Bohlin, & Rydell, 2003; Campbell et al., 1994; Marakovitz & Campbell, 1998). The majority of these studies (nine out of eleven) found a significant association between ADHD symptomatology and deficient behavioral inhibition in preschool children (Berlin & Bohlin, 2002; Berlin et al., 2003; Byrne, DeWolfe, & Bawden, 1998; Campbell et al., 1994; Campbell, Szumowski, Ewing, Gluck, & Breaux, 1982; Hughes, Dunn, & White, 1998; Marakovitz & Campbell, 1998; Sonuga-Barke, Dalen, Daley, & Remington, 2002; Sonuga-Barke, Dalen, & Remington, 2003). Such strong empirical findings add further credence to the hypotheses that early behavioral inhibition will predict later ADHD symptoms and may influence the relation between early and later ADHD symptoms.

Unfortunately, only three of these studies specifically examined the predictive relationship between behavioral inhibition at preschool age and ADHD symptomatology at school age; one of the studies explored the role behavioral inhibition plays in the development of ADHD symptomatology (Berlin et al., 2003; Campbell et al., 1994; Marakovitz & Campbell, 1998). Berlin and colleagues investigated this relationship in a large community sample of boys and girls. Behavioral inhibition at approximately five years of age was operationalized using the Go/No-Go task. Teachers and parents rated ADHD symptoms when children were on average 8 years old. A significant relationship was found between preschool inhibition and later ADHD symptoms both at school and home for boys and in the school context only for girls. Furthermore, Berlin et al. (2003) found that preschool inhibition and concurrent executive function measures contributed independently to the variance in ADHD symptoms in school for boys and the sample as a whole.

Campbell and colleagues (1994) examined the relationship between behavioral inhibition and ADHD symptomatology in a sample of preschool boys identified by parents and/or teachers as "hard-to-manage." These boys met approximate criteria for Attention Deficit Disorder with Hyperactivity according to DSM-III. A group of boys who did not meet these criteria and were matched with the hard-to-manage boys on classroom and birth date constituted the control group. An additional group of "problem boys" was referred to the study by parents complaining about their son's overactivity, inattention and discipline problems. Preschool data on behavioral inhibition was obtained using a delay of gratification task and a resistance-to-temptation task. A continuous performance task (CPT) and Matching Familiar Figures Task (MFFT) were used to measure behavioral inhibition at the follow-up visit, when the boys were approximately 6 years old. A significant longitudinal relationship was found for the entire sample between preschool delay performance and later behavior ratings. These later behavioral ratings consisted of observations of behavior during structured tasks in the laboratory and measured cooperation, restlessness, attentional focus, task involvement, out-of-seat behavior, and distraction.

Marakovitz and Campbell (1998) followed these same children at age nine and examined the relationship between preschool measures of inhibition and a diagnosis of ADD at school-age.

A significant relationship was found between preschool latency to touch on the resistance-to-temptation task at age four and age nine ADD diagnostic status. Specifically, boys diagnosed with ADD at age nine were less able to resist touching the forbidden toy at age four than control boys, although performance on the delay of gratification task was unrelated to later ADD status.

2.4 STUDY AIMS AND HYPOTHESES

Like the preschool study conducted by Berlin et al. (2003), one of the aims of the current study is to examine the relationship between behavioral inhibition measured at preschool age and ADHD symptoms measured in first grade in a large community sample of boys and girls. The second aim of this study is to examine the role behavioral inhibition plays as a potential mechanism underlying the development of ADHD symptomatology. Guided by these goals, this study will build upon Berlin and colleagues' findings by using a battery of behavioral inhibition measures to examine their predictive validity between preschool and first grade. Using several different empirically validated measures of behavioral inhibition will help to elucidate the relationship between behavioral inhibition in early childhood and later ADHD symptoms. Examining the predictive relationship during the critical and challenging transition to school should provide additional information regarding the developmental ramifications of behavioral inhibition. Furthermore, this study will go beyond Berlin's study by exploring whether behavioral inhibition mediates (i.e. whether levels of behavioral inhibition explain the longitudinal association between preschool and school-age symptoms of ADHD) or moderates (i.e. whether deficits in behavioral inhibition exacerbate early symptoms of ADHD leading to higher levels of ADHD symptoms at school entry) early ADHD symptoms across time.

Similarly, by examining the potential mediating or moderating role that behavioral inhibition plays in the development of ADHD symptoms, the present study differs from the studies conducted by Campbell et al. (1994) and Marakovitz and Campbell (1998). The present study also aims to build upon the findings of Campbell and colleagues regarding the predictive nature of behavioral inhibition by increasing the number, and hence range, of preschool behavioral inhibition measures, as well as examining the relationship in both boys and girls. In addition, the current study will examine the predictive relation in a large community sample not selected because of early symptoms, thereby allowing for greater generalization of results.

In conclusion, the aim of the current study is to investigate the role that behavioral inhibition plays in the development of ADHD symptomatology. Based on previous research, I hypothesize that:

1. Behavioral inhibition at 54 months will predict ADHD symptomatology in first grade.
2. The relationship between ADHD symptoms at preschool age and at first grade will be stronger among participants who exhibit deficits in behavioral inhibition at preschool age. That is, preschool behavioral inhibition will moderate the relationship between preschool and first grade ADHD symptomatology.
3. Deficits in behavioral inhibition at preschool age will mediate the relationship between ADHD symptomatology assessed at preschool and in first grade.

Overall, this study will add to the current literature by providing the rare opportunity to examine these questions with empirically validated measures in a large, diverse community based sample using a prospective longitudinal design.

3.0 METHOD

3.1 PARTICPANTS

The analyses for this study are based on data from 776 children, who are a subset of those participating in an on-going, multi-site study, the NICHD Study of Early Child Care and Youth Development. Children participating in this study were born between 1990 and 1991 in hospitals at 10 data collection sites across the U.S.: Little Rock, AR; Irvine, CA; Lawrence, KS; Boston, MA; Philadelphia, PA; Pittsburgh, PA; Charlottesville, VA; Morganton, NC; Seattle, WA; and Madison, WI. These children and their families were followed from birth through first grade.

Families were recruited during hospital visits to mothers shortly after their child's birth. During selected 24-hour sampling intervals, 8,986 women giving birth were screened for eligibility and willingness to be contacted again. Of these women 5,416 (60%) agreed to be called in 2 weeks and met the following eligibility criteria: a) the mother was over 18 years of age, b) the mother was conversant in English, c) the family did not plan to move, d) the child was not hospitalized for more than 7 days and did not have obvious disabilities after birth, e) the child was neither part of a multiple birth nor released for adoption, f) the mother did not have a known or acknowledged substance abuse problem, and g) the family lived within an hour of the research site in a safe neighborhood. A total of 1,364 mothers, who completed a home interview when their infant was 1 month old, became the study participants. The recruited sample was diverse, including 24% ethnic minority children, 11% mothers with less than a high school education, and 14% single mothers.

Out of the 1,364 participants constituting the original sample, a total of 1,100 continued in the study through first grade. Children from the NICHD sample were included in the present study if the relevant child predictor data (the TRF) were available at 54 months. Data from up to 776 children were available for analyses. Table 3 presents demographic and descriptive characteristics of the sample used for this paper.

Attrition analyses, comparing study families who were not included in the analyses due to missing TRF measures or because their child did not attend preschool at 54 months (N = 588) with those families who met the above criteria (N = 776), revealed significant differences between the groups. Based on the one month home visit, women included in this study (M = 14.68, SD = 2.44) were more educated than women who were excluded (M = 13.64, SD = 2.48), $t(1361) = 7.72$, p = .00. Using the income-to-needs ratio averaged across 6, 15, 24, 36, and 54 months, families who met the criteria for this study had more financial resources(M = 4.03, SD = 2.91) than families who were not included (M = 2.97, SD = 2.63), $t(1200) = 6.81$, p = .00. These analyses indicate that the sample for the current study is biased toward families with more financial and academic resources.

Table 3: Demographic Characteristics of the Final Sample

Demographic Variables	Descriptive Statistics	
	N	%
Child Gender		
Boys	383	49
Girls	393	51
Child Ethnicity		
Caucasian	654	84
African American	75	10
Other	47	6
Maternal Education (1 month)		
< 12 years	48	6
High School or GED	144	19
Some College	253	33
Bachelor's Degree	188	24
Postgraduate Work	143	18
Income-to-Needs Ratio (Average,1 month to 1^{st} grade)		
Less than 2.0 (poor)	173	22
Greater than or equal to 2.0 (not poor)	602	78

3.2 PROCEDURE

Inhibition was assessed in the laboratory at 54 months of age. As part of a longer laboratory visit, children were administered age appropriate versions of the Continuous Performance Test, Delay of Gratification Task, and Stroop Test. In preschool and first grade, symptoms of ADHD and externalizing behaviors were measured using the Teacher's Report Form (TRF, Achenbach, 1991) respectively. Preschool caregivers and first grade teachers completed the TRF in childcare and school. During a laboratory visit in first grade, children's inhibition was assessed again, using an age-appropriate version of the Continuous Performance Test.

Demographic information was obtained during interviews administered to mothers at regular intervals when children were between 1 and 54 months of age. Amongst other things, mothers reported on their education level and total annual family income (family's income to needs ratio was calculated by dividing total income by the poverty threshold for the family's size).

3.3 MEASURES

3.3.1 Inhibition Measures

3.3.1.1 Continuous performance task

At 54 months, children were individually administered the CPT toward the end of a 2-hour lab visit. The child was seated in front of a 2-inch square screen and a red button. Dot matrix pictures of familiar objects, such as butterflies, fish or flowers, were generated by a computer and presented consecutively on the screen. The child was instructed to press the red button each time a previously identified target stimulus (a chair) appeared on the screen.

Once the test session began, the stimuli were presented in 22 blocks. Each block contained ten stimuli resulting in a total display of 220 stimuli over the course of the test. The stimulus was flashed on the screen for 500 msec and the interstimulus interval (ISI) lasted for 1500 msec before the next stimulus appeared. Within each block of stimuli, the target stimulus was presented twice at random. The entire test lasted for approximately 7 minutes and 20 seconds.

The computer automatically provided scores on a number of performance parameters including the number of targets to which the child did not respond (errors of omission) and the number of times the child responded to a non-target stimulus (errors of commission). Poor inhibition was reflected in the number of errors of commission i.e. the number of incorrect button-press responses to non-target stimuli. Errors of commission are traditionally considered to represent impulsive responses or deficient behavioral inhibition (Barkley & Grodzinsky, 1994; Epstein et al., 2003). Whereas, errors of omission are thought to index lapses of attention (Corkum & Siegel, 1993; Losier et al., 1996).

3.3.1.2 Delay of gratification task

The DGT is another measure that has been used to assess inhibition. In this task, behavioral inhibition is operationalized by the ability to resist choosing an immediate smaller prize in lieu of a larger delayed prize. Delay of gratification as measured by this task has been related to cognitive and social problems, including attentional deficits, both concurrently and longitudinally (Campbell, 1994; Funder, Block, & Block, 1983; Marakovitz & Campbell, 1998; Mischel, Shoda, & Rodriguez, 1989; Rapport, Tucker, DuPaul, Merlo, & Stoner, 1986). In the current study a DGT was administered during the 54 month laboratory visit. It was modeled on Mischel's (1974, 1981) self-imposed waiting task.

Before the DGT was administered, the visit coordinator (VC) issued four sets of instructions to the child. First, the child was taught how to ring the bell, and the VC explained that s/he was going to leave the room and could be summoned back when the child rang the bell. This procedure was practiced before the experiment began. Second, the VC established which food i.e. M&Ms, animal crackers or pretzels the child would like to have as a reward. Third, the VC determined whether the child preferred to have a small amount or a larger amount of his/her favorite food for a reward.

Finally, after the VC determined that the child preferred a larger quantity of his or her chosen food, the VC provided the following explanation of how to play the “waiting game.” The VC told the child that s/he would play the waiting game while the VC was out of the room for a few minutes doing some work. Two plates were left in the room with the child, one holding a small pile of food and the other holding a larger pile of food. The VC told the child that s/he would be able to eat the larger amount of the desired food, if s/he was able to wait until the VC returned to the room, without the child summoning her back. In the event that the child was unable to wait for the return of the VC, s/he was told that s/he could ring the bell and the VC would return. However, the child was warned that if s/he summoned the VC back into the room by ringing the bell s/he would receive the smaller amount of food. The child was also told to remain seated in his/her chair while the VC was out of the room and not to eat any of the food until the VC returned.

After delivering these instructions the VC left the room and entered an observation booth to watch the child. If the child successfully waited for 7 minutes the VC returned, praised the child, and rewarded him/her with the larger pile of food. If the child did not use the bell but proceeded to eat any of the food, the amount of elapsed time was recorded and the VC returned to the room giving the child the smaller pile of food. If the child spontaneously ate the food, but also did not display convincing evidence that s/he comprehended the waiting rules to begin with, this child's data were treated as "missing" (i.e. no waiting time was entered on the scoring sheet, N = 72). The amount of time the child waited after the VC left the room was used to operationalize behavioral inhibition in the current study.

3.3.1.3 Stroop test

The original Stroop test presents subjects with the names of colors printed in incongruent colors. Subjects are asked to name the color in which the word is written rather than the color the word denotes. Behavioral inhibition must be employed to follow these directions successfully i.e. subjects must inhibit an over-learned, therefore dominant, response in order to comply with the instructions. Multiple studies and meta-analyses have found the Stroop to be related to ADHD symptomatology (Barkley et al., 1992; Berlin et al., 2004; Doyle et al., 2000; Gorenstein et al., 1989). In the current study an adapted version of the Stroop for preschool children was used.

Gerstadt, Young and Diamond (1994) adapted the original Stroop test into a children's version called the Day-Night Stroop test. The test consists of 18 cards; nine of the cards are black with a yellow moon and several stars and nine are white with a bright sun. The test cards were placed face down in front of the study child in a predetermined order. First, the child was shown a night card and instructed to identify it as "day" and then shown a day card and instructed to identify it as "night." If the child understood the directions and answered correctly on the first set of practice trials, the instructions were not repeated again and the test trials were initiated. However, if the child made a mistake on either of the first two practice trials, the instructions were repeated again and a new set of practice trials was begun. If the child made a mistake during the second set of practice trials the instructions were repeated once again before the test trials were started. Fourteen trials were administered to the child during the actual test.

In order for the data to be counted, the child had to answer correctly on both day and night in one of the two sets of practice trials. The percent incorrect out of the total number of non-missing responses, which is equivalent to an interference score on the Adult Stoop test, was used to operationalize inhibition in the current study.

3.3.2 Outcome Measures

3.3.2.1 Teacher report form

At first grade, teachers were asked to complete the TRF, the teacher version of the Child Behavior Checklist 4/18 (CBCL) which contains 120 items presenting a broad range of children's behavioral and emotional problems. For each item, the teacher was asked to ascertain how well that item described the target child currently or within the last two months. Teachers chose their answers out of the following options: 0 = Not True, 1= Somewhat or Sometimes True, and 2 = Very True or Often True. Symptoms of ADHD were measured using the T-score obtained on the Attention Problems subscale.

3.3.3 Control Measures

3.3.3.1 Maternal education

At the 1 month interview, mothers reported on the number of years of school completed and this was used as an index of maternal education.

3.3.3.2 Income-to-needs ratio

When the children were 6, 15, 24, and 36 (54 months??) months old, information about family income and family size were collected. The income-to-needs ratio measures the total family income divided by the poverty threshold (U.S. Department of Labor, 1994) according to size of family.

3.3.3.3 Teacher report form

Teachers were asked to complete the TRF when the study child was 54 months old. The Attention Problems subscale (see above) was used to represent ADHD symptomatology at 54 months.

4.0 RESULTS

Means, standard deviations, and sample sizes for all control, predictor and outcome measures are provided in Table 4.

Table 4: Sample Descriptive Characteristics for Control, Predictor and Outcome Variables (Total N = 776)

Variable	*M*	*SD*	*n*
Control Variables (1 month)			
Maternal Education	14.68	2.44	776
Mean Income-to-Needs	4.03	2.91	775
Predictor Variables (54 months)			
Delay of Gratification	4.79	2.91	681
Stroop Test	25.20	20.65	610
CPT – Commission Errors	12.39	19.14	711
CPT – Omission Errors	8.79	7.34	711
TRF – Attention T-Score	54.41	6.05	776
Outcome Variables (First Grade)			
TRF – Attention T-Score	53.46	5.73	730

For the sake of brevity, behavioral inhibition measures will be referred to as predictors except in the analyses examining their roles as moderators or mediators. As mentioned earlier, the Continuous Performance Task variables were log transformed due to their skewed distribution. Inspection of all other variables revealed distributions adequate for analyses assuming normalcy.

4.1 OVERVIEW OF ANALYTIC PLAN

First, preliminary analyses were conducted on demographic, predictor and outcome variables. Second, three sets of regression analyses were run; each set corresponded to one of the three research questions. Specifically, hierarchical multiple regression analyses were used to examine the first hypothesis: behavioral inhibition at 54 months predicts ADHD symptoms in first grade. Whether behavioral inhibition moderates or mediates the relationship between ADHD symptomatology at 54 months and first grade, hypotheses two and three, were also tested using hierarchical multiple regression, following the guidelines laid out by Baron and Kenny (1986).

4.1.1 Outlier analyses and regression diagnostics

Continuous predictor variables in all regression analyses were centered by subtracting the group mean from individual scores, in order to reduce nonessential multicollinearity. In addition, variance inflation factors, direct indices of the impact of multicollinearity on estimation, were examined. None of the regression models had variance inflation factors greater than 10 (highest VIF = 2.175); however, zero-order correlations among the predictors are presented to facilitate interpretation of the results (see Table 5).

Table 5: Zero-Order Correlations of Control, Predictor, and Outcome Variables

Variable	1	2	3	4	5	6	7	8
Control Variables								
1. Maternal Education (1 month)	---	0.541*	0.216*	-0.113*	-0.199*	-0.136*	-0.213*	-0.242*
2. Income-to-Needs (6-54 months)		---	0.205*	-0.115*	-0.085*	-0.075*	-0.149*	-0.208*
Predictor Variables (54 months)								
3. Delay of Gratification			---	-0.101*	-0.268*	-0.207*	-0.156*	-0.227*
4. Stroop Test				---	0.146*	0.043	0.079	0.058
5. CPT Commission Errors					---	0.222*	0.206*	0.209*
6. CPT Omission Errors						---	0.148*	0.209*
7. TRF Attention Problems							---	0.373*
Outcome Variables (First Grade)								
8. TRF Attention Problems								---

* $p < .05$

4.2 PRELIMINARY ANALYSES

4.2.1 Correlations between demographics, predictors, and outcomes

Table 5 provides the matrix of zero-order correlations among demographic (education and income), predictor, mediator and outcome variables. Maternal education was significantly correlated with the predictors (behavior problems and behavioral inhibition at 54 months) as well as the outcome variables (behavior problems at first grade). Similarly, all predictor and outcome variables were significantly associated with mean income-to-needs.

Overall, higher maternal educational achievement was related to child behavior and behavioral inhibition in the expected directions. Children with more highly educated mothers displayed lower levels of attention problems at 54 months and first grade according to their teachers. Higher levels of maternal education were also significantly associated with higher levels of behavior inhibition in children at 54 months. Since maternal education was related to both the predictor and outcome variables it was controlled in all regression analyses. Because the average income-to-needs ratio was correlated with the same predictor and outcome variables as the maternal education variable, and it was moderately correlated with maternal education (r = .54, p = .00), only the maternal education variable was controlled in the regression analyses.

4.2.2 Gender analyses

Gender differences in the predictor variables were examined using independent sample t-tests. Analyses indicated that girls (M = 9.08) made significantly fewer errors of commission on the

CPT at 54 months than boys (*M* = 15.85), $t(601) = 4.75$, $p = .000$. Subsequently, gender was controlled in all regression analyses involving this variable. No other inhibition measure showed sex differences.

4.2.3 Correlations among behavioral inhibition measures

Only modest correlations were found between the preschool behavioral inhibition and inattention measures (see Table 5). As a result, these measures were treated separately in all further analyses.

4.3 QUESTION 1: DOES BEHAVIORAL INHIBITION PREDICT BEHAVIOR PROBLEMS?

Hierarchical regressions were used to test whether behavioral inhibition at 54 months predicted attentional problems in first grade, while controlling for these same behavior problems at 54 months. Maternal education was entered first as a control variable, followed by either ratings of attentional problems at 54 months, and finally one of the three behavioral inhibition measures or one inattention measure was entered. In addition, analyses examining CPT commission errors also included sex in step 1 and the interaction term (CPT commission errors x sex) in step 4. Results are shown in Table 6 and 7.

Table 6: Hierarchical Regression: Predicting Behavior Problems at First Grade from Behavioral Inhibition at 54 months, controlling for concurrent behavior problems and maternal education

Predictor	*β*	*SE β*	*β*	*ΔR²*
Delay of Gratification				
Step 1. Maternal Education	-0.59	0.09	-0.25**	0.06 [a]
Step 2. Maternal Education	-0.45	0.09	-0.19**	0.12
Attention Problems: 54 mo	0.35	0.04	0.35**	
Step 3. Maternal education	-0.38	0.09	-0.16**	0.02
Attention problems: 54 mo	0.33	0.04	0.33**	
Delay of Gratification	-0.28	0.07	-0.14**	
CPT Commission Errors[a]				
Step 1. Maternal education	-0.55	0.09	-0.24**	0.06 [a]
Sex	0.64	0.42	0.06	
Step 2. Maternal Education	-0.41	0.08	-0.18**	0.10
Sex	0.79	0.40	0.07*	
Attention Problems: 54 mo	0.30	0.04	0.03**	
Step 3 Maternal education	-0.34	0.08	-0.15**	0.003**
Sex	1.20	0.40	0.11**	
Attention problems 54 months	0.27	0.04	0.28**	
CPT commission errors	0.47	0.10	0.18**	
Step 4. Maternal education	-0.34	0.08	-0.15**	0.003
Sex	1.37	0.41	0.12**	
Attention problems 54 months	0.26	0.04	0.27**	
CPT commission errors	0.33	0.13	0.12*	
Sex x CPT commission errors	0.32	0.19	0.08	

Note. [a] Sex also controlled. ***p* < .01 and **p* < .05.

[a] R^2 value.

Table 7: Hierarchical Regression: Predicting Behavior Problems at First Grade from Behavioral Inhibition at 54 months, controlling for concurrent behavior problems and maternal education

Predictor	*β*	*SE β*	***β***	***ΔR²***
CPT Omission Errors				
Step 1. Maternal education	-0.55	0.09	-0.24**	0.06 [a] *
Step 2. Maternal education	-0.41	0.08	-0.18**	0.09**
Attention problems 54 months	0.30	0.04	0.31**	
Step 3. Maternal education	-0.37	0.08	-0.16**	0.02**
Attention problems 54 months	0.28	0.03	0.29**	
CPT omission errors	0.11	0.03	0.15**	

**$p < .01$ and *$p < .05$.

[a] R^2 value.

Behavioral inhibition at 54 months, as measured by CPT commission errors and the Delay of Gratification task, as well as inattention measured by CPT omission errors, were found to predict ADHD symptoms at first grade. However, the Stroop test did not contribute unique variance to teacher ratings of child behavior problems, as was anticipated from the non-significant correlations shown in Table 5. No sex effects were found in the analyses involving CPT commission errors.

4.4 QUESTION 2: DOES BEHAVIORAL INHIBITION MODERATE THE STABILITY OF BEHAVIOR PROBLEMS?

Hierarchical regressions were used to test whether or not behavioral inhibition at 54 months moderated the relation between attention problems as reported by teachers at 54 months and first grade. The attention problems subscale of the TRF was regressed on maternal education in step one. One of the four behavioral inhibition measures was added in step two, followed by attention problems at 54 months in step three, and finally the corresponding interaction term (attention problems x behavioral inhibition) in step four. Again, for the analyses involving CPT commission errors, sex was added in step 1 as an additional control variable and the corresponding interaction terms were added in step 4 and step 5. Table 8 and 9 present the results of the moderation analyses.

Table 8: Regression Analyses for Behavioral Inhibition as Moderator of the Relation between Behavior Problems at 54 months and First Grade.

	Predictor	*β*	*SE β*	***β***	***ΔR²***
Delay of Gratification (*N* = 652)					
Step 1.	Maternal Education	-0.59	0.09	-0.25**	0.06 a **
Step 2.	Maternal Education	-0.50	0.09	-0.21**	0.03**
	Delay of Gratification	-0.37	0.08	-0.18**	
Step 3.	Maternal Education	-0.38	0.09	-0.16**	0.10**
	Delay of Gratification	-0.28	0.07	-0.14**	
	Attention Problems 54 months	0.33	0.04	0.33**	
Step 4.	Maternal Education	-0.39	0.09	-0.16**	0.00
	Delay of Gratification	-0.28	0.07	-0.14**	
	Attention problems 54 months	0.33	0.04	0.33**	
	Delay of Grat. x Attn problems	-0.00	0.01	-0.01	
CPT Commission Errors (*N* = 677)					
Step 1.	Maternal Education	-0.55	-.09	-0.24**	0.06 a **
	Sex	0.64	0.42	0.06	
Step 2.	Maternal E	-0.44	0.09	-0.19**	0.05**
	Sex	1.21	0.42	0.11**	
	CPT Commission errors	0.63	0.10	0.24**	
Step 3.	Maternal education	-0.34	0.08	-0.15**	0.07**
	Sex	1.20	0.40	0.11**	
	Commission errors	0.47	0.10	0.18**	
	CPT Attention problems 54 months	0.27	0.04	0.28**	
Step 4.	Maternal education	-0.35	0.08	-0.15**	0.00
	Sex	1.14	0.40	0.10**	
	CPT commission errors	0.47	0.10	0.18**	
	Attention problems 54 months	0.26	0.04	0.27**	
	Commission errors x Attention Problems	0.02	0.02	0.05	

$^{**}p < .01$ and $^{*}p < .05$.

a R^2 value.

Table 9: Regression Analyses for Attention as Moderator of the Relation between Behavior Problems at 54 months and First Grade.

Predictor		β	*SE* β	β	ΔR^2
CPT Omission Errors (*N* = 677)					
Step 1.	Maternal Education	-0.55	0.09	-0.24**	0.06[a]**
Step 2.	Maternal Education	-0.49	0.09	-0.21**	0.03**
	CPT Omission Errors	0.14	0.03	0.18**	
Step 3.	Maternal Education	-0.37	0.08	-0.16**	0.08**
	CPT Omission Errors	0.11	0.03	0.14**	
	Attention Problems 54 months	0.28	0.03	0.29**	
Step 4.	Maternal Education	-0.37	0.08	-0.16	0.00
	CPT Omission Errors	0.11	0.03	0.14**	
	Attention Problems 54 months	0.29	0.04	0.31**	
	Omission errors x Attention Problems	-0.01	0.01	-0.04	

**p < .01 and *p < .05.

[a] R^2 value.

The attention problem x behavioral inhibition variable interactions were not significant in the models, indicating that the behavioral inhibition measures did not act as a moderator of the association between teacher ratings of child behavior at 54 months and first grade.

4.5 QUESTION 3: DOES BEHAVIORAL INHIBITION PARTIALLY MEDIATE THE STABILTIY OF BEHAVIOR PROBLEMS?

Baron and Kenny's (1986) guidelines were used to determine whether behavioral inhibition mediated the relations between preschool behavior problem variables (predictor) and the parallel behavior problem variables at first grade (outcome). In order for a variable to qualify as a mediator, four significant relationships (path 1, 2, 3, and 4) must be demonstrated (see Figure 1): (1) the predictor must be significantly associated with the outcome, over and above the control variables (path 1); (2) the predictor must be significantly associated with the hypothesized mediator (path 2); (3) the hypothesized mediator must be significantly associated with the outcome variable (path 3); and (4) the observed association between the predictor and outcome in step 1 must be attenuated, due to the indirect effects of the mediator (path 4).

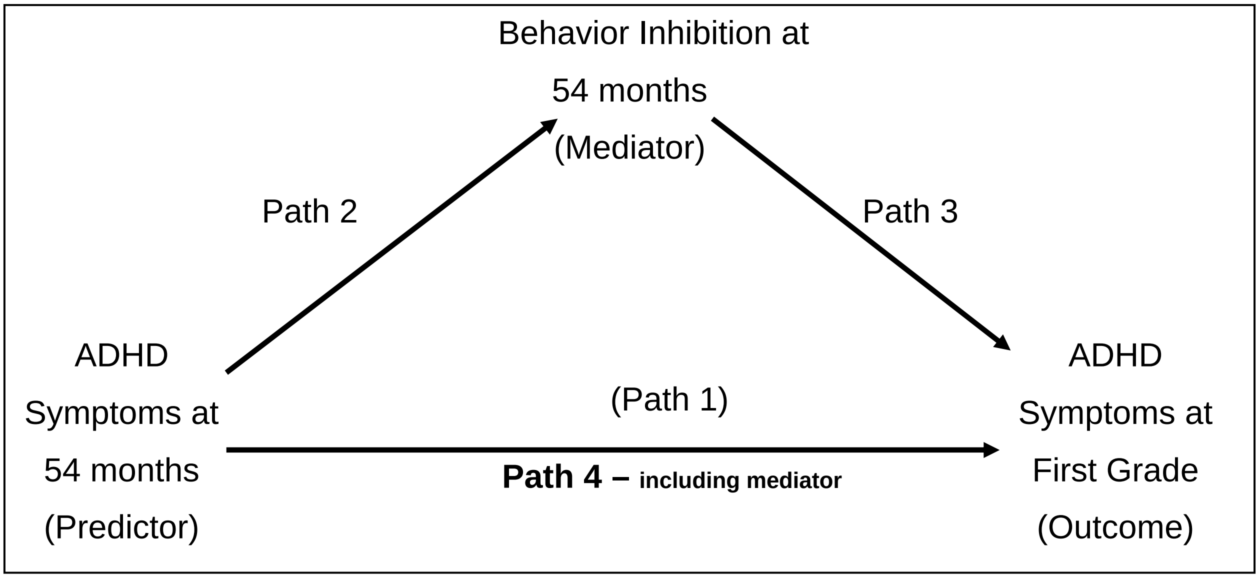

Figure 1: Mediation Model: illustrating 4 associations (pathways) integral to establishing mediation.

These four steps were tested by examining whether: (1) preschool attention problems (predictors) were significantly associated with children's attention problems in first grade (outcomes); (2) preschool attention problems (predictors) predicted behavioral inhibition at 54 months (mediators); (3) preschool behavioral inhibition (mediators) predicted attention problems in first grade (outcomes); and (4) the relations found in step 1 diminished when the relations specified in steps 2 and 3 were controlled (Baron & Kenny, 1986).

Because the Stroop test was not associated with the outcome variables in the initial analyses, it was dropped from all further analyses.

4.5.1 Step 1:Does the predictor variable significantly predict the outcome variable?

As expected, attention problems predicted the equivalent behavior problem ratings approximately 18 months later ($\beta = .338$, $p < .001$). The significant findings indicate that there is a degree of stability in childhood attention problems across time according to teacher reports.

4.5.2 Step 2: Does the predictor variable significantly predict the hypothesized mediator?

Hierarchical regression analyses, reported earlier, showed that preschool attention problems were significantly related to preschool behavioral inhibition measures.

4.5.3 Step 3: Do the hypothesized mediators predict the outcome variable?

Again, hierarchical regression analyses, reported earlier, indicated that behavioral inhibition at 54 months, as measured by Delay of Gratification, CPT Commission errors and CPT Omission errors, significantly predicted attention problems at first grade.

4.5.4 Step 4: Testing mediation

Finally, path 4 was tested (see Figures 2 and 3).

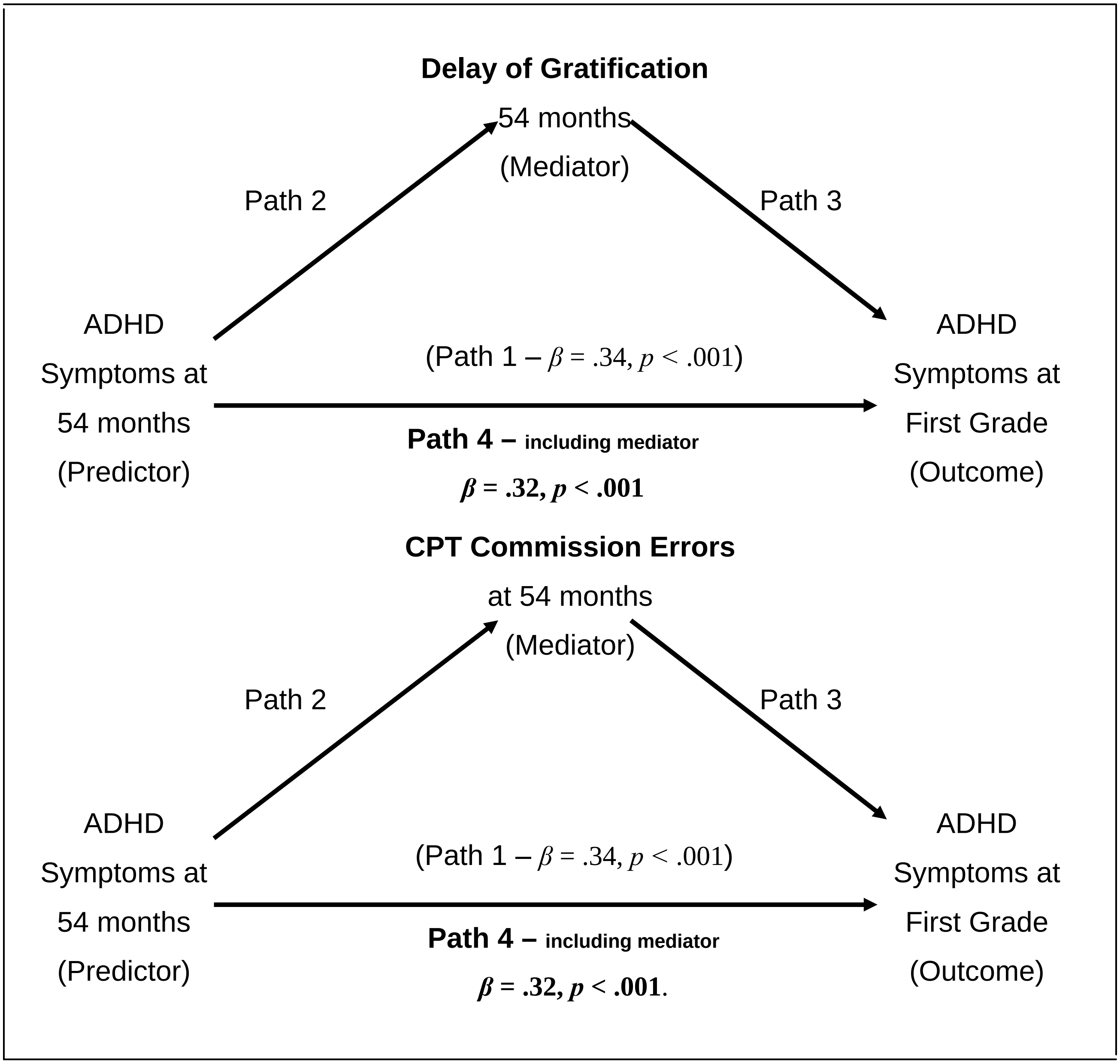

Figure 2: Behavioral Inhibition as mediators of the stability of ADHD Symptoms

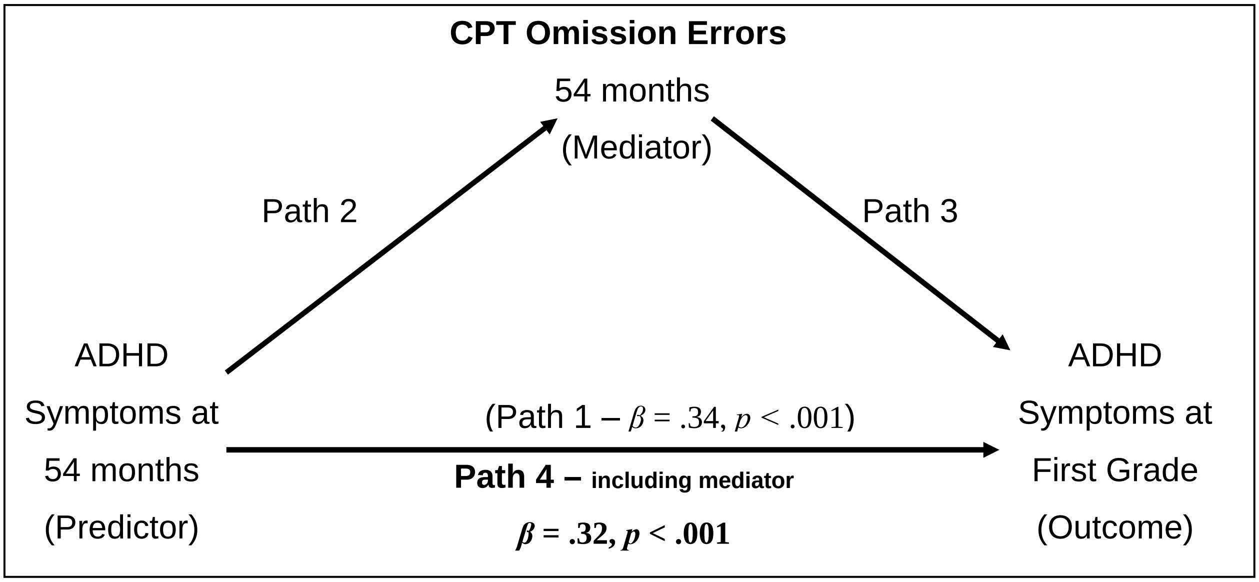

Figure 3: Inattention as mediator of the stability of ADHD Symptoms

The longitudinal relationship between attention problems remained significant despite the addition of the behavioral inhibition measures into the equation. Complete mediation was ruled out by these results. Further analyses were conducted to test for partial mediation. Partial mediation occurs when a significant difference is found between the regression coefficients in step 1 and step 4, after complete mediation has been ruled out. However, partial mediation was also ruled out (using a method introduced by Kenny in 1998 (Frazier, Tix, & Barron, 2004)) when none of the differences between the regression coefficients were found to be significant.

4.6 EXPLORATORY ANALYSES

Two additional hierarchical regression analyses were conducted to test whether the three behavioral inhibition measures accounted for unique variance when entered together to predict behavior problems in first grade. After controlling for maternal education in step 1 and gender and concurrent behavior problems in step 2, the three behavioral inhibition measures were entered in step 3. Results indicated that CPT commission errors ($\beta = .092$, $p < .05$), CPT Omission errors ($\beta = .110$, $p < .01$), and Delay of Gratification ($\beta = -.102$, $p < .05$) each accounted for unique variance in behavior problems in first grade.

5.0 DISCUSSION

5.1 SUMMARY OF RESULTS

The overarching goal of this study was to examine the early emergence and developmental course of ADHD symptoms in early childhood. More specifically, in line with current theory and research, we first examined whether behavioral inhibition deficits in preschool predicted school-age ADHD symptoms directly. In addition, we examined the indirect role that behavioral inhibition deficits may play in the development of ADHD symptomatology by testing whether the longitudinal stability of ADHD symptoms at preschool and first grade was mediated or moderated by deficits in preschool behavioral inhibition. Overall, we found that inhibition deficits in preschool predicted ADHD symptomatology in first grade (β ranged from -.147 to .141, $p < .01$) after controlling for the stability in symptoms from preschool to first grade. Furthermore, exploratory analyses revealed that two out of the three behavioral inhibition measures, and the inattention measure, accounted for unique variance in first grade symptoms of ADHD (β ranged from -.102 to .110, $p < .05$). Finally, we did not find any evidence that preschool behavioral inhibition or inattention either moderated or mediated the relation between symptoms of ADHD in preschool and first grade.

Consistent with the literature, two of the behavioral inhibition measures and the inattention measure (CPT commission errors, delay of gratification and CPT omission errors) were found to predict ADHD symptoms at first grade (Berlin et al., 2003; Campbell et al., 1994; Marakovitz & Campbell, 1998). However, as far as we know, the current study is the first to examine and find these effects even after controlling for longitudinal stability in ADHD symptoms. In addition, behavioral inhibition and inattention were also significantly related to concurrent measures of ADHD symptoms at 54 months. These findings indicate that behavioral inhibition deficits, as measured by laboratory tasks, in preschool children are related to ADHD symptomatology, as rated by teachers, both concurrently and longitudinally.

5.2 DISCUSSION OF RESULTS

Even though the findings are robust, the preschool behavioral inhibition measures only account for approximately 2% of the variance in ADHD symptoms at school age, after controlling for preschool ADHD symptoms. In comparison, Berlin and colleagues' (2003) "Go-No-Go" task accounted for between 6 and 17% of the variance in their sample's school-age ADHD symptoms. Whereas, Campbell and colleagues (1994) reported that their inhibition task predicted 4% of the variance in school-age behavioral symptoms. Unfortunately, Marakovitz and Campbell (1998) did not report the percentage of variance attributable to preschool behavioral inhibition. Upon examining the other relevant studies, it appears that our findings, though somewhat smaller, are in line with those reported in the relevant literature.

The small discrepancies between our findings and those of others (e.g. Berlin et al., 2003; Marakovitz & Campbell, 1998) may be due to differences in methods of analysis, sample composition, and measures between the studies. The current study is unique in that it alone controlled for preschool ADHD symptoms when examining the predictive relationship between preschool behavioral inhibition and school-age ADHD symptoms. Indeed, the bivariate associations between the behavioral inhibition tasks and first grade ADHD symptoms indicated that about 4%-5% of variance is accounted for when stability of ADHD symptoms is not considered. This may explain why the inhibition measures in the current study accounted for a smaller percent of the variance in ADHD symptoms at first grade. Neither Campbell et al. (1994) nor Berlin and colleagues (2003) controlled for potential stability of ADHD symptoms from preschool to school age.

Other differences among the three studies which may account for the discrepancy in results include sample characteristics. For instance, the current study employed a large (N = 776), mixed sex sample, which was recruited directly from the community. In comparison, Campbell et al. (1994) employed a smaller (N = 112), male sample, which included teacher and parent identified "hard-to-manage" boys and control boys. The clinical criteria used by Campbell and colleagues were designed to obtain a group of children who displayed significantly above average numbers of hyperactive, inattentive, and impulsive behaviors, thereby placing them at risk to develop ADHD and related problems by school entry. In turn, due to the longitudinal stability of behavior problems, a higher number of behavioral symptoms would have been found at follow-up. Therefore, aside from limiting the generalizability of the study's results, the clinical nature of Campbell and colleagues' sample, as well as the fact that preschool behavioral symptoms were not controlled in their analyses, may account for the higher percentage of variance attributed to preschool behavioral inhibition.

Berlin and colleagues (2002) also recruited their participants from the community. However, in contrast to the present study, they employed an outcome measure that specifically tapped DSM delineated ADHD symptoms. Using the ADHD Rating Scale IV, Berlin and colleagues gathered teacher reported information on 9 hyperactive and impulsive symptoms and 9 inattentive symptoms. In contrast, the current study measured ADHD symptoms using the attention scale on the TRF. This measure neither directly corresponds to DSM criteria, nor is it clearly separated into hyperactive /impulsive and inattentive subscales. Therefore, the lower amount of variance ascribed to preschool inhibition in the current study may be the result of the non-specific nature of the outcome measure. Indeed, Berlin et al. suggested that the specific nature of their outcome measure was partially responsible for the strength of their reported association.

One of the behavioral inhibition measures we used, the Day-Night Stroop test, was not found to be significantly related to either 54 month or first grade ADHD symptomatology, even though it was moderately correlated with the other measures of inhibition. The Day-Night Stroop test was created in 1994 by Gerstadt, Young and Diamond as a preschool version of the Stroop task. As a result, it has not been widely used in research, and, therefore, studies reporting on its reliability and construct validity as a preschool version of the Stroop test are limited. In contrast, the original Stroop test has a long history in the research literature, and its validity has been established. Furthermore, the original Stroop test has been often found to be related to ADHD symptomatology (Homack & Riccio, 2004). Therefore, the Day-Night Stroop test was included in the current study based on its face validity as a preschool adaptation of the original Stroop measure. The null findings reported in this study suggest that the Day Night Stroop task is not capturing behavioral inhibition as manifested in preschoolers.

Alternatively, the preschool version of the Stroop may be capturing an aspect, or aspects, of behavioral inhibition that may either not be related to ADHD symptoms, or may not be a primary engine leading to the development of ADHD. As evidenced by the leading theoretical models of ADHD, and documented by Nigg (2001), the research literature suffers from a lack of precision regarding the nature and definition of behavioral inhibition. In an attempt at clarification, Nigg proposed a binary division. He suggested that two general types of inhibition exist: inhibition that is under executive control and inhibition that is under motivational control. This distinction, in fact, mirrors a division found in the theoretical literature. For instance, Sonuga-Barke (1994) in the Delay Aversion Hypothesis conceptualizes behavioral inhibition deficits exhibited by children with ADHD as behavioral strategies, which are, in turn, generated by their primary motivation to escape or avoid delay. In contrast, Barkley (1999) and Quay (1988) hypothesize that executive function deficits in inhibition are responsible for the behavioral inhibition deficits evidenced in children with ADHD.

In line with Barkley (1999) and Quay (1988), Nigg (2001) argues that ADHD is due to a deficit in an executive motor inhibition process rather than a motivational inhibitory control deficit. If this definitional division is indeed theoretically significant, then the measure used to operationalize behavioral inhibition becomes highly pertinent. The current study used behavioral inhibition measures that are related to both executive function (CPT) and motivation (DOG). As previously reported, preschool behavioral inhibition deficits as captured by both of these measures were found to significantly and *independently* predict school-age ADHD symptoms. These results indicate that both motivational and regulatory aspects of behavioral inhibition are involved in the development of ADHD. This conclusion is in line with the Cognitive-Energetic Model proposed by Sergeant (2000), which states that deficits in *both* executive and motivational controlled behavioral inhibition contribute to ADHD.

Regarding the development of ADHD symptomatology, we found that teacher rated behavior problems, such as attention problems, are significantly associated across time, from 54 months to first grade, despite the difference in settings and reporters. Caregiver ratings of behavior problems in child care settings when the participants were 54 months old significantly predicted teacher reported behavior problems when the children entered first grade. These results are consistent with the findings reported by Lahey and colleagues (2005). These results indicate that there is some modest stability in the development and manifestation of ADHD symptomatology over time even at this early age.

Based on past research and our findings that both preschool behavioral inhibition and preschool teacher ratings of ADHD symptomatology predict symptoms of ADHD at first grade, it would be intuitive to assume that the interaction of these two variables would predict the first grade ADHD symptoms. Common sense suggests that higher levels of behavioral inhibition deficits would exacerbate the development of ADHD symptoms, especially in children showing early behavioral symptoms, and that lower levels of behavioral inhibition deficits at 54 months might act as buffer against the future persistence of behavior problems. However, our results did not support this hypothesis. The fact that both ADHD symptoms and behavioral inhibition are found to be independent predictors of later ADHD symptomatology suggests that, even though these two measures are related, their associations with later behavioral problems are independent of one another. These findings suggest that the laboratory measures of behavioral inhibition are capturing different facets of impulsive behavior than the teacher ratings of symptoms.

In summary, our findings did not support the contention that behavioral inhibition may serve as an underlying mechanism explaining the consistency and stability of ADHD symptomatology across time. Behavioral inhibition was not found to mediate, either wholly or partially, or moderate the relation between ADHD symptoms at 54 months and first grade. These findings introduce questions regarding the development of ADHD symptoms. However, in addition to these null findings, preschool behavioral inhibition was found to be significantly related to school-age ADHD symptoms, even after controlling for preschool ADHD symptoms. This relationship was found using both the CPT and the DOG indicating that deficits in both executive and motivationally controlled inhibition precede, indeed predict, the development of ADHD symptomatology. Finally, these findings support the Cognitive-Energetic Model of ADHD (Sergeant, 2000), which incorporates both motivational and executive controlled behavioral inhibition.

5.3 LIMITATIONS AND FUTURE DIRECTIONS

One limitation of the current study involves the somewhat biased nature of the sample. For instance, the children included in this study were primarily Caucasian, and their families were characterized by more parental education and higher average income-to-needs ratios. As a result, the findings of this study may not generalize to samples with greater ethnic diversity and higher socio-economic risk. Future studies examining the early development of ADHD symptomatology should employ a sample with greater ethnic and socio-economic diversity, in order to ensure the generalizability of results.

Measurement limitations are also apparent in the current study. Although the Day-Night Stroop test possesses face validity, in that it appears to be similar to the adult Stoop test, based on our results it does not appear to have construct validity. The current interest in executive function deficits, including behavioral inhibition, in preschool children has spurred increased interest in preschool executive function measures. Future research should make sure to employ preschool behavioral inhibition measures that have been empirically validated.

The amorphous definition of behavioral inhibition poses another constraint on this area of research, including the current study. Behavioral inhibition is defined and measured in numerous ways throughout the literature. Even though the definitions of behavioral inhibition can be categorized as variations on the same theme, their existence underlines the fact that the exact nature of behavioral inhibition, and its constituent aspects have, as of yet, not been fully clarified. Unfortunately, the current opaque nature of behavioral inhibition prohibits true clarity regarding the role of behavioral inhibition in the development of ADHD.

In addition, the use of a more sophisticated method of analysis, such as a semi-parametric group-based modeling technique (Nagin & Tremblay, 1999; Shaw, Lacourse, & Nagin, 2005), would facilitate a richer interpretation of our data. For instance, trajectory analysis, as discussed by Nagin and Shaw, would identify ADHD trajectory groups that differ in their underlying pattern and level of teacher-reported ADHD symptoms over time. In turn, this would allow a test of the predictive relationship between early behavioral inhibition deficits and patterns of ADHD symptom development over time. For example, deficits in behavioral inhibition may account for more variance among children with generally higher levels of ADHD symptoms over time. Future research should take advantage of sophisticated statistical methodologies to explore the relationship between ADHD symptoms and potential precursors and underlying mechanisms in greater depth.

In summary, future research should include younger and more diverse samples. More diverse samples will ensure the generalizability of the findings and younger samples will help clarify the early development of ADHD symptoms and the role played by behavioral inhibition. Future research also should try to use more precise measures of behavioral inhibition and more sophisticated methods of analysis. Utilizing the growing brain imaging literature may help to identify a more precise definition of behavioral inhibition. Employing trajectory analysis would enable a richer interpretation of the current data. Finally, brain imaging techniques should also be employed to elucidate how ADHD develops and what role executive function, such as behavioral inhibition, play in its development.

5.4 CONCLUSIONS

We can conclude, based on our findings, that behavioral inhibition and inattention at 54 months (operationally defined by the DGT and commission and omission errors on the CPT) predict ADHD symptoms at first grade above and beyond longitudinal stability in ADHD symptoms. Furthermore, these findings suggest that behavioral inhibition at preschool can be used as an independent marker of developing ADHD symptomatology. This marker, if used in tandem with other early indicators, could be used to create a risk index profile. Consequently, children at risk for ADHD could be identified and then targeted for intervention and treatment.

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