Application of ADHD Theory Outside The Laboratory: Children’s Cognitive Performance in Real-Life Contexts

by

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This thesis is submitted through the Graduate School of Education for the degree of Doctor of Philosophy undertaken at The University of Western Australia

2002
Abstract

One current theory of Attention-Deficit/Hyperactivity Disorder (ADHD) proposes that a primary deficit in behavioral inhibition gives rise to secondary deficits in four executive functions (EF) and motor control. This theory is purported to account for the cognitive and behavioral problems associated with the Combined subtype of ADHD but not those of the Predominantly Inattentive subtype. To date, empirical support for this theory is primarily from laboratory-based cognitive methods. It is not known whether children with ADHD also exhibit deficient inhibition or executive dysfunction in real-life activities. The purpose of the present research was to test current theory by examining behavioral inhibition and EF in children with a diagnosis of ADHD (Combined Type or Predominantly Inattentive Type) in two real-life contexts (videogame play and route tasks at the zoo) as well as during traditional laboratory tasks (Stroop, Wisconsin Card Sorting Task).

Participants included a community sample of 57 boys diagnosed with ADHD (20 Inattentive Type, 37 Combined Type, no diagnosed comorbidity, unmedicated) and 57 non-disordered control boys (matched on age and IQ). Operationally defined measures of behavioral inhibition, specific EF and motor control were derived from real-life indoor and outdoor activities, and assessed under contrasting conditions of low/high working memory and distractor loads.

Results indicated that the children with ADHD exhibited impairments in some aspects of inhibition and other EFs (particularly working memory), as well as in motor control during the highly motivating real-life activities as well as on the laboratory-based cognitive tasks, but problems varied across context (videogame, zoo) and task demands (e.g., cognitive load). The ADHD group were able to use similar strategies to those used by the controls during the challenging videogame, but
overused less efficient strategies. There was no evidence of a primary deficit in inhibitory control or in any specific aspect of EF. Moreover, there was little evidence that performance on the laboratory measures reflected performance in the real-life activities or vice versa. Thus, the results from this study provide only partial support for the inhibitory model of ADHD. However, the findings do support the proposed multi-dimensional and dissociable nature of behavioral inhibition. The present research provides the first theoretically based understanding of the cognitive performance of primary schoolchildren with ADHD in real-life contexts. The educational implications of this research raise important questions concerning the nature, presentation, and administration of educational tasks for schoolchildren with ADHD.
Acknowledgements

I would like to thank all the people who assisted me in various ways with this research. In particular, I thank the children and parents who participated; and Professor Stephen Houghton, who had the initial idea to examine the EF performance of children with ADHD in real-life contexts, and who, with Dr Graham Douglas and Professor Kevin Durkin, obtained funding to support this research. The advice, supervision, and support of Professor Houghton, Dr Douglas and Professor Durkin are greatly appreciated. Also, special thanks are extended to Professor Russell Barkley for his advice regarding the initial design of the research; Dr Ken Whiting, for his unfailing help and assistance in referring families; the Western Australian members of LADS, and Carol, June, and Wendy (now deceased) for their untiring support and assistance; the Principal Mr David Bryant and staff at Greenwood Primary School for their invaluable assistance; Ms Kerry Hartley for her encouragement; Sony, for the contribution of the playstations and videogames, and the management and staff at Perth Zoo for their generous assistance. I thank my fellow doctoral students at GSE, Shane, John, Georgia, Myra, and Wai-Sam for their comradeship, good times, and games of cricket; Drs Rick Kellner and Sandra Carrivick for their friendship and support; Dr Lesley Vidovich, a great educator who inspires with her warm encouragement, and all the other academic staff at GSE who advised and encouraged me along the way; Kerry Bedford of the EDFAA Library; and the general office staff for assistance, especially Robyn and David’s smiles on the demanding days.

Thank you to my supervisors Dr Marnie O’Neill and Associate Professor Rosemary Tannock. Dr O’Neill has my lasting gratitude for her professional advice and endeavor, and I have deeply appreciated her professional support during the
writing of this thesis. The excellence of Associate Professor Rosemary Tannock’s professional contribution is evident throughout the best of this thesis. Associate Professor Tannock, a Senior Scientist, is an inspirational role model for all educators, with her pragmatically applied wisdom, unstinting work ethos, integrity, humanitarianism, and great generosity of spirit.

Finally, my heartfelt thanks go to my own very special support team who provide always the rationale: Cliff, Courtney, and Brett, who continually love, teach and inspire me.

This research was partially funded by an Australian Research Council Grant awarded to Professors Houghton and Durkin, and Dr Douglas. The research was also funded by the graduate stipend of an Australian government postgraduate APA scholarship.
Dedication

This research and thesis is for the children who participated, and for all children who struggle to learn.
Declaration

In accordance with the regulations for presenting theses and other work for higher degrees, I hereby declare that, as detailed in the following paragraphs, this thesis incorporates entirely my own work and my own original contribution to current scientific knowledge, and that it has not been submitted for a degree at this or any other university.

Professor Houghton, Dr Douglas, and Professor Durkin provided guidance through all stages of the thesis research – from its initial conceptualization through data collection to preliminary data analysis. Associate Professor Tannock provided advice in the initial stages, and then with Dr Marnie O’Neill, assumed primary supervision and guidance in the final stages including manuscript and thesis preparation.

My original contribution to the research described in the present thesis comprises: (a) substantial contribution to the overall conceptualization of the research study and design, (b) conceptualization and design of the videogame phase, (c) conceptualization and development of videogame and zoo measures used in the research, including indexing them to the constructs of executive function described in Barkley’s (1997) theoretical model of ADHD, (d) data collection (e) all data entry and analyses (f) interpretation of results and (g) all aspects of the written exposition in this thesis including the abstract, critical review of the literature, the three data-based chapters, the integrative discussion presented in the final chapter, as well as all responsibilities associated with primary authorship on each of the three data reports submitted for publication.

Vivienne Patricia Lawrence

The University of Western Australia, June 2002

Note: This thesis has been formatted in accordance with modified American Psychological Association (1994) publication guidelines.
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PUBLICATION DETAILS FOR THE THESIS MANUSCRIPTS

CHAPTER THREE

STUDY ONE

This chapter has been accepted for publication in manuscript form by the Journal of Abnormal Child Psychology. The manuscript is entitled: ADHD Outside the Laboratory: Boys’ Executive Function Performance on Tasks in Videogame Play and on a Visit to the Zoo. Contributing authors to the manuscript are listed in order as follows: Vivienne Lawrence, Stephen Houghton, Rosemary Tannock, Graham Douglas, Kevin Durkin, and Ken Whiting. I, Vivienne Lawrence, fulfilled all of the responsibilities required of the first author.

Preliminary findings of Study One were presented by myself, Vivienne Lawrence, as part of a joint presentation entitled Children do not live in laboratories: ADHD and executive functions in ecologically valid domains of childhood functioning at the international conference - ADHD in the Third Millennium: Perspectives for Australia - held in Sydney, Australia, March 2001. Dr Stephen Houghton (Chair) introduced the presentation; and the presenters included Vivienne Lawrence, John West and Dr Graham Douglas from the Centre for Attention and Related Disorders, the University of Western Australia.

CHAPTER FOUR

STUDY TWO

A manuscript form of this chapter, entitled: Cognitive Processing in ADHD: A Comparison of Children’s Performances on Laboratory and Real-Life Tasks, is currently under review by the Journal of Attention Disorders for consideration for publication. Contributing authors to the manuscript are listed in order as follows: Vivienne Lawrence, Stephen Houghton, Graham Douglas, Kevin Durkin, Ken
Whiting, and Rosemary Tannock. I, Vivienne Lawrence, fulfilled all of the responsibilities required of the first author.

CHAPTER FIVE

STUDY THREE

A manuscript form of this chapter, entitled: *Strategy Use in ADHD: Efficacy of Children's Controlled Responses on Challenging Videogame Tasks*, has been submitted for review by the Journal of Child Psychology and Psychiatry. Contributing authors to the manuscript (listed in order) are: Vivienne Lawrence, Stephen Houghton, Graham Douglas, and Rosemary Tannock. I, Vivienne Lawrence, fulfilled all of the responsibilities required of the first author.
CHAPTER ONE

INTRODUCTION

This research investigates the cognitive difficulties of children with Attention-Deficit/Hyperactivity Disorder (ADHD) during their performance on tasks and activities in real-life settings. Children who are excessively inattentive or hyperactive compared to their peers may meet diagnostic criteria for ADHD, one of the most prevalent and controversial of childhood disorders. ADHD is a heterogeneous behavioral syndrome of developmentally inappropriate persistent and impairing levels of inattention, impulsivity and hyperactivity. Some impairment from the symptoms must be evident in at least two different settings of childhood, for example, at home and at school (see the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition: DSM-IV, American Psychiatric Association, 1994). Chronic problems with attention and behavior are associated with the academic and social failure of children with ADHD. These problems are demonstrated during everyday activities and are known to continue throughout the lifespan (Barkley, 1997; Tannock, 1998).

Extensive research on the neuropsychological functions of the prefrontal cortex of the brain has resulted in theories of impaired executive function in ADHD. The construct of executive function is poorly defined having no exact definition or description (see Eslinger, 1996; Tannock, 1998). However, it is understood that executive functioning enables an individual to plan future actions and to hold those plans in mind in order to inhibit irrelevant actions until the planned action is executed (Fuster, 1989; Goldman-Rakic, 1987; Luria, 1966; Shallice, 1988). Thus, inhibition, problem solving, strategic responding, cognitive flexibility, set shifting, working memory, and planning, all require executive functioning (Douglas, 1999;
Lezak, 1995; Pennington & Ozonoff, 1996). Children with ADHD have demonstrated difficulties in these abilities when performing laboratory tasks. However, while it assumed that these difficulties are also evident during the children's daily activities in complex real world settings, this assumption has not yet been tested.

One of the most comprehensive of the current theories of ADHD hypothesizes that a primary deficit in behavioral inhibition produces inefficient performance in other executive functions (involving working memory, motivation, and adaptive behavior), resulting in poor motor control (see Barkley, 1997). Three dimensions of behavioral inhibition are proposed, of which the most essential is thought to be inhibition of a "prepotent" response (i.e., a response associated with positive or negative reinforcement) so as to create a delay in responding. The second dimension is conceptualized as the interruption of an ongoing response that is rendered inappropriate or inaccurate by sudden or unexpected changes in task demands (a sensitivity to error). The third is defined as sustained protection of response from disruption by competing events and responses (interference control or resistance to distraction).

These deficits in behavioral inhibition are proposed to result in secondary and associated deficits in four other EFs of nonverbal working memory (involving a retrospective and prospective sense of time), verbal working memory (internalization of speech), self-regulation of emotion and motivation, and reconstitution (creative use of past experience) (see Barkley, 1997, 2000). The distinction between nonverbal and verbal working memory in Barkley's model (1997, 2000) is not consistent with other models of working memory (e.g., Baddeley, 1986). Rather, nonverbal working memory is defined as involving on-line maintenance of information and organization
of behavior over time, whereas verbal working memory involves self-talk and one’s internal dialogue used for self-regulation. Reconstitution refers to the higher order use of existing actions or thoughts to create novel responses during problem solving. These secondary deficits, in turn, interact to influence motor control, resulting in significantly reduced goal-directed persistence and poor self-regulated behavior in children with ADHD. The theory proposes that deficit in behavioral inhibition allows the cognitive performance of children with ADHD to be more vulnerable to the influence of immediate salient contingencies than that of their non-disordered peers (see Barkley, 1997, 2000).

This neuropsychological model of ADHD, which focuses on behavioral inhibition and executive function (Barkley, 1997; Quay, 1997), is purported to apply primarily to the combined subtype of ADHD. To date, it is not known whether the DSM-IV inattentive subtype shares the deficits in inhibition and other executive functions with the combined subtype or exhibits distinct deficits (e.g., Houghton et al., 1999; Nigg, Blaskey, Huang-Pollock, & Rappley, 2002). The performance of both DSM-IV subtypes: ADHD Combined Type (ADHD-C) and ADHD-Predominantly Inattentive Type (ADHD-I) are examined in the present study, in order to test these hypotheses outside the laboratory in real-life settings.

Current theory of ADHD is based largely on findings from empirical studies using traditional methods and paradigms. To date, the extensive evidence of cognitive problems in children with ADHD is derived almost exclusively from studies using adult-based neuropsychological tasks in laboratory settings. Poor performance on such tasks (see Douglas, 1999; Pennington & Ozonoff, 1996 for reviews) is consistent with current theories of ADHD. However, the totality of this empirical evidence is confounded by discrepancies between reported findings. It is
not yet known to what extent these inconsistencies are (a) the result of differing methodological approaches and paradigms, (b) evidence of inherent heterogeneity of the syndrome of ADHD, or (c) an artifact created by the influence of different settings and task demands.

Empirical laboratory based studies are conducted in highly controlled settings where many restrictions are placed on a child's behavior. While laboratory based research is essential to advance scientific knowledge, it remains possible that laboratory performance may not be an accurate reflection of a child's typical performance during activities in the course of everyday life. Further, the use of neuropsychological laboratory tasks with children has been critiqued, with subsequent focus placed on the adult orientation, and repetitive and monotonous nature, of many of the tasks. These critiques have raised questions concerning motivation (e.g., Slusarek, Velling, Bunk, & Eggers, 2001). Therefore, the focus of the present research is child oriented, and motivating tasks are chosen that have relevance and meaning to children's daily lives. Specifically, the tasks selected comprised route tasks during adventure videogames and at the zoo. Challenging videogames are a popular activity among school-aged children, particularly boys, which provide an ideal (indoor) testing medium that is familiar and relevant to every day life. Route tasks in the holiday atmosphere of a day outing to the zoo also provide an attractive (outdoor) setting of real world activities.

Purpose of the Research

The purpose of the research is to test current theory of ADHD by examining the cognitive performance of children with ADHD on challenging tasks set in real-life contexts. To achieve this objective, the task performance of a community sample of primary school-aged children with a diagnosis of ADHD (comprising an
unmedicated sample with either ADHD-C or ADHD-I) is compared with that of their normally developing peers (individually matched on age and IQ). Task performance is examined: (a) during real-life indoor activities when playing a cognitively challenging videogame, and on outdoor route tasks at a zoo, (b) during traditional laboratory-based neuropsychological tasks of the Stroop Color and Word Test (Stroop: Golden, 1978) and the Wisconsin Card Sort Test (WCST: Heaton, Chelune, Talley, Kay, & Curtis, 1993), and finally (c) in an exploratory micro-analysis of salient differences in the children’s use and success of game strategies on the cognitively challenging videogame tasks. Given that there is a gender bias with boys over-represented approximately three to one, both in diagnoses of ADHD and in preference for playing videogames, only boys are included in the study.

Significance of the Present Research
The research is significant in three ways. First, this research is the first study to systematically investigate the executive function performance of children with ADHD (two subtypes, unmedicated) and their non-disordered peers on indoor and outdoor tasks in real-life contexts. Second, the focus of the study is child oriented, and thus motivating tasks are used that are relevant and meaningful to the every day lives of children. Third, the study makes a direct comparison of the same children’s performance on indoor and outdoor tasks during real-life activities and on laboratory neuropsychological tasks.

Organization of the Thesis
Chapter Two of the thesis provides a critical review of relevant literature and describes the etiology, diagnostic taxonomy, and behavioral characteristics of ADHD. The rationale for choosing the ecologically valid mediums of an adventure videogame and route tasks at a zoo to examine children’s cognitive performance, is
discussed. The aims and hypotheses of the thesis are listed at the conclusion of this chapter.

Data from the examination of children’s cognitive performance in three different contexts (videogames, zoo and laboratory) are presented in Chapters Three, Four, and Five. Each chapter reports a distinct aspect of data from the research. Data are derived from the one community sample of primary school-aged boys diagnosed with either of the subtypes ADHD-C and ADHD-I (unmedicated) and their non-disordered peers (individually matched on age and IQ). Chapter Three examines the performance of the boys during real-life activities when using a challenging videogame and on route tasks at a zoo (and includes the total sample of participants, \( N = 114 \)). The report of data in Chapter Three has been accepted in manuscript form, for publication by the Journal of Abnormal Child Psychology. Chapter Four directly compares the performance of the boys during real-life activities and during traditional neuropsychological tasks of the Stroop and the WCST (and includes only those boys, individually matched, who completed all real-life and neuropsychological tasks, \( N = 44 \)). A report of these data has been submitted in manuscript form, for review by the Journal of Attention Disorders. Chapter Five examines in detail the boys’ cognitive approach to problem solving in their use and success of strategic responding during the real-life challenging videogame tasks (and includes only those boys, individually matched, who clearly demonstrate the use of game strategy, \( N = 112 \)). A report of this set of data has been submitted in manuscript form, for review by the Journal of Child Psychology and Psychiatry.

Chapter Six, the final chapter of the thesis, provides an integrated discussion of findings from this research, current theory, and previous research findings as reported in the literature. The educational, theoretical, and clinical implications and
significance of the present investigation of children’s performance on cognitive tasks in real-life contexts are then discussed. The chapter concludes with recommendations for future research.
PART A: ATTENTION-DEFICIT/HYPERACTIVITY DISORDER (ADHD)

2.1 Significance of ADHD

ADHD is the current diagnostic label (APA, 1994) for one of the most controversial and intensively studied developmental disorders of childhood. It is currently conceptualized and defined as a disruptive behavior disorder, characterized by developmentally inappropriate and impairing levels of inattention and/or hyperactivity/impulsivity. Children exhibit the chronic and disabling behavioral symptoms of ADHD in everyday environments of school and home. ADHD has long been associated with a variety of neurocognitive impairments, but there is no robust evidence of impairments that are specific to this disorder.

2.1.1 Prevalence

A highly prevalent developmental disorder of childhood, ADHD is conservatively estimated to occur in three to six percent of school-aged children from varied cultures and countries worldwide (APA, 1994; Baumgartel, Wolraich, & Dietrich, 1995). A recent epidemiological Australian study investigating the prevalence of ADHD in the Barwon region of Victoria over a 12 month period found that 34.8% of all community pediatric consultations involved behavioral problems, of which 76% related to ADHD (Hewson et al., 1999). Prevalence rates vary worldwide, however, recent studies suggest accurate rates may be two or three times higher than those typically cited (Paule et al., 2000). The authors also indicate a frequency of both under diagnosis and over diagnosis, along with gaps in epidemiological literature regarding diagnosis and treatment approaches in community as compared to clinic based settings.
Attempts to explain why ADHD is found in approximately three times more boys than girls include a range of differing gender, social, environmental, familial and heritability factors (Danforth & DuPaul, 1996; Schachar, Sandberg, & Rutter, 1986; Silverthorn, Frick, Kuper, & Ott, 1996; Pineda et al, 1998). Studies have revealed that girls with ADHD exhibit the same cognitive difficulties as boys with the disorder (Castellanos et al., 2000; Rucklidge & Tannock, in press). However, in comparison to boys, girls exhibit less externalized behavior problems and more internalizing problems, and thus may tend to be under diagnosed (Biederman et al., 1999; Rucklidge & Tannock & 2001).

2.1.2 Prognosis

Follow-up studies consistently find 70% of children with ADHD exhibit developmentally inappropriate behaviors through to adolescence (Biederman et al., 1996; Claude & Firestone, 1995; Jackson & Ferrugia, 1997; Weiss & Hechtman, 1993). Although persistence rates vary according to the function and the methods of the study, 50% - 65% of children with ADHD in North America have been found to continue to exhibit behavior problems and ADHD symptoms in adulthood (Barkley, Fischer, Fletcher, & Smallish, 1990; Mannuzza, Gittleman-Klein, Bessler, Malloy & LaPadula, 1993). The symptoms of inattention tend to persist into adolescence and adulthood, whereas hyperactivity and impulsivity decline with increasing age (Biederman, Mick, & Faraone, 2000). However, it has been proposed that the hyperactive/impulsive symptoms confer the greatest risk for a negative outcome throughout the individual’s life span (Barkley, 1998).

It is not, however, the primary behavioral symptoms of ADHD that produce such a high risk for negative social, academic, and familial outcomes in children with the disorder. Rather, it appears that the risk stems from a compounding effect of the
potent combination of underlying cognitive difficulties and behavioral problems that develop over time. The result is an ever-increasing spiral of failure across social environments. The problems include difficulties with school work, family, peers and figures of authority (e.g., teachers), and emotional problems of low self-esteem (Weiss & Hechtmann, 1993; Treuting & Hinshaw, 2001). The costs of ADHD are enormous and wide-ranging (Leibson, Katusic, Barbaresi, Ransom, & O’Brien, 2001). The adverse effects of secondary problems associated with ADHD in adolescence and adulthood are well documented, with individuals at significantly higher risk of alcohol, nicotine, drug and substance abuse (Burke, Loeber, & Lahey, 2001; Clure et al., 1999), police arrests, driving infringements and accidents, antisocial behavior (Barkley, Guevremont, Anastopoulos, DuPaul, & Shelton, 1993; Biederman et al., 1996; Mannuzza, Klein, Bessler, Malloy & LaPadula, 1998; Murphy & Barkley, 1996) and additional psychopathology during adolescence and adulthood (Barkley, Murphy, & Kwasnik, 1996; Biederman et al., 1995; Weiss & Hechtmann, 1993).

ADHD currently is recognized to adversely affect the lives of a substantial number of children in countries and cultures around the world. The disorder is significantly associated with a negative life course for many individuals, the majority of whom are males. The resultant cost to individuals, families, and society in general, makes it imperative that the cognitive manifestations of ADHD are understood more fully so that more effective interventions may be developed than are currently available.

2.2 DSM-IV Definitions of ADHD and its Subtypes

The Diagnostic and Statistical Manual of Mental Disorders (DSM), established by the American Psychiatric Association, defines ADHD by a descriptive
taxonomy. The DSM criteria are clinically derived and based on professional consensus from contemporary research findings and clinical field trials (Hartman et al., 2001; Lahey et al., 1994). Current research has consistently challenged the validity and accuracy of the DSM taxonomy, reflected in the repeated revisions of successive DSM editions (APA, 1968, 1980, 1987, 1994). Recently, the increased use of the DSM-IV (1994) as a model for empirical assessment resulted in re-evaluation of the internal validity of the measures of DSM-IV (Hartman et al., 2001). The aim of the re-evaluation was to make further advances toward a common conceptualization, and an integrated clinical and empirical taxonomy of ADHD.

2.2.1 Subtypes of ADHD

The DSM-IV (1994) describes two distinct characteristic symptom clusters: namely inattention and hyperactivity-impulsivity (APA, 1994, see Appendix A). Although individuals with ADHD typically exhibit some symptoms from both clusters, three subtypes of ADHD are distinguished based on the predominant symptom cluster profile:

1. Attention-Deficit/Hyperactivity Disorder, Combined Type (ADHD-C), requires six or more symptoms of inattention as well as six or more symptoms of hyperactivity-impulsivity.

2. Attention-Deficit/Hyperactivity Disorder, Predominantly Inattentive Type (ADHD-I), requires six or more symptoms of inattention, but less than six symptoms of hyperactivity/impulsivity.

3. Attention Deficit/Hyperactivity Disorder, Predominantly Hyperactive-Impulsive Type (ADHD-HI), involving six or more symptoms of hyperactivity-impulsivity and fewer than six symptoms of inattention.
The Combined Type (ADHD-C) is the most common, whereas the ADHD-HI subtype is the least common and is thought to be evident primarily in preschoolers and a precursor to ADHD-C (Hart, Lahey, Loeber, Applegate & Frick, 1995).

2.2.2 Diagnosis of ADHD in Children

Current valid clinical diagnoses of ADHD must be based on DSM-IV (1994) criteria (see Appendix A). Developmentally inappropriate levels of the behavioral symptoms of ADHD must be evident in the child before seven years of age and to have persisted for at least six months. Symptoms must be evident in at least two settings of childhood (e.g., home and at school). The DSM-IV criteria give examples of task situations or settings that are considered to increase or decrease symptom severity (e.g., worsening of symptoms is associated with sustained or effortful attention and monotonous, boring or repetitive tasks, while highly structured, novel or interesting tasks are associated with minimal or absent symptoms (APA, 1994). Individuals with ADHD show impairment on a wide range of laboratory tests requiring effortful cognitive processing, but none of the measures have been established as a diagnostic marker for this disorder (APA, 1994). The requirement for objective and accurate ADHD assessment tools for use with children is a cause for much concern (Paule et al., 2000). Attempts to find such objective measures have led to extensive research using laboratory tests in the attempt to identify specific neuropsychological or biological markers distinct to ADHD (Tannock, 1998). However, there are marked inconsistencies in findings and ongoing concerns about the ecological validity and the adult-oriented nature of many of the tasks used.

2.2.3. Comorbidity

Exact delineation of the cause(s), definition and diagnosis of ADHD have been confounded by the prevalence of comorbidity in those with the disorder.
Comorbidity refers to the co-occurrence of two or more disorders in an individual. In such cases, the core behavioral symptoms of inattention, hyperactivity and impulsivity in children with ADHD are accompanied by associated learning, social and affective problems. Cognitive difficulties at school include speech, language, maths and reading problems (Benedetto-Nasho, 2000; Carte, Nigg & Hinshaw, 1996; Mayes, Calhoun, & Crowell, 2000; Tannock, Martinussen & Frijters, 2000). These problems are accompanied by non-compliance with rules, frustration, aggression, depression, anxiety, poor self-esteem, peer rejection and social isolation (see Barkley, 1998; Hinshaw & Melnick, 1995; Treuting & Hinshaw, 2001).

It is not yet clear how comorbid conditions relate to ADHD, or to specific subtypes of ADHD (see Jensen, Martin, & Cantwell, 1997; Pliszka, 1998). It is possible that some comorbid diagnoses in those with ADHD result from diagnostic or referral bias, whereby core deficits remain indistinguishable and unidentified next to more salient though secondary characteristics (Lyytinen, 1995). Attempts to identify and distinguish core deficits in ADHD from those of associated disorders have prompted recent laboratory based research to adopt rigorous screening procedures to ensure that ADHD samples are as clear of comorbid conditions as is possible (Houghton et al., 1999; Tannock, Ickowicz, & Schachar, 1995).

2.3 Etiology

2.3.1. Background

ADHD, since its first clinical description by a British physician (Still, 1902), has been poorly defined and described (see Barkley, 1998; Tannock, 1998). Distinctions between ADHD and associated disorders remain blurred, as does the relationship between cognitive and behavioral processes affected in those with the disorder (MacLeod & Prior, 1996; Nigg, 2001). Attempts to identify the cause of
ADHD have been hindered by the heterogeneity of the disorder and discrepancies among findings. Difficulties contributing to the inconclusiveness of findings include different methodologies, the use of single focus tasks to examine multifaceted constructs associated with ADHD, and the lack of identified markers unique to the disorder (Tannock, 1998).

Concern regarding inconsistencies in the clinical definition and description of ADHD has been reflected by extensive research attempts to identify cognitive markers distinct to ADHD. Such markers have been referred to as primary or fundamental deficit. Criteria proposed as necessary for a *primary* or *fundamental* deficit are that it has to: (a) exist in most affected individuals and their relatives, (b) be developmentally stable (i.e., be evident in affected individuals of various ages), (c) be specific to the disorder (i.e., not be manifest in other disorders), and critically, (d) cause the disorder (see Pennington, 1991). Thus, in order to meet these criteria a primary deficit must be pervasive across settings and tasks (i.e., not task specific).

The concept of a primary or fundamental deficit is related to that of an endophenotype (i.e., a biological or vulnerability marker), or a characteristic that is essentially associated with the disorder (including cognitive or neuropsychological characteristics). The identification of a (marker) (endophenotype) in complex genetics requires it to be: (a) associated with illness in the population, (b) heritable, (c) state independent (i.e., as manifest in an individual irrespective of whether the illness is active), and (d) within families with marker and illness co-segregated (see Lander, 1988; Leboyer et al., 1998). The meeting of such criteria would therefore also require that the marker be evident across different contexts.

It is thought that the identification of cognitive markers unique to ADHD will increase diagnostic precision, advance genetic linkage studies, and the development
of animal models of the disorder. Hence, current research continues to seek identifying cognitive markers for ADHD, as well as for other associated disorders such as schizophrenia (cf. Seidman, Biederman, Monuteaux, Weber, & Faraone, 2000; with Cornblatt & Malhotra, 2001).

2.3.2. Environmental, Perinatal and Familial Risk Factors

Early hypotheses of perinatal brain damage were based on evidence of children developing inattentive and hyperactive symptoms after brain trauma. Most children with ADHD have no history of brain trauma (Levy, Barr, & Sunohara, 1997). Moreover, prenatal and perinatal complications including maternal smoking and alcohol consumption, have since been shown to account for less than five percent of all children with the disorder (Faraone & Biederman, 1998; Milberger, Biederman, Faraone, Chen, & Jones, 1996; Swanson, Castellanos, Murias, LaHoste, & Kennedy, 1998). Further, familial and social adversities, including family conflict and exposure to maternal psychopathology, have been found to be more accurate predictors of children's emotional and adaptive functioning in general, than causative of ADHD (Faraone & Biederman, 1998). However, the sum of such findings must be weighed against those from molecular research indicating that stress and emotional trauma have a negative effect on the biological substrate of individuals (see Arnsten, 1999).

2.3.3. Genetics, Neurochemistry, Neuroimaging, Neuropsychology

The possibility of familial genetic influence and the use of modern medical technology has resulted in research advances that suggest ADHD symptom clusters are highly heritable (Levy, Barr, & Sunohara, 1997; Thapar, Holmes, Poulton, & Harrington, 1999). Australia recently conducted one of the largest twin family studies with children aged 4 – 13 years that showed a heritability rate of between 75-
91% (Levy, Hay, McStephen, Wood, & Waldman, 1997). Findings from the Australian study indicated a continuum rather than a categorical nature of ADHD. Studies suggest a 20-30% probability that parents and siblings of a child with ADHD also have the disorder (Levy, Hay et al., 1997; Metcalf, 1993). However, the manner in which genes and environment interact at critical periods of development remains unclear (Rutter, Silberg, O’Connor, & Simonoff, 1999).

Hypotheses regarding the effect of stimulant medication on the neurotransmitter systems of the brain have prompted genetic and neurochemical studies to investigate the dopaminergic and noradrenergic systems. Molecular studies have found some evidence to link these systems to the etiology of ADHD (Faraone & Biederman, 1998; Levy, Barr et al., 1997; Sunohara et al., 2000; Swanson, et al., 1998). In addition, findings from neurochemical studies exploring these biological processes provide further insight and extended hypotheses of proposed neurochemical imbalance in children with ADHD (Castellanos, 1997; Pliszka, McCracken, & Maas, 1996; Arnsten, Steere, & Hunt, 1996). Concurrent with the genetic and neurochemical research have been advances made in neuroimaging investigations. Findings from structural (MRI; CT) and functional (PET; SPECT) imaging studies, have consistently linked the fronto-striatal neural networks of the brain to ADHD (see Tannock, 1998; Vance & Luk, 2000).

The increasing focus of research on the cognition of schoolchildren and adolescents with ADHD was reflected in the revised diagnostic criteria of the DSM-IV (APA, 1994). Hypotheses have related the behavioral symptoms of children with ADHD to deficits in the executive function processes of the brain that enable self-control. For example, the executive functions of self-regulation, planning and mental flexibility include more specific functions such as response inhibition, sustained
attention and ability to self-motivate (see reviews by Douglas, 1999; Pennington & Ozonoff, 1996; Tannock, 1998).

The brain regions associated with executive functioning vary somewhat according to neuropsychological models, but essentially are thought to implicate the prefrontal brain regions and associated neural networks (see Tannock, 1998). It is also thought that the cerebellum is implicated in problems with flexibility and adaptability to task and environmental demands exhibited by children with ADHD (Courchesne & Allen, 1997). Although these findings from studies using neuropsychological measures are generally supported by neurochemical and neuroimaging findings, it has not been possible to conclusively identify cognitive deficits distinct to children with ADHD (see Tannock, 1998; Paule et al., 2000).

2.4 Treatment

2.4.1 Stimulant Medication

The most often used and efficacious treatment of ADHD to date continues to be medication, using two currently available psychostimulants: methylphenidate, and dexamphetamine (National Health & Medical Research Council, 1997; Cyr & Brown, 1998; Mathys & Bender, 1997). These medications are short acting central nervous system and respiratory center stimulants. However, it is not clear what processes they affect or how these processes involve central nervous system functioning to produce the behavioral effects they have on children with ADHD (American Society of Health-System Pharmacists, 1998; Thomas, 1997). It is thought that these stimulant medications influence biological substrates involving the neural transmitter systems (Kimko, Cross, & Abernathy, 1999; Solanto, 1998; Volkow, Fowler, Hitzemann, & Wang, 1996).
Stimulant medication produces immediate and marked improvements in children’s activity level and concentration (Solanto, 2002). These behavioral improvements are indicated by the reduction in parent and teacher ratings of hyperactivity/impulsivity and inattention across home and school settings (Richters et al., 1999). By contrast, improvements in academic achievement and cognitive functioning are less clear (Rapport, Denney, DuPaul, & Gardner, 1994). For example, larger effect sizes have been found for behavioral (0.8 – 1.0) than for cognitive changes (0.6 – 0.8) (Spencer et al., 1996). This suggests that stimulant treatment may not be targeting some critical aspects of cognitive functioning in ADHD. Further, no lasting benefits have been found in the children’s performance after medication is stopped (see reviews by Greenhill & Osman, 1999; Solanto, 2002).

There is some cause for concern regarding the broadband effects of stimulant medicines on cognitive processes, given (a) the possibility of inadvertent overstimulation of the dopaminergic systems (Arnsten, Mathew, Ubriani, Taylor, & Li, 1999), and (b) the similarity in chemical effect of the stimulants to cocaine (Gatley et al, 1999; Rush & Baker, 2001). On the one hand, recent animal studies have linked long-term cocaine administration to disrupted orbitofrontal efferents to the striatum, with resulting problems in response inhibition and perseveration (Jentsch, Olausson, De la Garza & Taylor, 2002). On the other hand, previous research has not found evidence that dosage levels of methylphenidate in the clinical range cause problems in response inhibition or perseveration in children with ADHD; rather, methylphenidate has been found to improve mental flexibility and persistence (Douglas, Barr, Desilets, & Sherman, 1995; Tannock & Schachar, 1992; Tannock, Schachar, Carr, Chajczyk, & Logan, 1989). However, given problems with
incorrect diagnoses, poor management of treatment, and problematic side effects (Angold, Erklanli, Egger, & Costello, 2000; Vance & Luk, 2000), it is imperative that specific areas of deficit be identified to permit the development of targeted treatments. Therefore, ongoing concerns regarding the prevalent use of such medication (Vance & Luk, 2000) have led to extensive research into behavioral and cognitive-behavioral treatment approaches.

2.4.2 Cognitive - Behavioral and Multi-Model Interventions

The major limitation of behavioral interventions for schoolchildren with ADHD to date has been the extent of their generalizability from academic tasks to home settings, and long-term effectiveness (Vance & Luk, 2000). These behavioral interventions are limited, as are those involving stimulant medication because they lack specific areas of deficit to target. Hence, broad based approaches are necessitated, until cognitive problems distinct to children with ADHD have been clearly identified. Until then, treatment interventions target broad and diffuse areas of processing that may or may not underpin the behavioral symptoms displayed daily by children with ADHD.

Academic interventions for children with ADHD initially focused on behavioral strategies using positive re-inforcers and contingent rewards, or response costs for appropriate behavior. However, these approaches had little success in sustaining improvements in academic performance, on-task behavior, or intrinsic motivation in the children (Fiore, Becker, & Nero, 1993; Hinshaw & Melnick, 1992). These early interventions may have been limited by their focus on contingencies and agents of change external to the child. Hence, the effectiveness of extrinsic motivators and external regulators of behavior were determined by, and limited to, factors outside the child’s control. These approaches were unable to develop intrinsic
motivation and self-regulation and thus lacked generalizability of effect (Hinshaw & Melnick, 1992). The ineffectiveness of concentrating sole focus on the behavioral symptoms of ADHD coincided with the increasing interest of educators and researchers in the cognitive underpinnings of these behaviors (Shapiro, Du Paul, Bradley-Klug, 1998).

Studies attempting to map underlying cognitive deficits to the off-task behaviors of hyperactive and inattentive children found evidence that these children responded to certain pedagogical approaches. For example, varying the presentation rate of information and situational context was found to beneficially influence the performance of inattentive, but not hyperactive children with ADHD (Conte, Kinsbourne, Swanson, Zirk, & Samuels, 1987). Further the presence of hyperactivity in school children was demonstrated to be independent of their slowed cognitive performance (Shroyer & Zentall, 1986). Moreover, it was found that hyperactive schoolchildren performed better when global rather than detailed information initially was given about a task (Zentall & Gohs, 1984). Also, the use of color as an in-task factor has been found to affect the performance of children with ADHD (Belfiore, Grskovic, Murphy, & Zentall, 1996). In one example, hyperactive children were found to outperform those without hyperactivity on a spelling recognition task when black-letter trials preceded color-letter trials (Zentall, 1989). Novel or stimulating tasks, and tasks allowing for active motor engagement were also found to improve the performance and behavior of these children (Zentall & Meyer, 1987).

Among the most effective of academic behavioral interventions used by educators to date, have been those teaching self-management, self-evaluation, and self-monitoring strategies to children with ADHD. These interventions, especially those involving self-evaluation, have been found to have a positive affect on these
children’s behaviors, with some evidence of extension from school to home settings (Hinshaw & Melnick, 1992; Hoff & DuPaul, 1998; Shapiro et al., 1998; McDougall, 1998). Such interventions can teach children not only cognitive strategies (e.g., the use of self-verbalized instruction), but also understanding of their purpose and benefit. Previous research has emphasized that interventions with children are most effective when they have meaning and relevance for the child (Westby & Cutler, 1994).

Findings from the recent large-scale MTA study (National Institute of Mental Health’s Collaborative Multisite Multimodal Treatment Study of Children with ADHD) indicate however, that behavioral interventions for children with ADHD remain less effective than stimulant medication (Richters et al, 1999). Although, it has been noted with interest, that lower doses of stimulant medication were required when used in conjunction with behavioral therapy during that study (Vance & Luk, 2000).

2.5 Summary

ADHD is a highly prevalent childhood disorder of chronic impairment that is evident in individuals across academic and social settings throughout the lifespan. Clarification of the etiology of ADHD and development of improved treatments remain important clinical problems and the focus of extensive research investigations.

Debate continues concerning the three subtypes of ADHD currently distinguished by the DSM-IV (APA, 1994) and defined by two distinct symptom clusters (Inattention, Hyperactivity/Impulsivity). Researchers concur however, on the need for further examination of the DSM-IV subtypes of ADHD-C and ADHD-I.
Heterogeneity of symptoms, problems associated with other conditions that are prevalent in ADHD, and conflicting research findings, highlight the need to screen and control for comorbidity in research involving children with this disorder. This has been taken into account in the present study: by selecting a community rather than a clinical sample and by controlling for comorbidity to obtain as “pure” an ADHD sample as is possible.

The sum of findings from the broad areas of research into the etiology of ADHD shows converging evidence of dysfunction in prefrontal cortical-striatal neural circuitry, involving catecholaminergic dysfunction. This evidence, in turn, implicates cognitive impairment in ADHD. These advances in understanding of the neurobiology of ADHD indicate a need to reconceptualize ADHD, as a disorder with a neurobiological basis and cognitive impairments.

Stimulant medication is effective in reducing the behavioral symptoms of ADHD, however, the effects on cognitive and academic function are less robust. Delineating cognitive impairments distinct to ADHD may provide insight into the pathophysiology of the disorder, enabling the development of more specifically and appropriately targeted treatments.

**Part B: Neuropsychology Of ADHD**

**2.6 Executive Function: Concept and Definition**

The past decade has witnessed an increasing focus on the cognitive underpinnings of self-control in developmental psychopathology. The higher order cognitive processes that enable self-control have been termed *executive functions*. The construct of executive function (EF) is, like that of ADHD itself, a broadly and
imprecisely defined one (Eslinger, 1996; see review by Tannock, 1998). The term
does not refer to basic cognitive processes (e.g., attention, memory, perception, or
motor activation), but rather to psychological or metacognitive executive control
processes (Fuster, 1989, Goldman-Rakic, 1987; Luria, 1966; Shallice, 1988). These
processes enable the goal directed behaviors required in the planning and carrying
out of a behavior over time, in spite of distractions. Hence, a synergy of cognitive
processes is engaged, enabling EF abilities that include: self-regulation, organization,
mental flexibility and adaptability. Two such functions, response inhibition and
working memory, figure prominently in current theory proposing response inhibition
to be a core deficit in ADHD (Barkley, 1997; 2000; Quay, 1988; Sonuga-Barke,
1995). Response inhibition (the stopping of a cued motor movement) and working
memory (the use of information held in mind in the determination of future action)
are both multidimensional constructs (see Tannock, 1998).

2.6.1 EF and ADHD: A Behavioral Inhibition Model

One current comprehensive model proposes that behavioral inhibition is the
fundamental deficit in ADHD (Barkley, 1997; 2000). Three components of
behavioral inhibition are defined. The first component, deemed the most critical,
refers to the ability to inhibit a “prepotent” response (i.e., a response associated with
positive or negative reinforcement) so as to create a delay in responding. The second
component is defined as the ability to interrupt an ongoing response rendered
inappropriate or inaccurate by sudden or unexpected changes in task demands (i.e., a
sensitivity to error). The third is conceptualized as the sustained protection of a
response from disruption by competing events and responses (interference control or
resistance to distraction).
Deficits in behavioral inhibition, particularly in the inhibition of a prepotent response, are proposed to render ineffective the deployment of four other EFs, resulting in secondary and associated deficits in nonverbal working memory (involving a retrospective and prospective sense of time), verbal working memory (internalized speech), self-regulation of emotion and motivation, and reconstitution (generation of novel responses from past experience) (see Barkley, 1997, 2000). The distinction between nonverbal and verbal working memory in Barkley’s model (1997, 2000), does not map onto other models of working memory (e.g., Baddeley, 1986). Rather, nonverbal working memory is defined as involving on-line maintenance of information and organization of behavior over time, whereas verbal working memory refers to self-talk and one’s internal dialogue used for self-regulation. Reconstitution refers to the judicial use of thoughts and actions to create novel responses during problem solving. These secondary deficits, in turn, interactively influence motor control, resulting in significantly reduced goal-directed persistence and poor self-regulated behavior in children with ADHD. The theory proposes therefore, that primary deficit in behavioral inhibition results in the sustained attention of children with ADHD being more vulnerable to contextual influence, than that of normally developing children.

This neuropsychological model of ADHD, which focuses on response inhibition and executive function (Barkley, 1997; Quay, 1997), is purported to apply primarily to the combined subtype of ADHD. For example, the inattention exhibited by children diagnosed with ADHD-I is suggested to stem from inefficiencies in both speed of information processing and selective and focused attention (Barkley, 1997). Whereas, the inattention displayed by those diagnosed with the subtype ADHD-C is proposed to be one caused by deficits in sustained attention. To date, it is not known
whether the DSM-IV inattentive subtype shares the deficits in behavioral inhibition and other executive functions with the combined subtype or exhibits distinct deficits of attention (e.g., Houghton et al., 1999; Nigg et al., 2002). Therefore the model proposes that the two symptom clusters currently describing ADHD (DSM-IV, 1994) more accurately reflect a qualitative difference between two types of inattention (Barkley, 1997). The first type of attention deficit identified by disorganization (ADHD-I), and the second (ADHD-C) defined by distractibility (APA, 1994). There is no clear understanding of the cognitive processes underpinning these behavioral symptoms of inattention exhibited by children with ADHD. Therefore further examination is required with focus on theory-based phenotypes using cognitive measures of response inhibition, working memory and attention (Tannock, 1998).

2.6.2 Other Neuropsychological Models of ADHD

Two other current models offering alternative explanations for the etiology of ADHD, both propose that biological neural substrates are fundamentally involved in cognitive and behavioral symptoms of the disorder (cf. Oosterlaan & Sergeant, 1996; Sergeant, 2000; Sergeant, Oosterlaan, & van der Meere, 1999; with Sonuga-Barke, 1995, 2002). One model of ADHD proposes that primary deficits arise from the inefficient activation of biological energy systems subserving the cognitive processes (Oosterlaan & Sergeant, 1996; Sergeant, 2000; Sergeant et al, 1999). While the other model proposes that psychological heterogeneity splits the ADHD-C subtype into two separate phenotypes (Sonuga-Barke, 1995; 2002). The first phenotype distinguished by a poor inhibitory control associated with the dopamine system of the pre-frontal cortex. The second distinguished by motivational style (delay aversion) and associated with the reward circuits of the meso-limbic branch of the dopamine system. This dual-pathway model is similar to Barkley’s (1997) model in
proposing that the inhibitory failure of children with ADHD to delay responses, both momentarily and on a repeated basis over time, results in secondary cognitive and behavioral manifestations (Sonuga-Barke, 1995, 2002).

Extensive empirical support exists for these hypotheses of deficient executive functioning on children with ADHD. This support is largely from studies conducted in laboratory settings using neuropsychological measures (see Douglas, 1999; Pennington & Ozonoff, 1996; Sergeant et al., 2002; Tannock, 1998, for reviews). These measures include the Stroop, WCST, stop signal paradigm, and continuous performance tests (CPTs). A review of literature on four common developmental disorders (ADHD, Tourette’s syndrome, conduct disorder and autism) found executive function deficits consistently related to children with ADHD and autism (Pennington & Ozonoff, 1996). However, a more recent review determined that while there is evidence that some aspects of EF are impaired in ADHD, no single or combined aspects of EF have been found to be specific to ADHD (Sergeant et al., 2002).

2.6.3 Neuropsychological Measures

The Stroop (Golden, 1978) and the WCST (Heaton et al., 1993) were selected for use in the present study, because of empirical evidence that they differentiate children with ADHD from control children by level of executive function performance impairment (see review by Sergeant et al., 2002). The Stroop and the WCST have been used to examine executive function processes in ADHD and both tasks are believed to be sensitive to response inhibition (see also reviews by Barkley, 1997; Pennington & Ozonoff, 1996). Accordingly these two measures are described in detail as follows.
Among the many versions of the Stroop, one classic version (Golden, 1978) consists of three conditions administered in fixed order: reading words aloud (word), naming colors (color), and incongruent color naming of color words (interference). The latter condition requires the participant to name the color of the ink in which the word is printed rather than to read the word (i.e., if the word green were printed in red ink, the correct response would be red). For each condition participants are instructed to read the words (or name the colors) as quickly and as accurately as possible. Each condition is timed to 45 seconds.

The WCST (Heaton et al., 1993) consists of 128 cards printed with geometric designs that vary according to color, form and number. A participant is given four cards and asked to sort the remaining cards using specific feedback from the examiner (as to correct or incorrect prior sorting). After 10 correct placements in one sorting category the examiner switches to another sorting category without informing the participant of the switch. The set order of the sorting categories is predetermined as color, form and number respectively.

2.6.4 Laboratory Based Evidence of EF deficits in ADHD

There are many inconsistencies among findings from laboratory studies using the Stroop and WCST, with not all studies finding equivalent performance distinctions either between ADHD subtypes or between ADHD and normally developing children (see reviews by Douglas, 1999; Pennington & Ozonoff, 1996; Sergeant et al., 2002; Tannock, 1998; cf. Carter, Krener, Chaderjian, Northcutt, & Wolfe, 1995; Klorman et al., 1999; Perugini, Harvey, Lovejoy, Sandstrom, & Webb, 2000; Pineda et al., 1998; Seidman, Biederman, Faraone, Weber, & Ouellette, 1997). Impaired behavioral inhibition has distinguished between the DSM-IV subtypes of ADHD-C and ADHD-I in some studies (e.g., Nigg et al., 2002), but not in others.
Moreover, most common reports of impaired ADHD performance on the Stroop have been on the interference subscale (Carter et al., 1995; Murphy, Barkley, & Bush, 2001; Pennington, Grossier, & Welsh, 1993; Seidman et al., 1997), though other studies found no evidence of ADHD difficulties on this condition but did so on the other subscales (see Barkley, 1997; Doyle, Biederman, Seidman, Weber, & Faraone, 2000).

Heterogeneity of samples, and differing measurement and methodological approaches may account for many differences in findings from the Stroop and the WCST. For example, methodological approaches have varied in whether or not they have controlled for basic naming speed for separate variables of color and word in the Stroop (Tannock et al., 2000; Stuss, Flodena, Alexandera, Levinea, & Katzd, 2001). While approaches have also varied as to the inclusion of screening methods to control for: differing conditions comorbid in ADHD populations, medication effects, developmental effects, and IQ and age differences.

Other laboratory paradigms used to test response inhibition and mental flexibility as shown by the ability to switch rapidly from one type of responding to another according to task demands are the stop-signal (Schachar, Tannock, Marriott, & Logan, 1995), and CPT's (Carte et al., 1996; Mariani & Barkley, 1997; Rovet & Hepworth, 2001). Findings from the stop signal have indicated that children with ADHD may have problems in response organization, arousal or effort (Oosterlaan, Logan & Sergeant, 1998). However, the stop signal is not without confounding factors (e.g., auditory stop tone combined with a visual go stimulus), and an association found between inhibitory failure on this task and reading problems (Nigg, 1999; Purvis & Tannock, 2000). Alternatively, CPTs are noted to be repetitive and
boring, the cognitive processes they assess unclear (Spreen & Strauss, 1998), and their ecological validity questionable (Barkley, 1991; 1998).

2.6.4.1 Laboratory Findings and ADHD Symptoms

One of the earliest studies to link ADHD with the EF processing areas compared the cognitive performance of children with ADHD to that of patients with frontal lobe impairments (Shue & Douglas, 1992). Since then, numerous studies using neuropsychological measures have demonstrated performance deficits in children with ADHD. These deficits are found in the cognitive self-regulatory mechanisms responsible for planning, goal-directed and adaptive behavior (Carte et al., 1996; Casey, et al., 1997; Cornoldi, Barbieri, Gaiani, & Zocchi, 1999, Schachar et al., 1995; Swanson et al., 1991). Children with ADHD have exhibited difficulty with ability and flexibility in memory processes involved in holding and manipulating information in mind according to cognitive task demands. However, these difficulties were not evident when the children were given regulatory support in knowing how to select and apply the appropriate organization strategies (Cornoldi et al., 1999). Further, a study involving adolescents with ADHD found they demonstrated executive function problems in generating strategies and in self-monitoring ongoing behavior (Clark, Prior, & Kinsella, 2000). These findings have critical implications in relation to learning and behavior management approaches.

2.6.4.2 Laboratory Findings in ADHD Subtypes

Although studies have consistently found children with the subtypes of ADHD-C and ADHD-I to be more impaired academically than their non-disordered peers, findings diverge on distinctions between the two subtypes in level and type of impairment. Some studies have found no major differences (Casey, Rourke, & Del Dotto, 1996; Lamminmaki, Ahonen, Narhi, Lyytinen & de Barra, 1995), while others
have (Morgan, Hynd, Riccio, & Hall, 1996). In addition, although all of the children with the subtype ADHD-I were found to exhibit slow cognitive processing, the presence or absence of symptoms of hyperactivity (albeit below diagnostic cut-off levels) has been found to differentiate between them (Dane, Schachar, & Tannock, 2000; McBurnett, Pfiffner, & Frick, 2001). Dane and colleagues also found indications that situational factors had an influence on these children’s behavior. Recent neuropsychological studies found slowed cognitive processing problems distinguish children with the subtypes ADHD-I and ADHD-C from those with ADHD-H (Chhabildas, Pennington, & Willcutt, 2001), those with other associated disorders, and from their normally developing peers (Manassis, Tannock, & Barbosa, 2000; Tannock et al., 2000). However, these studies also found no distinctions between the type, or level, of problems exhibited by the ADHD-C and ADHD-I subtypes.

Teachers report that children with ADHD-C demonstrate more severe behavioral symptoms and pervasive problems in school settings than the other two subtypes, although children with ADHD-I require more assistance with schoolwork (Faraone, Biederman, Weber & Russell, 1998; Gaub & Carlson, 1997). Nevertheless, as yet there has been no conclusive identification of cognitive markers distinct to ADHD and each subtype to explain these performance problems.

Therefore, although debate remains over the demarcation of subtypes, findings from studies such as those cited above largely support the distinction between ADHD-PI and ADHD-CT (see Barkley, 1998). Hence, these two subtypes will be the focus of the present research.
2.6.4.3 Laboratory Performance and Ecological Validity

Ecological validity has been defined as the functional and predictive relationship between individuals' performance on neuropsychological tests and their behavior in a variety of real-world settings such as at home and at school (Sbordone, 1996, 1997). It is thought that the executive functions were developed as ecological tools, enabling and promoting the daily adaptive functioning required for survival in social environments (Barkley, 1997, 2000). Correspondingly, the critical effect that daily environmental activities have on ability and skill levels of individuals has also been noted elsewhere in empirical literature (Greenfield, 1999). Attention has been drawn to an evolving cultural IQ, and the importance of further examining the cognitive effects of childhood activities such as videogames on children (Greenfield & Cocking, 1996, 1996). It seems essential then, that the executive functioning performance of children with ADHD be examined, not just during laboratory tasks, but also during cognitively challenging everyday tasks and activities in real-life environments of childhood.

2.7 EF in Everyday Contexts: Relevance of Laboratory Measures

The difficulties associated with using a single criterion variable to estimate the ecological utility of an executive task have been noted (Burgess, Alderman, Evans, Emslie, & Wilson, 1998; Tannock, 1998). Previous studies on executive functioning in children with ADHD have yielded inconsistencies in findings of behavioral inhibition deficits and so far have failed to delineate inhibitory deficit in ADHD (Nigg, 2001). Further, no specific executive function has been identified as distinct to ADHD (Sergeant et al., 2002; Tannock, 1998).

While such neuropsychological tests provide essential information used to advance and guide scientific research, they cannot provide a measure of the
performance demanded during everyday tasks in complex daily environments (Barkley, 1998; Burgess et al., 1998; Ponsford, 2000; Tannock, 1998). Such laboratory measures are static and narrowly focused, whereas performance during real-life tasks is dynamic, involving interaction between developmental influences, cognitive processes, and the environment (Tannock, 1998).

2.7.1 Motivation and Testing For Best Performance

The affective problems frequently found in children with ADHD are as typical of this population as is their lack of sustained attention and task persistence. The combination of these characteristics have raised questions and initiated hypotheses as to whether lack of effort or motivation are fundamental to the cognitive problems these children exhibit academically (Ackerman & Dykman, 1995; Hoza, Pelham, Waschbusch, Kipp, & Owens, 2001; Nigg, 2001). The repetitive and boring nature of many neuropsychological tasks used to test children with ADHD were developed for use with adults. These tasks may not encourage optimal performance in children, especially those with ADHD. The predominant focus of investigations so far has been at the level of deficit within the disorder. It is also not yet clear how executive function deficit demonstrated by children with ADHD during neuropsychological laboratory measures relates to their everyday behavioral symptoms during tasks that also place high demand on executive processes (Tannock, 1998).

Problems of children with ADHD are demonstrated in everyday dynamic contexts of childhood, at school and at home. To date however, almost all studies assessing executive or cognitive processes of children with ADHD have used adult focused rather than child focused neuropsychological testing measures. The majority of these measures were designed specifically to enable specific, static, and thus
thorough, focus on areas of possible deficit. Such testing instruments thereby rigorously control for the dynamics that are otherwise integral to a developing child’s daily performance in real-life environments (Tannock, 1998). It is critical therefore, that future assessments of these children recognize the environmental and developmental influences that are integral to children’s cognitive ability and behavior.

To obtain a true measure of an individual’s cognitive ability, it is essential that testing tasks and settings are used that promote optimal performance (Lezak, 1995). The existing questions regarding effort and motivational bias in children with ADHD are supported by the fact that effortful tasks in everyday settings are known to worsen these children’s behavioral symptoms (APA, 1994). Lezak, (1995) describes the importance of utilizing the best performance method to gauge an accurate measure of cognitive performance. This involves a thorough integration of historical data, test scores, and other observations to determine an individual’s highest level of functioning. The point is emphasized that such a method allows a broad range of the participant’s abilities to be taken into account when identifying a comparison standard for the evaluation of cognitive deficit. This point is important given the heterogeneity, and developmental nature of childhood ADHD, and an apparent impact of environmental influence on both the etiology and symptoms of the disorder (Tannock, 1998).

2.7.2 EF Performance and Adventure Videogames

Computer games provide a valuable, ecologically valid, indoor activity in which to test the performance of children. Videogame play is a popular leisure activity of primary school-aged boys in our society today (Cupitt & Stockbridge, 1996; Durkin & Aisbett, 1999; Emes, 1997; Greenfield & Cocking, 1996). These
games are known to be very motivating to children with ADHD, and many parents and practitioners have observed that ADHD children will concentrate and work quietly on this activity for lengthy periods (Tannock, 1997). The author notes that the contrast provided by such familial reports, clinicians' observations of hyperactive behavior, and laboratory findings of slowed and variable responses, has challenged the conceptualized core deficit of ADHD and prompted hypotheses of motivational deficit.

Adventure videogames involve challenging cognitive and EF demands, such as the dynamic representation of space, planning, anticipation of temporal events and avoidance of distractors (Donchin, 1995; Greenfield & Cocking, 1994, 1996). All of these have been identified with laboratory based neuropsychological measures as being problematic for children with ADHD. However, no research to date appears to have investigated this issue using real world settings that provide either intrinsically motivating tasks, or extrinsically motivating contingencies, for the duration of task performance. This utilization of non-traditional experimental tasks in real world settings promises optimal performance of the ADHD child on repetitive response measures, which traditionally have suggested problems with motivational bias (Barkley, 1998). There is some evidence that videogame play is a catalyst for the activation of dopaminergic neurotransmitter systems, which have been implicated in the pathophysiology of ADHD (see Koepp et al., 1998). Given hypotheses concerning imbalances in these biological neural substrates in ADHD, optimal task performance from children with ADHD should be expected in this context.

2.7.3 Children, EF, Sequential Tasks and Route Directions

Everyday tasks and activities, both indoors and outdoors, require directions to be followed and cognitive sequential actions to be successfully completed. Self-
regulatory processes are thought to be involved in the successful completion of sequential tasks (Li, Lindenberger, Rünger, & Frensch, 2000). Notably, children with ADHD have been found to exhibit EF problems in task switching (Cepeda, Cepeda, & Kramer, 2000), as well as difficulties suggesting inability in the effective mental organization of sequential information (Tannock, 1996; Tannock, Purvis, & Schachar, 1993).

Recent research confirms that children as young as 4 or 5 years old are capable of: comprehending information presented in map form, recognizing aerial views as representations of space, identifying the meaning of map symbols, identifying positions within simple maps, interpreting spatial information, and using a map to navigate (see Bremner & Andreasen, 1998). Very young children have also been shown capable of successfully using photographs as representations of space (DeLoache & Burns, 1994; Dow & Pick, 1992). Studies on children’s ability to find their way along routes, indicate that young children rely to a great degree on landmarks and sequencing of points along a route (Piaget & Inhelder, 1956; Piaget, Inhelder, & Szeminska, 1960). This evidence has been replicated by subsequent studies that have also found that young children’s mental maps involve a sequence of landmarks (see Spencer, Blades & Morsley, 1989; Blades & Spencer, 1987, 1990). However, it has not yet been investigated whether children with ADHD demonstrate comparable cognitive ability to their normally developing peers in the organization and flexibility required to form mental maps, follow directions, and complete sequential route tasks in real-life contexts.

2.8 Summary

Neuroscientific understanding of ADHD has made many advances from genetic, neuroimaging, neurochemical, and neuropsychological investigations.
Evidence of executive function impairment in children with ADHD has informed current theoretical models that propose response inhibition to be a core deficit of ADHD. This evidence has been largely obtained from laboratory-based studies and the use of adult-oriented neuropsychological measures. However, no cognitive marker has been identified as distinct to ADHD. Findings consistently involve the fronto-striatal and cerebellar brain regions. However, it is most probable that multiple causative factors will be involved in ADHD, thus multiple assessment measures must take into account the dynamic effects of development and environment on performance (Tannock, 1998). A child-oriented approach is essential given that the behavioral problems of children with ADHD are exhibited daily during dynamic childhood tasks and contexts. Moreover, there is an urgent need to examine cognitive function in everyday contexts and to map the relationship of task performance in the laboratory to real-life activities.

**Part C: Aims and Hypotheses of the Present Research**

The literature reviewed, emphasizes the requirement for theoretically driven cognitive assessments of children with ADHD that take into account the dynamic effects of development and environment on performance. This literature provides the rationale for the present research. This rationale is governed by awareness and consideration of the problems met by previous researchers of ADHD. These problems have resulted in certain considerations being instrumental to this research's approach and design, which are detailed as follows. The research focus on how performance impairments relate to underlying cognitive processes in children with ADHD, demand the use of a range of varied measures, tasks and contexts. The mapping of behavioral symptoms of children with ADHD to underlying cognitive processes may enable markers distinct to ADHD, and each subtype, to be identified.
This mapping requires, concurrently, both a global and a detailed focus in order to match with any specificity underlying cognitive processes to a behavior. This is especially so given the multidimensional nature, not only of the key construct of response inhibition, but also of the other executive functions and cognitive constructs being examined. Thus, each developmentally and environmentally appropriate measure must be able to map a dynamic aspect of performance to a related dimension of theoretical cognitive construct. From a global perspective, such mapping must provide a detailed account of behavioral and cognitive performance, which can be dismantled to allow each aspect to be examined separately and in comparison.

Child oriented, intrinsically motivating measures of relevance and meaning in a child’s daily life, are required to encourage optimal cognitive performance and control for motivational bias. In addition, methodology that controls for the confounding impacts of comorbidity and medication on performance will be more likely to reveal behavioral and cognitive markers distinct to ADHD. The present research is respectful of concern among researchers that matching children with ADHD by IQ with other children may remove an inherent part of the disorder one is attempting to examine (see Barkley, 1997). Nevertheless, matching on age and IQ also encourages as homogenous a sample as possible in such a heterogeneous, developmental disorder. An equivalent developmental age span and as homogeneous a sample as possible may more clearly reveal performance distinctions between the DSM-IV subtypes, ADHD-C and ADHD-I and their normally developing peers.

Thus, the present research has been designed to add to the empirical literature on the cognitive performance of children diagnosed with subtypes of ADHD-C and ADHD-I. It is the first theory driven research to examine executive functioning of
children during cognitive tasks and activities relevant to their daily lives. It is also the first research to examine the cognitive performance of the same children during neuropsychological tasks and real-life indoor and outdoor tasks demanding executive function processes. The following aims and hypotheses have been generated from a basis provided by previous empirical research.

2.9 Primary Aims and Hypotheses

Specific Aim 1: To delineate and operationally define measures of specific executive functions (e.g., behavioral inhibition, working memory) during videogame tasks and route tasks at the zoo.

Hypothesis 1: Not applicable

Approach 1: Specific segments of the selected videogames and zoo routes were reviewed to identify repeated opportunities for deployment of specific executive functions (as defined by Barkley, 1997) and to specify the precise responses required to confirm their deployment. For example, during the adventure videogame: (a) the player’s ability to stop forward trajectory by lifting the thumb from the down-pressed position on the controls at specific appropriate times in game play, demonstrates the ability to inhibit a prepotent or an ongoing response; (b) to remember and maintain the researcher-imposed game rules (rules contradictory to usual game play) demonstrates working memory ability; (c) to be able to self-generate other ways than the usual methods (which under the imposed rules are no longer viable) to protect game life in order to complete the goal-directed task (to reach the checkpoint or as far down the path as possible as fast as possible) demonstrated ability in reconstitution; and (d) to be able to execute all of the above to such an extent so as to perform overall as successfully and in a comparative amount of time as the remainder of the cohort, demonstrated ability in motor control.
Donchin’s (1995) recommendations for the successful use of videogames in research were referred to in the choice of videogames and construction of the EF game tasks. For example, that author stated that the game would be a valuable research tool only if the researcher exercised systematic control over the parameters of the game used. Further, he advised that a systematically multidimensional game be chosen, which would provide for very detailed measures of performance, and that the game be recorded for replay. This advice was also heeded in respect to the zoo context, and the same approach as described for the videogame context was used to determine tasks and specific EF measures at the zoo.

Specific Aim 2. To determine whether children with ADHD (uncomplicated by comorbidity and unmedicated) are impaired in behavioral inhibition and other EFs in comparison to normally developing peers (case matched on age and IQ), in everyday relevant, contexts of videogame play and route tasks on a visit to the zoo.

Associated Aim 2a. To determine whether impairments increase in children with ADHD relative to increasing demands on working memory or with high levels of distraction.

Associated Aim 2b. To determine whether behavioral inhibition and other EFs are differentially impaired in Inattentive versus Combined subtypes of ADHD.

Hypotheses 2: Children with ADHD exhibit impairments in behavioral inhibition and other EFs (working memory, reconstitution) and in motor control during adventure videogames and zoo tasks.

Hypotheses 2a: Impairments increase relative to increasing demands on working memory and distractor level.

Hypotheses 2b: Impairments are greater in the ADHD-C compared to the ADHD-I subtype.
Approach 2: EF performance is examined during videogame and zoo tasks in a community sample of boys with ADHD (unmedicated, no diagnosed comorbidity, two subtypes) and a healthy peer group without ADHD (case matched on age and IQ). Performance is assessed under contrasting conditions of low and high EF, working memory and distractor loads.

Specific Aim 3. To examine the relationship between behavioral inhibition and other EFs in the laboratory-based tasks and real-life tasks.

Hypotheses 3: Behavioral inhibition and EF in the laboratory tasks is related to performance in the real-life tasks (videogame, zoo).

Approach 3: A direct comparison is made of the executive functioning performance (behavioral inhibition and general executive functioning) during traditional neuropsychological tasks (Stroop, WCST) and real-life activities (videogame and zoo tasks) of a community sample of boys with ADHD (no comorbidity, unmedicated, two subtypes) and their healthy peers (case matched on age and IQ).

Specific Aim 4. To examine the choice, use and success of strategic game responses (pauses, prespins, backward pauses) of children with ADHD and their healthy peers during cognitively challenging videogames.

Hypotheses 4: Children with ADHD use fewer and less varied strategies, and demonstrate less success in their strategic game responses than their healthy peers during cognitively challenging videogame play.

Approach 4: The use and success of strategic game responses of a community sample of boys with ADHD (no comorbidity, unmedicated, two subtypes) and their healthy peers (case matched on age and IQ) is examined during cognitively challenging videogame play.
2.10 Unique Features of the Research Plan

Distinct to the present research are a number of unique and original contributions that it makes to the existing empirical literature on ADHD. It is the first theoretically driven examination of the performance of primary schoolchildren with ADHD across real-life and laboratory tasks and contexts in which the level of cognitive task demand is experimentally controlled and varied. It is also the first research to directly compare the relationship between the laboratory and real-life EF performance of the same group of community schoolchildren. The global though detailed and comparative design of the research recognizes the dynamic effect of development and environment on children's cognitive performance. In addition, the research is child oriented as well as child focussed, with motivating real-life tasks and activities chosen of meaning and relevance to children's daily lives. Moreover, screening and control for comorbidity and medication effects, individual case matching for age and IQ, and the inclusion for comparative examination of two DSM-IV subtypes, addresses factors that have confounded previous research in ADHD.
CHAPTER THREE

STUDY ONE

3.1 Introduction

One comprehensive theory of ADHD proposes that a fundamental EF deficit in behavioral inhibition gives rise to secondary executive dysfunction and impaired motor control resulting in impaired self-regulation of behavior (Barkley, 1997; 2000). Three components of behavioral inhibition are distinguished. The first, which is deemed to be the most important, refers to inhibition of a “prepotent” response (i.e., a response associated with positive or negative reinforcement) so as to create a delay in responding. The second component is conceptualized as the interruption of an ongoing response that is rendered inappropriate or inaccurate by sudden or unexpected changes in task demands (a sensitivity to error). The third is defined as sustained protection of response from disruption by competing events and responses (interference control or resistance to distraction).

Deficits in behavioral inhibition, particularly in inhibition of a prepotent response, are believed to preclude the effective deployment of four other EFs, resulting in secondary and associated deficits in nonverbal working memory (involving a retrospective and prospective sense of time), verbal working memory (internalization of speech), self-regulation of emotion and motivation, and reconstitution (creative use of past experience) (see Barkley, 1997, 2000). The distinction between nonverbal and verbal working memory in Barkley’s model (1997, 2000), does not map onto other models of working memory (e.g., Baddeley, 1986). Rather, nonverbal working memory is defined as involving on-line maintenance of information and organization of behavior over time, whereas verbal working memory refers to self-talk and one’s internal dialogue used for self-
regulation. Reconstitution refers to the selection and combination of existing actions or thoughts to create a novel response during problem solving. These secondary deficits, in turn, interact to influence motor control, resulting in significantly diminished goal-directed persistence and poor self-regulated behavior in children with ADHD.

This neuropsychological model of ADHD, which focuses on response inhibition and executive function (Barkley, 1997; Quay, 1997), is purported to apply primarily to the combined subtype of ADHD. To date, it is not known whether the DSM-IV inattentive subtype shares the deficits in response inhibition and other executive functions with the combined subtype or exhibits distinct deficits (e.g., Houghton et al., 1999; Nigg et al., 2002).

Empirical support for the hypothesized EF deficits in children with ADHD has been based on studies conducted in laboratory settings, using traditional EF tests and continuous performance tests (see Pennington & Ozonoff, 1996 for a review; Houghton et al. 1999). This evidence has been obtained in highly controlled laboratory settings where rigorous constraints have been placed upon the ADHD child's behavior, thereby possibly either exaggerating or conversely masking the true magnitude of these executive dysfunctions. These studies have yielded inconsistent results: evidence of behavioral inhibition deficits is equivocal (e.g., Nigg, 1999; Schachar, Mota, Logan, Tannock, & Klim, 2000; cf. Kuntsi, Oosterlaan, & Stevenson, 2001; Scheres, Oosterlaan, & Sergeant 2001) and there is no known executive function (or other cognitive construct) that is uniquely associated with ADHD (see review by Tannock, 1998). Furthermore, the repetitive and boring nature of many of the tasks (e.g., continuous performance tasks) may not elicit
optimal cognitive performance, and as a result the findings may reflect motivational issues rather than EF deficits (Lezak, 1995).

Although laboratory research is essential to test and develop theoretical understanding, it remains the case that the problems of children with ADHD are manifest in the real world in the course of their everyday activities in complex environments (Rapport, Chung, Shore, Denney, & Isaacs, 2000). The generalizability of accounts based on laboratory work does not appear to have been tested in more authentic childhood contexts. Hence, the present study tests the critical claims of current theory (Barkley, 1997) by examining the EF and motor control performance of children on sequential route-tasks in videogame play and on a day outing to a zoo.

Videogame play is a complex, multi-requirement cognitive domain (Greenfield, 1999; Greenfield, & Cocking, 1994, 1996). This ecologically valid medium is known to be very motivating to children including those with ADHD (Cupitt & Stockbridge, 1996; Durkin & Aisbett, 1999; Emes, 1997; Mitchell, Chavez, Baker, Guzman, & Azen, 1990; Tannock, 1997). Furthermore, videogame tasks should promote optimal cognitive performance (relative to experimental tests) in children with ADHD by providing external motivating contingencies just prior to and at the moment of responding. Tasks administered in this medium should also heighten the activation/arousal state of boys with ADHD, which may also promote their optimal performance (Koepp et al., 1998; Kuntsi et al., 2001). By contrast, the zoo enabled a field setting for EF performance tasks in an external social environment, also providing high motivation (Carlson & Tamm, 2000; Slusarek et al., 2001) along a sequential route with many salient, deliberate and spontaneous distractions (Li et al., 2000).
The overall aim of the investigation was to test the generalizability of EF performance in children with ADHD to non-laboratory tasks and settings. Specific aims were threefold: (a) to compare behavioral inhibition, nonverbal working memory, verbal working memory, self-regulation, reconstitution and motor control in boys with ADHD and normal peers during real-life activities; (b) to examine the effect of different settings and task contingencies (e.g., working memory load, distractors present or absent) on the EF performance of children with ADHD; and (c) to compare the performance of boys with ADHD-inattentive subtype to those with ADHD-combined subtype. Based on current theory, predictions were that: (a) children with ADHD would exhibit impairments in behavioral inhibition and the other executive functions compared to the control group in both the videogame and zoo contexts, (b) these impairments would be greatest when under conditions with many salient distractors or with high working memory load, (c) children with the combined subtype of ADHD would be more impaired than those with predominantly inattentive type.

3.2 Method

3.2.1 Participants

A cohort of 114 boys aged 6 to 12 years ($M = 9.6$ years, $SD = 2.1$) participated, of whom 57 had received a diagnosis of ADHD and 57 were free of any diagnosis and thus constituted the normally developing comparison group. ADHD participants were recruited primarily through one consultant pediatrician with a clinical practice serving a large urban population in Perth, Western Australia. The normal comparison group was recruited from one local public primary school situated within the same socio-economic region of the city as the pediatrician's practice. An
information letter and consent form was mailed to the parents of all boys in Grades Two through Seven and resulted in a 70% response rate.

To be included in this study, children had to have an estimated verbal or performance IQ score of at least 80, based on four subtests (Vocabulary, Similarities, Block Design, Object Assembly) of the Wechsler Intelligence Scale for Children, 3rd Edition (WISC-III, Wechsler, 1991). All participants had normal or corrected vision and none had hearing impairments.

Children comprising the ADHD group had all been diagnosed by a Consultant Pediatrician as meeting the DSM-IV (APA, 1994) criteria for ADHD on the basis of a clinical interview and had subsequently been referred to a clinical psychologist (by the pediatrician) for the assessment of undiagnosed comorbid disorders. Also parents completed the ADHD rating scale (Du Paul, Power, Anastopoulos, & Reid, 1998) that covers the DSM-IV symptoms for ADHD. Only children with a confirmed diagnosis of ADHD from the consultant pediatrician, who met the clinical cut-offs on the ADHD rating scale, and had no other diagnosed comorbid conditions were included in the present study. Based on these criteria, 75 children with ADHD (64 boys, 11 girls) were eligible.

Children in the normal comparison group had no identified problems based on the annual screening conducted by the school, in accordance with criteria stipulated by the Education Department of Western Australia to identify students at risk of educational failure and reading disabilities (using the Neale Analysis of Reading Ability, Neale, 1989). Approximately 20% of those children volunteering to participate were excluded because either their school psychological assessments, academic records, or both, indicated diagnosed conditions (including learning difficulties). None of the remaining children had any record of problems from
previous screening procedures, and had no indication of difficulties on any of their school term reports. As an additional check the school principal in consultation with the resident school psychologist confirmed the absence of learning difficulties or any other conditions. A total of 155 children (68 boys, 87 girls) were eligible for this study.

3.2.2 Matching Procedures

In consideration of anticipated effects of age and nonverbal motor and visuospatial abilities on performance, each child in the ADHD group was individually matched on age (within 6 months) and performance IQ (within 1 SD, that is within 15 scaled score points) with a child in the normal comparison group. Individual matching decreases the error variance and prevents the matching variables from becoming competing causal factors of any effects (Kirk, 1995).

A decision was made to exclude females from this study for several reasons: First, there were few females in the ADHD group \((n = 11)\) and thus insufficient numbers of each subtype for meaningful analyses. Second, boys \((7 \text{ to } 15 \text{ years})\) are the primary users of home videogames (Durkin & Aisbett, 1999; Greenfield & Cocking, 1996; Tannock, 1997); and third, there is no robust evidence of any gender-related differences in cognitive functioning in children with ADHD (Biederman, et al., 1999; Castellanos et al., 2000; Houghton et al., 1999; Rucklidge & Tannock, 2001). Also, since the study included two components (videogame, zoo) and used a matched-pair design based on age and performance IQ (as described below), data for children who did not complete both the videogame and zoo components of the study, or for whom there was no appropriate match, were excluded from the analyses reported here.
The combined requirements for completion of both the videogame and zoo components as well as the matching procedure necessarily resulted in some reduction of the available sample. Specifically, 3 children in the ADHD group and 2 comparison children were excluded because they did not complete both components. Also, the criteria for matching resulted in the exclusion of data an additional 4 boys with ADHD and 4 comparison boys for whom there was no appropriate match for age and IQ. Hence, the data reported here were derived from 57 boys with ADHD case-matched with 57 boys from the normal comparison group. The ADHD group included 20 boys classified as ADHD predominantly inattentive type (ADHD-PI) and 37 classified as ADHD combined type (ADHD-CT) as defined in the DSM-IV (APA, 1994). The mean ages, verbal and performance IQ scores for boys in each of the groups and subgroups are summarized in Table 3.1, along with the mean behavior ratings on the ADHD Rating Scale IV (DuPaul et al., 1998) for the ADHD groups.

Prior to testing, information was obtained to ascertain the extent of each participant's familiarity with videogame play and the zoo. Videogame answers were on a yes/no basis and were quantified into three categories of novice, average and skilled players. The video categories were determined by answers to the following questions: (a) extent of the player's prior experience with the two games and (b) with the Sony controls used in the study, (c) having a game at home, and (d) frequency of play on an average weekly basis. The zoo categories were determined by when the participants had last visited the zoo previous to the date of testing. This information is summarized in the lower section of Table 3.1.
Anot: ADHD = Attention-Deficit/Hyperactivity Disorder; ADHD-I = Predominantly Inattentive ADHD Subtype; ADHD-C = Combined ADHD Subtype; NC

---

### Table 3.1: Sample Characteristics for ADHD and NC Groups

<table>
<thead>
<tr>
<th>ADHD I</th>
<th>Matched NC</th>
<th>ADHD C</th>
<th>Matched NC</th>
<th>Total ADHD</th>
<th>Total NC</th>
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</tbody>
</table>

Note: ADHD = Attention-Deficit/Hyperactivity Disorder; ADHD-I = Predominantly Inattentive ADHD Subtype; ADHD-C = Combined ADHD Subtype; NC

Last visit over 6 months
Last visit over 12 months ago

**Zero Familiarity:**
- Skilled player
- Average player
- Novice player

**Videogame Familiarity:**

<table>
<thead>
<tr>
<th>Hyp/Imp</th>
<th>Inattenuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5 (1.5)</td>
<td>7.5 (2.0)</td>
</tr>
<tr>
<td>6.5 (2.0)</td>
<td>6.0 (3.5)</td>
</tr>
<tr>
<td>5.5 (3.5)</td>
<td>4.0 (4.5)</td>
</tr>
<tr>
<td>102.2 (15.3)</td>
<td>103.2 (16.4)</td>
</tr>
<tr>
<td>102.5 (16.9)</td>
<td>103.2 (16.0)</td>
</tr>
<tr>
<td>106.3 (10.5)</td>
<td>108.0 (14.8)</td>
</tr>
<tr>
<td>111.6 (20.3)</td>
<td>113.2 (17.1)</td>
</tr>
<tr>
<td>12.9 (3.0)</td>
<td>12.7 (2.0)</td>
</tr>
</tbody>
</table>

**ADHD Ratings:**
- Estimated VIG: 105.0 (17.5)
- Estimated PIQ: 112.9 (20.3)

**Adj. VIG:**
- u = 2.7
- u = 3.7

---
3.2.3 Methods and Measures: Videogame Component

Two types of videogames were selected. One was a simple target game (*Point Blank™*) in which success depended primarily on motor control involving visuospatial and eye-hand coordination abilities. The other was an adventure game (*Crash Bandicoot™*) which required response inhibition and other executive functioning abilities as well as motor control involving visuospatial and eye-hand coordination skills. Both games were played on a Sony Play Station (computer software) and a Sony hand-held control panel with a left-hand and right-hand keypad. The keypad on the left of the control contained four response buttons arranged in a cross formation, which controlled the directional movement of the videogame character, as indicated on each button (forward, backward, left, right). The other keypad contained 4 response buttons, only two of which were used in the present study to control two types of vertical action of the character (*spin*, indicated by a circle on the button, and *jump*, indicated by an X on the button). The response buttons on each keypad were spaced approximately 2 cm apart and are activated by the thumb of each hand.

3.2.3.1 Target Game (*Point Blank™*): Four game segments of equal duration (approx 20 seconds each segment) were chosen ("castle turret," "parachutes," "shelves," "shooting gallery"), all of which required the participant to aim at and hit round black and white bulls-eye targets within a limited time while they appeared on the screen. To do so, the participant was required to manipulate the four directional buttons on the hand-held control with the left-hand thumb to move a small cross on the screen to the target and then immediately press the designated action button (the *spin* button) with the right-hand thumb. Participants completed one trial in each of the four segments.
The four game segments vary in the number of targets visible at any one time (one versus more than one), possible locations of the targets (fixed, variable), target movement (stationary, moving), and the number of response buttons used (left-right plus spin, left-right plus up-down plus spin). Hence, the games can be ranked in terms of visuospatial and motor demands. The order of the game segments, which remained constant for all children, was designed to alternate between the lesser and more demanding, in terms of visuomotor skills (1 = least, 4 = most). The segments were presented in the following order: castle turret (rank=2), parachutes (rank = 4), shelves (rank=3), shooting gallery (rank=1). Children were instructed to hit as many targets as possible, and not to waste bullets by firing randomly, because the computer kept score of the number of bullets used as well as the number of targets hit. Therefore, this task did require some degree of inhibition although in contrast to the adventure game described below, the cognitive demands of this game were minimal. Since the response of firing was associated with immediate reinforcement (e.g., the bullet hit or missed the target) in the absence of any specific signal to inhibit, this measure was conceptualized as an index of the ability to inhibit a prepotent response. Scores were shown on the screen and recorded and of these the number of correct hits expressed as a percentage of total shots fired (% correct hits), was used as the primary dependent measure of motor performance and visuospatial ability.

3.2.3.2 Adventure Game (Crash Bandicoot™): This adventure game required the participants to use the response buttons on the hand-held console to control the movements of a small, animated figure - Crash Bandicoot (CB) - to allow it to negotiate successfully through various hazards that occur while moving along a jungle path to reach a designated checkpoint. An auditory soundtrack provided an
accompanying rhythmic metronomic beat. The journey was hazardous, involving risks of falling into chasms or being prevented from progressing along the path by rolling wheels, skunks, and snapping plants. The game afforded opportunities (additional lives) to re-try the journey following errors. Hence, the game required the deployment of behavioral inhibition and other executive functions (e.g., working memory, reconstitution in the form of responses to novel tasks, and rule governed behavior) as specified in a current model of ADHD (Barkley, 1997). Pressing the forward-movement response button was associated with immediate auditory and visual reinforcement (positive and negative) and so was conceptualized as a prepotent response. Thus inhibiting the forward button press indexed two types of inhibition - inhibition of a prepotent response and interruption of an ongoing response that was suddenly rendered inappropriate by the occurrence of a hazard, which served as the signal to stop.

Participants were required to complete one specific game segment under four experimental conditions (presented in random order), which varied along two dimensions - working memory load (low, high) and distraction (low, high). Each experimental condition included three attempts (a total of 12 attempts or “lives” per participant). *Condition 1 (low working memory load, no added distractor)* required the participant to maneuver the CB as quickly as possible from the designated starting point down the jungle path to a specific checkpoint, without touching any of the boxes that appeared along the path. *Condition 2 (high working memory load, no added distractor)* required participants to maneuver CB down the jungle path as quickly as possible to the checkpoint, while remembering to apply a specific game rule (*spin* boxes marked with an arrow), once at the commencement and again about a quarter of the way along the route (i.e., twice each trial, six times overall).
Condition 3 (low working memory, distractor added) and 4 (high working memory, distractor added) were identical to conditions 1 and 2, respectively, but with the added distractor of a recorded segment of a popular television show *The Simpsons* (Cary, 1997) that was presented simultaneously on an adjacent monitor. The number of on task glances made by each participant toward this distractor was recorded by video camera and later computed as a performance measure under this condition.

Specific event-related actions occurring during the *Crash Bandicoot™* videogame were selected to index behavioral inhibition, the four dependent executive functions (nonverbal working memory, verbal working memory, self-regulation of motivation and reconstitution), and motor control, as defined by Barkley (1997). These measures and their operational definitions are presented in Table 3.2 (top section).
<table>
<thead>
<tr>
<th>Concept</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reversal</td>
<td>A pre-spin was a unique and distinct execution of a spin.</td>
</tr>
<tr>
<td>Number of backswim pauses</td>
<td>(Goal) Consistent novel swim-directed actions to maintain a reversal and series of previous behavior to reversal.</td>
</tr>
<tr>
<td>Number of pre-spins</td>
<td>Verbal Working Memory</td>
</tr>
<tr>
<td>Verbalizations and vocalizations</td>
<td>Number of self-directed, on-task verbalizations and vocalizations</td>
</tr>
<tr>
<td>Number of non-directed boxes span</td>
<td>On-line maintenance of information</td>
</tr>
<tr>
<td>Number of non-directed boxes span</td>
<td>Nonverbal Working Memory</td>
</tr>
<tr>
<td>(Condition) Behavioral Inhibition</td>
<td>Inhibition of ongoing action or proposed response</td>
</tr>
<tr>
<td>(Condition) VideoGame Component</td>
<td>Measure (computed separately for each Operationalization)</td>
</tr>
</tbody>
</table>
Time taken to complete the route

and 1 task). Simple Route had one checkpoint and 2 tasks; Simple Route had 2 checkpoints and 1 task. Complex Route had 2

described as (pass/fail): achievement of checkpoints and

additional information to complete the checkpoint task.

in the need for

Nonverbal requests were defined as eye gaze to examiner, 

explicit nonverbal requests for additional information, 

indicated by the child's verbal requests or observable and

Failure to keep rule (touch checkpoints) in mind was

an eye gaze towards a nondescribed animal or location.

on direct route (other than to move around an obstacle) plus

A deviation was an observable and deliberate movement

away from the desired route

Number of deviations from the desired route

Mean total time (in seconds) to complete each game

challenges included within-game distractions (non-

ADHD Theory Outside the Laboratory
3.2.4 Methods and Measures: Zoo Component

Two routes in the zoo were selected, which varied in length and the number of distracting animal exhibits, as well as in the number of designated checkpoints and tasks to be completed. The *simple route* (shorter and least challenging) commenced at a cluster of three zoo signposts (Starting Point) and required the participants to walk as quickly as possible along the path, past trees and vegetation surrounding a playground, and on to the signs outside the Aviary Walk and Australian Birds area (Checkpoint 1), which they were to touch (Task 1) and then remain beside.

The *complex route* (longest and most challenging) required the participants to walk as quickly as possible from the Starting Point (outside the entrance to the Reptile House) to the inside far end of the Reptile House to a large crocodile skin on the wall (Checkpoint 1), where they were to touch the rail (Task 1). Next, they were required to walk out of that area, proceed via the Penguin Plunge to the far end of the Wetlands area, and then on to the Crocodile House (Checkpoint 2), where they were to look at the big crocodile (Task 2) before returning to the Starting Point. This route included many auditory and visual distractors, resembling the jungle scenery in the videogame *(Crash Bandicoot)TM*. For example, the Reptile House included the sound of a waterfall, closed glass cases with snakes, and attractive open-topped enclaves containing tortoises and lizards; the Penguin Plunge involved baby penguins swimming, and recorded ocean sounds triggered by the approach of the participant; the Wetlands included approach-activated recordings of frog croaks, ponds and large water birds.

Each boy completed both routes in a randomized order during the normal morning opening hours of the zoo. At these times, the paths and public areas around the animal exhibits are generally crowded with adults and children and so reflect
typical route and viewing conditions. The time of the zoo visit (early versus late morning) was also randomized for the boys because the animals were more noisy and active early in the morning and there were fewer visitors, whereas the reverse was true in the later morning.

Specific behaviors occurring during the zoo study were selected as representative of behavioral inhibition, nonverbal and verbal working memory, and motor control. These measures and their operational definitions are presented in the lower portion of Table 3.2. The zoo tasks did not provide an appropriate measure of reconstitution (i.e., novel responses or behavior).

3.2.5 Procedures

The Research Review Board of The University of Western Australia approved the two components of the study (videogame, zoo). Authorities of the Perth Zoo also approved the zoo component of the study. The parents of all boys gave written informed consent and all boys gave informed verbal assent. Appointment times for the testing sessions were arranged by telephone. During the telephone conversation, parents were reminded of the section in the information letter requesting that no stimulant medication be administered to their children on the afternoon or evening prior to the testing (a minimum of 20 hours medication free). This was checked again immediately prior to testing. All parents complied with this request so that all children were tested in an unmedicated state. Previous to the study, the examiners (first author, second author) conducted practice trials in administering the videogame and zoo tasks with approximately twenty volunteer primary school children. All boys were tested individually and completed the two components in the same order (videogame first, zoo second), at an interval of approximately six months.
3.2.5.1 Videogame Component: Boys in the ADHD group were tested in a quiet room located in the university, and boys in the normal comparison group were tested at their school, in a room designated for the study. In both settings, the room was quiet, well lit and ventilated, free of extraneous distractors, and the layout of equipment and furniture was comparable. All boys were tested in the morning and were allowed a 3-minute practice time (longer for novices) prior to commencing the experimental conditions, to ensure that each boy was sufficiently competent to perform the motor skill and visuospatial aspects of Point Blank™ and to be able to maneuver CB past the fourth challenge along the route (which was required to yield adequate measurement of executive function). The examiner held the controls and gave instructions immediately preceding the participant’s undertaking of each of the four conditions (see Appendix B). Participants were informed that their best time and performance would be chosen from the three attempts for each task.

Each boy was videotaped while performing the videogames to record any vocalizations, body and facial movements of participants, particularly eye movements towards the distractor, during videogame play. Also, participants’ videogame play was downloaded directly onto a videocassette. The sound volume and graphics’ tuning of both televisions was equal and monitored to ensure constancy throughout the testing for all participants. The adult examiner remained with the boy throughout the testing, but stood out of his line of sight. Administration of all four game conditions lasted about 20 minutes, after which the participants were allowed to play the game for five minutes with no imposed rules.

3.2.5.2 Zoo Component: The testing took place in the morning hours between 8 am and 12.30 pm during the summer school holidays. Route instructions were given in such a way as to optimize the participants' ability to follow route directions
(Bremner & Andreasen, 1998). Standardized directions and instructions were given to each participant by the adult examiner immediately prior to commencement of the relevant route (see Appendix C). The verbal instructions were accompanied by pointing toward the relevant locations and showing photographs of the pertinent locations on the route (some not being visible from the starting place). The examiner ensured that the participants understood the directions and instructions prior to commencement. Participants were told to walk as fast as they could normally, but not to run. The examiner followed (at a distance of 4 or 5 paces) and recorded the participant's progress with the audio-video camera. The entire exercise took no more than 15 minutes for each participant.

3.2.6 Data Analysis

The computer automatically scored performance on the target videogame (*Point Blank™*). Performance on the adventure videogame was scored manually from the videotape. Specifically, two event-related coding sheets were developed. The first for recording the start and finish times and an itemized list of the challenges completed for each trial and each task. The second recorded the occurrence of each event-related action selected to represent inhibition and the four executive functions as defined in Table 3.2. Scoring was conducted from subsequent review of the videotaped game play. A second trained independent observer, who was blind to the children's group status, simultaneously scored the measures of EF from 10% of the recorded videotapes of game play. The following levels of inter-rater reliability were obtained: behavioral inhibition 89%, nonverbal working memory 98%, verbal working memory 92%, reconstitution 97% and motor control 93%. Overall the mean level of agreement was 94%.
Performance at the Zoo was scored manually using separate event-related coding sheets for each route. Each coding sheet contained a detailed list of landmarks along each route. During subsequent review of the videotaped child, each relevant action and verbalization was recorded on the coding sheet beside the landmark at which it occurred, and this was used for scoring. There was no inter-rater reliability data collected for the scoring of the children’s performance at the zoo.

To test for group differences between the ADHD and case-matched normal comparison boys, a series of Multivariate Analyses of Variance (MANOVA) for repeated measures were conducted for continuous data generated from the video and zoo contexts. Group (ADHD, NC) and the experimental conditions (e.g., game in *Point Blank*™, working memory load and distractor in *Crash Bandicoot*™, route in the zoo context) were used as repeated measures. Significant MANOVAs were followed by univariate ANOVAs to locate the source of differences.

Although children were case matched for age and performance IQ, they differed in verbal IQ. Also there was a large age range in the sample (i.e., 6 – 12 years), which raises the possibility that age may correlate differentially with the dependent variables by group. Pearson bivariate correlations were subsequently conducted to examine possible relations between age, performance IQ, verbal IQ and the dependent variables indexing EF. Performance IQ did not relate to any of the dependent variables. However, there were group differences in how age and verbal IQ related to certain videogame and zoo dependent variables. Therefore analyses were rerun for all EF variables with age and verbal IQ as covariates.

A planned contrast was used to test for differences between the two ADHD subgroups (inattentive, combined subtypes). Chi-square analysis was used for categorical data (e.g., yes/no responses on videogame and zoo familiarity, and
pass/fail on checkpoint tasks in the zoo context). Also, a repeated measure ANOVA for matched pairs (group) was conducted to determine differential effects of time of testing (early versus late morning) in the zoo context. Since there were no significant differences, subsequent analysis was conducted collapsing across this variable. Effect sizes were ascertained by dividing the difference between the two means being compared by the standard deviation of the data, obtained by the square root of the mean square for error in the denominator of the F ratio used to test the overall hypothesis (Cohen, 1988). Statistical analyses were performed using SPSS Version 10.0.

3.3 Results

3.3.1 Check on Matching Procedures: A repeated measures MANOVA conducted on the means of age, verbal IQ and performance IQ revealed no significant group differences at multivariate level. Univariate tests showed the ADHD group was higher in verbal IQ than the normal comparison (NC) group, $F, (1, 55) = 4.99, p < .05$; however there were no significant group differences with respect to age, $F, (1, 55) = 0.03, ns$, or performance IQ, $F, (1, 55) = 0.19, ns$. There were no significant subtype group differences on any of these matching variables.

Participant responses relating to videogame and zoo familiarity (see lower section of Table 3.1) were subjected to chi-square analysis. No group differences were revealed for level of videogame familiarity, $X^2 (2, N=114) = 3.78, ns$; or for zoo familiarity, $X^2 (1, N=114) = 1.42, ns$.

3.3.2 Videogame Component

3.3.2.1 Target Game (Point Blank\textsuperscript{TM}): There was no difference between the ADHD group ($M = 64.1, SD = 16.2$) and NC group ($M = 66.2, SD = 15.0$) in the target games in terms of the overall mean percentage of correct shots fired. Nor did
the demands of the various target games have a differential effect on the two groups of boys, as indicated by the absence of a significant interaction between group and game. As predicted by the design of this measure, a main effect of game, $F$, $(3, 165) = 131.97, p < .05$, was revealed. Post hoc tests on the scores (% correct hits) showed each adjacent pairwise comparison as significant ($p < .01$), with the predicted order (from most to least difficult) of the game segments as follows: parachutes ($M = 41.94, SD = 15.21$); shelves ($M = 65.00, SD = 18.75$); castle turret ($M = 72.52; SD = 14.47$); and shooting gallery ($M = 81.17, SD = 10.75$). There were no significant subtype group differences revealed on any of the target game measures.
Table 3.2. Scores on Video Game Condition for ADHD and NC Groups

<table>
<thead>
<tr>
<th>Group (G)</th>
<th>WM</th>
<th>WM x D</th>
<th>WM x Dis</th>
<th>WM x A</th>
<th>D x A</th>
<th>D x N</th>
<th>A x N</th>
<th>WM x A x D</th>
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<tbody>
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</table>

Note: HI = Behavioral inhibition; NWM = Nonverbal working memory; WM = Verbal working memory; F = Response latency; R = Reaction time in seconds.

Changes in significant group differences after covarying for age and verbal IQ are reported.

Motor control condition: DIS = Discrimination (high vs. low load); WM = Working memory (high vs. low load) condition. Means and standard deviations reported for number of each action reported and for mean of total time on generic task (in seconds).

MC/F: Challenges completed

WWM: Verbal interference

NWM: Nonverbal interference

WM: Visual interference

NDWM: Non-distracted boxes

Duration (sec): Total game time

Pre-trial: Challenges completed

Backward passes

Pre-trial: Challenges completed

R: Non-distracted boxes
3.3.2.2 Adventure Game (*Crash Bandicoot™*): Contrary to predictions, there were no significant group differences (see Table 3.3) on the measure of behavioral inhibition (pauses), nonverbal working memory (information maintenance, as indexed by spinning or jumping on non-designated boxes), or on one of the aspects of reconstitution (creation of novel responses, indexed by backward pauses). However, the ADHD group did differ from the NC group in terms of the other aspect of reconstitution (number of prespins), verbal working memory (delayed internalized speech, indexed by on task exclamations and self-talk respectively), and motor control/fluency (indexed by number of challenges completed). The accompanying effect sizes were 0.25; 0.26 and 0.24; and 0.21 respectively. Hence, the ADHD group performed more prespins and made more on task affective exclamations and self-talk, although they completed fewer challenges than the NC group. No significant subtype group performance differences were revealed on any of the adventure game measures.

As indicated in Table 3.3, main effects for the (low versus high) working memory and distractor conditions indicated the impact of these experimental conditions on several aspects of the children’s performance. All children made more rule violations (i.e., touched more non-designated boxes) during the low working memory condition (ADHD, $M = .22$, $SD = .56$: NC, $M = .10$, $SD = .44$) than during the high working memory condition (ADHD, $M = .006$, $SD = .33$: NC, $M = .005$, $SD = .06$). By contrast, all children made more prespins under the high working memory load (ADHD, $M = 1.79$, $SD = 2.06$: NC, $M = 1.10$, $SD = 1.77$) compared to the low working memory load (ADHD, $M = 1.50$, $SD = 2.02$: NC, $M = .90$, $SD = 1.63$). The significant interaction between group and working memory for the measure of motor control/fluency (total game time) reveals that the ADHD group ($M = 25.5$, $SD$
took equivalent time to the NC group \((M = 24.9, SD = 8.6)\) under the low working memory condition, but with a higher working memory load the ADHD group \((M = 30.4, SD = 14.7)\) took longer to complete the tasks than did the NC group \((M = 25.3, SD = 8.63)\). There was a similar tendency under the high working memory condition for the ADHD group to complete fewer challenges, although this did not reach significance.

The main effect for distractor condition (low versus high) on verbal working memory (verbal utterances) was qualified by a significant interaction between group and distractor condition. Post hoc tests confirmed that the ADHD group \((M =1.14, SD = 2.62)\) engaged in more task-relevant self-talk than the NC group \((M =.23, SD = .80)\) during videogame tasks without the added distraction of the adjacent televised cartoon show (The Simpsons), but did not differ on tasks with the added distractor (ADHD group \(M =.39, SD = 1.38\): NC group \(M = .07, SD = .37\)).

Visual gazes towards the television that was adjacent to the videogame were also analyzed. A repeated measures MANOVA conducted on glances made by the participant's toward The Simpsons while completing the videogame tasks, revealed no significant group differences between the ADHD and the NC group.

3.3.2.3 Effect of Covarying Age and Verbal IQ: Results with age and verbal IQ covaried are reported in the lower portions of Table 3.3. With age covaried, ADHD children were found to exhibit more problems in nonverbal working memory (i.e., spun more undesignated boxes). However, group differences on verbal working memory (exclamations and self-talk) were no longer significant. Group differences in terms of prespins and number of challenges completed remained robust. With verbal IQ covaried, group differences for verbal working memory (exclamations and
self-talk) and motor control/flexibility (number of challenges completed) were no longer significant, however, the group difference in prespins remained robust.

Covarying verbal IQ reveals a significant interaction between group and working memory (low vs. high) condition. The ADHD group (\(M = 88.37\), \(SD = 39.64\)) achieved significantly fewer challenges than the NC group (\(M = 105.68\), \(SD = 34.13\)) under low, but an equivalent number under high working memory conditions (ADHD group \(M = 89.84\), \(SD = 39.24\); NC group \(M = 97.33\), \(SD = 33.45\)). Post hoc tests confirmed that the ADHD group performance was consistent under both working memory conditions, while the NC group achieved significantly less under high, than under low, working memory conditions, \(F, (1, 55) = 4.89, p < .05\).
<table>
<thead>
<tr>
<th>Time to complete</th>
<th>Motor Control/Flexibility</th>
<th>Behavioral Inhibition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task completion</td>
<td>Time to complete</td>
<td>Motor Control/Flexibility</td>
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<tr>
<td></td>
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<td>Behavioral Inhibition</td>
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<td>Working Memory</td>
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<td>ADHD</td>
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<td>AD/HD</td>
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</tbody>
</table>

Table 3.4: Scores on ZOO component for AD/HD and NC groups.
3.3.3 Zoo Component

The ADHD group performed more poorly than the NC group in terms of behavioral inhibition (made more deviations) and motor control (more time to complete) on the zoo tasks (see Table 3.4). The accompanying effect sizes were 0.35 and 0.43, respectively. However, the groups did not differ in working memory (information and rule maintenance). No ADHD subtype group performance differences were revealed on any of the zoo measures.

As indicated in Table 3.4, the significant main effect for route complexity indicates that all children made more deviations, verbal and nonverbal queries and took more time on the complex route compared to the simple route. However, the significant interaction between group and route complexity for the measures of behavioral inhibition (deviations) and motor control (time to complete), indicate that route complexity had a greater negative effect on these aspects of performance in children with ADHD.

3.3.3.1 Effect of Covarying Age and Verbal IQ: With age covaried, the group difference in behavioral inhibition (deviations) was no longer significant, but the interaction between group and route remained robust, indicating that the ADHD group exhibited more problems in inhibition on the complex route. However, neither the group difference in motor control/flexibility (time to complete) nor the interaction between group and route, remained significant. Verbal IQ did not correlate with any of the zoo task variables.

3.4 Discussion

The goal of this study was to examine behavioral inhibition and other executive functions in children with ADHD during real-life activities: videogame play and route tasks on an outing to a zoo. According to current theory, behavioral inhibition
is deemed a core impairment in ADHD that in turn gives rise to deficits in other executive functions (Barkley, 1997). The present study revealed that in the videogame context, the ADHD group exhibited impairments in nonverbal working memory and motor control/fluency but not in behavioral inhibition. By contrast, in the zoo context the ADHD group exhibited problems in behavioral inhibition and in motor control/fluency, but not in working memory. There were no discernible performance differences between the predominantly inattentive and combined subtypes of ADHD. Thus, the present findings provide only partial support for this inhibitory model of ADHD (Barkley, 1997).

3.4.1 Behavioral Inhibition

In the present study, the ability to withhold responses in the target and adventure videogames (i.e. pausing) was used to index the efficiency of two aspects of behavioral inhibition: momentary inhibition of prepotent responses and momentary interruption of an ongoing response. In the zoo task, the ability to proceed rapidly along the direct route to the designated checkpoint without deviating was used as a measure of the third component of behavioral inhibition - interference control. The findings that the ADHD group was impaired in one component of behavioral inhibition (interference control) but not in the others (inhibition of prepotent responses, interruption of ongoing responses) support the proposed multidimensional nature of behavioral inhibition (Barkley, 1997; Fuster, 1989). These findings also suggest that inhibitory deficits in ADHD may be more circumscribed than proposed by Barkley's inhibitory model.

One striking finding was that the ADHD group was equally as able as the NC group to inhibit responses during the target videogame and the more cognitively challenging adventure videogame. That is, the children with ADHD were able to
stop, immediately and completely, at critical moments (i.e., before hazards) during these fast paced videogames. This finding contrasts with the impaired performance of children with ADHD on validated laboratory measures of response inhibition, such as the stop-signal task (e.g., Nigg, 1999; Schachar et al., 2000).

Important differences between the videogame tasks used in the present study and standard laboratory-based tasks may account for the discrepant findings regarding response inhibition. One marked difference is that videogames provide immediate and continuous visual and auditory feedback and reinforcement (positive and negative) to every response, whereas laboratory tasks rarely do so. Another difference is that although both videogames and laboratory measures of inhibition require speeded responses that are paced by the computer, the videogame tasks also allowed the children to self-pace. The allowance for self-pacing may have been sufficient for visual and auditory cues to assist inhibitory processes in the children with ADHD, by relieving other cognitive, timing, and on-line working memory demands. For example, the visual and auditory cues in videogames, prompt on-task responses and response set switching immediately prior to and at the moment of responding. Together with the feedback and reinforcement, these cues structure the videogame into "signposted" performance segments (Cepeda et al., 2000), requiring less information to be held on line (Bremner & Andreasen, 1998; Logie, Baddeley, Mané, Donchin, & Sheptak, 1989; Nelson et al. 2000; Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000). This assistance to working memory may be sufficient to enable the processes that are required for momentary inhibition to work effectively (de Fockert, Rees, Frith, & Lavie, 2001).

Another possibility is that timing processes involved in inhibition may have been externally regulated by the auditory accompaniment to the *Crash Bandicoot™*
videogame. The rhythmic metronomic beat, which provides a regulated momentum to the game, may promote the children's ability to delay responses momentarily (Rubia et al. 1998; Schaffer et al. 2001). Furthermore, there is some evidence that videogame play promotes the release of striatal dopamine (Koepp et al., 1998). As striatal dopamine is thought to be deficient in ADHD (Dougherty et al., 1999; Krause, Dresel, Krause, Kung, & Tatsch, 2000), playing videogames may temporarily increase dopaminergic tone, which in turn may temporarily enhance arousal and cognitive control functions, such as inhibition and working memory.

By contrast to their lack of inhibition deficits in the videogame context, the ADHD group did exhibit inhibition problems in the zoo context. Specifically, the children with ADHD deviated from the route (particularly the complex route) many more times than the NC group, reflecting problems in sustained interference control. Differences in task duration and pacing may have contributed to the children's problems with sustained but not momentary inhibition. The children were instructed to walk as fast as they could along the designated route, but the task required self-pacing and self-direction over a much longer time period compared to the videogame segments. The zoo provided plentiful, intermittent, and varied sounds from people, animals, birds, and recorded sound effects (approach activated), which could interfere with the ongoing task response (i.e., walking quickly towards designated checkpoint). These task parameters may have contributed further to any inherent vulnerability to salient visual and auditory distractors.

3.4.2 Working Memory

The children with ADHD exhibited problems in working memory during the videogame but not during the zoo tasks. Specifically, the children with ADHD spun more undesigned boxes than the NC group (with age covaried), indicating their
difficulty in maintaining this specific rule (spin the arrow boxes only) across time throughout the videogame. Also, these children made more on-task affective exclamations and self-talk during the videogame tasks, particularly in the non-distractor condition (i.e., no concurrent televised cartoon). Although these group differences did not hold once age and verbal IQ were covaried, this is not surprising since verbal IQ includes measures of working memory (e.g., digit span). Greater use of self-directed speech by children with ADHD has been evident in previous studies (Benedetto-Nasho, 2000; Berk & Potts, 1991; Tannock, 1997; Winsler, 1998). By contrast, the ADHD group did not differ from the NC group in their use of verbal and nonverbal queries for information at the zoo, indicating that they had no difficulty remembering what they were to do at various points during the zoo task. Collectively, the pattern of findings indicates that working memory deficits are transient and vary as a function of task-demand.

3.4.3 Reconstitution

Reconstitution refers to the generation of novel actions from one's existing behavioral repertoire, through the processes of analysis and synthesis. Evidence of this EF was indicated by two novel game strategies (prespins, backward pauses) used by both the ADHD and the NC groups immediately before engagement with a hazard. In contrast to the hypothesized deficits in this EF, the ADHD group used more rather than fewer of one novel strategy (prespins) and did not differ from the NC group in terms of their use of the other novel action (backward pauses). It is possible that the greater use of prespins by the ADHD group before a hazard reflects an adaptive coping strategy, to overcome problems in precision of response timing. Specifically, prespins prolong a forward-moving/spinning response, which in turn eliminates the requirement for precision in response timing. This tactic cannot be
achieved using the run and jump buttons, as the duration and length of the jump is preset in the game. Backward pauses comprised a novel synthesis of two videogame movements: a distinct pause followed by movement backwards or sideways. The use of backward pauses immediately prior to hazards, allowed a strategic “time out” delay in the time of response engagement with the hazard. Use of this novel action demonstrated the ability of the ADHD group to inhibit forward trajectory and to re-engage an alternative movement (backwards, sideways). By contrast, laboratory based studies have indicated that children with ADHD are impaired in response re-engagement (e.g., Schachar et al., 1995). The specific timing mechanisms (hindsight, forethought) required to analyse and synthesize past game moves into these novel responses suggests that these mechanisms may be intact in children with ADHD.

3.4.4 Motor Control/Flexibility

One very striking finding was the overall slowness of the boys with ADHD in performing the tasks. On the one hand, this finding stands in direct contrast to the typical clinical portrayal of ADHD of exhibiting impulsively fast motor responses and speeded motor activity. On the other hand, it is in accord with findings from the majority of laboratory-based studies using speeded reaction time tasks, which report slow and variable reaction times in children with ADHD. Notably, the ADHD group did not differ on the target video game (Point Blank™) so this slowness cannot be attributed to a generalized slowness. Rather the fact that their slowness accompanied cognitive challenge during the videogame (high working memory condition) and zoo tasks (high working memory and distractor condition of the complex route), suggests that it reflects underlying cognitive difficulties in completing the tasks, despite intrinsic task appeal and motivation.
3.4.5 Limitations

The innovative method and measures create both strengths and limitations of this study. Specifically, the use of outcome measures for which there are no data on their psychometric validity is a major limitation of the study. Also specific actions during the videogame and zoo tasks were deemed to reflect certain aspects of EF, and it is possible that each action may have reflected more than one EF or that a specific EF may have been better measured by another action. The primary examiner, who manually scored the videogame and zoo performance was not blind to group status, and as reliability was only coded on 10% of the sample on scoring from the videogame but not the zoo, this raises the possibility of some bias. Further, the sample was somewhat atypical being high functioning and restricted to boys with no comorbidity, therefore the findings may not be generalizable to a general ADHD population. The study may also have had lack of power to detect differences between the ADHD subtypes.

3.4.6 Theoretical Implications

The basic premise of the inhibitory model of ADHD is that primary deficits in behavioral inhibition give rise to secondary impairments in four other EFs that depend on behavioral inhibition for their effective deployment, as well as impairment in the motor control that these EFs afford. Behavioral inhibition is conceptualized as a multidimensional construct.

On the one hand, findings from the present study do not support the hierarchical relationship between behavioral inhibition and EFs in ADHD. For example, analysis of performance during the videogame revealed impairments in working memory and motor control, but not in behavioral inhibition. By contrast, in the zoo context, the ADHD group exhibited impairments in one aspect of behavioral inhibition
(interference control) and in motor control, but not in working memory (the one of the four associated EFs that was measured). Although this pattern of findings could be attributable to measurement problems, as acknowledged previously, the findings from this study do question the postulated EF deficits and their interrelationships.

On the other hand, the present findings do support the proposed multidimensional nature of behavioral inhibition. Moreover, the results not only suggest that ADHD is associated with deficits in some (but not all) aspects of behavioral inhibition and other EFs, but also that these cognitive impairments are evident in developmentally appropriate and child-preferred activities. The cognitive deficits in the ADHD group were context dependent, as reflected by the different pattern of results across the videogame and zoo contexts and by the effects of working memory and distractor manipulations. This pattern of findings suggests that the observed differences in performance reflect context-dependent problems rather than stable immutable deficits.

The present findings do not support the postulated differences in cognitive deficits between the subtypes of ADHD. One explanation could be that both videogame and zoo tasks required more visuo-spatial performance ability than verbal IQ based ability. Notably, the Inattentive and Combined subtypes did not differ in performance IQ. Perhaps then, subtype differences may be more evident in tasks and contexts demanding verbal abilities. Alternatively, it is possible that it is the dimensions of symptoms (inattention, hyperactivity/impulsivity), rather than the subtypes distinguished by DSM-IV, which are differentially associated with cognitive impairments (e.g., Warner-Rogers, Taylor, Taylor, & Sandberg, 2000). Also, as previously acknowledged, the study may have had limited power to detect subtype differences.
3.4.7 Clinical Implications

It may be the case that traditional laboratory tasks, such as the stop-signal task, Stroop or continuous performance tasks actually promote less successful performance from children with ADHD. Such laboratory tasks are set up to examine scientifically the variable(s) denoting fallibility in the child, and to do so they must essentially screen out other variables, to examine those chosen in isolation. As a result such laboratory tasks allow for no strategic reallocation of other available resources in compensation for areas of weakness. Such tasks recognize only success or failure from the isolated variable. Thus while adhering to scientific rigor and gaining true scientific findings, those findings in this case do not reflect the child's performance in real-life settings.

Hence, from a clinical perspective, findings from the current study suggest that it may not be appropriate to extrapolate all laboratory-based findings to real-life settings. Moreover, the findings indicate that children with ADHD instigate novel and adaptive strategies to facilitate performance (e.g., prespins, backward pausing) when they are able to pace the activity themselves. Indeed the greater number of prespins made by the ADHD group suggests that they may have more need to control (or slow) the pacing of the task to compensate for inaccurate response times if they are to succeed. Performance deficits evident on computer-paced tasks such as stop-signal, continuous performance tests and so forth may reflect problems with anticipation, planning and timing, rather than inhibition deficits per se.

The greater use of on-task self-talk by the ADHD group suggests the use of a “think aloud” strategy to maintain optimal focus and arousal. This may represent their attempts to self-provide continuous prompts needed during cognitively challenging tasks or activities. From the perspective of education this finding
suggests that "thinking aloud" may not necessarily reflect disruptive behavior. Rather, educators should promote the use of quiet self-talk in children with ADHD during problem solving.

Also the findings of greater susceptibility to distraction at the zoo during the more complex route, suggests that high working memory load may give rise to distractibility in ADHD (i.e., a vulnerability to distraction, as suggested by de Fockert and colleagues, 2001). This would suggest that these children's difficulties in sustaining concentration with high levels of distractibility in school or when doing homework may indicate an overload on their working memory. The continued use of visual and verbal prompts just prior to and at the moment of responding (as visually supplied in the videogame) may help to reduce working memory load and lead to improved concentration.

Optimal sustained EF performance from children with ADHD requires contextually relevant contingencies that relieve working memory load and cue timed responding (e.g., Zentall, 1993). Visual and auditory cues and short dynamic performance segments have been shown to facilitate aspects of performance in children with ADHD in the present study. Recent research shows that current theoretical knowledge of EF problems in ADHD has not generalized to appropriate or successful intervention strategies in classrooms (DeBonis, Ylvisaker, & Kundert, 2000; Rapport, 2001). Children with ADHD have demonstrated in the present study a self-discriminatory deployment of limited resources that is usually not evident at laboratory task levels of success or failure. Further examination of how these children perform during cognitively demanding real-life activities is critical for understanding the impact of ADHD on a child's life.
CHAPTER FOUR

STUDY TWO

4.1 Introduction

Current theoretical understanding and defining of Attention-Deficit/Hyperactivity Disorder (ADHD) is based primarily on empirical research findings using traditional laboratory paradigms and instruments. Evidence from this research has focused attention on an apparent deficit in behavioral inhibition in children with ADHD. This deficit is thought to cause secondary and associated impairments in other executive functions of working memory, and cognitive and behavioral fluency. These secondary impairments, in turn, influence motor control, and result in the errant motor responses and lack of sustained attention typical of those with the hyperactive and combined subtypes of ADHD (Barkley, 1997).

Behavioral inhibition is understood to be a multidimensional construct comprising the abilities to (a) inhibit prepotent responses, (b) inhibit ongoing responses, and (c) protect an ongoing response by sustaining interference control against competing distractors (Barkley, 1997). The latter ability enables the protection of a response set over a prolonged period of time.

There is considerable laboratory-based empirical support for behavioral inhibition and executive function impairments in children with ADHD (reviewed by Douglas, 1999; Pennington and Ozonoff, 1996; Tannock, 1998). However, it is not yet clear how deficits on neuropsychological tasks are related to problems in performing real-life tasks that also place high demands on behavioral inhibition, working memory and other executive function processes. One recent study appears to provide the sole test of the generalizability of current ADHD theory to performance on tasks in children's real-life environments (Lawrence et al., in press,
see Chapter Three, Study One). That study derived measures of behavioral inhibition and associated executive function constructs (as defined by Barkley, 1997, 2000) from an adventure videogame and route tasks at the zoo. Findings indicated that there were no deficits evident in the ADHD boys' performance in comparison to their non-disordered peers on the measure of behavioral inhibition in the videogame context. However impairment in behavioral inhibition (sustained interference control) was evident on the relevant measure in the zoo context.

The present study compares the children's behavioral inhibition and general executive function performance during two traditional neuropsychological tasks and during real-life tasks (videogame, zoo). The Stroop (Golden, 1978) and the WCST (Heaton et al., 1993) were selected because they are both believed to be sensitive to behavioral inhibition problems in ADHD (see Barkley, 1997; Barkley, Grodzinsky, & DuPaul, 1992; Houghton et al., 1999; Seidman et al., 1997). All tasks allow for self-pacing (i.e., the child can interrupt and momentarily stop in any of the tasks). However important distinctions exist. Task success in the Stroop requires speeded responses, and the correct timing of speeded responses is necessary for success in the videogame tasks. On the other hand, task success in the WCST and zoo tasks allows for somewhat slower self-paced progress, but over a more prolonged period.

The specific objectives were to (a) compare behavioral inhibition and general executive functioning in children with ADHD and their normally developing peers (matched for age and IQ) during neuropsychological and real-life tasks, and (b) examine the relationship between performance on the laboratory and real-life measures. The two major predictions were that (a) children with ADHD would be more impaired than their non-disordered peers on laboratory and non-laboratory
tasks requiring behavioral inhibition and executive function; and (b) behavioral inhibition during the laboratory and non-laboratory tasks would be related.

4.2 Method

4.2.1 Participants

A group of 44 boys aged 6 to 12 years ($M = 9$ years 8 months, $SD = 21.9$) participated, of whom 22 had received a diagnosis of ADHD and 22 were a normally developing comparison (NC) group free of any diagnosis. The participants were a subset of the larger sample (ADHD, $n = 57$, NC, $n = 57$) who had participated in the previously reported study of executive functioning during videogame play and route tasks at the zoo (see Chapter Three, Study One). The larger sample had been selected from among a community cohort of 230 volunteer children (ADHD, $n =75$, NC, $n = 155$), and more details pertaining to the inclusion criteria are reported in Chapter Three. For inclusion in the present study, boys had to have completed both the Stroop and WCST, as well as the videogame and zoo components of the previous study.

Each child had an estimated verbal or performance IQ score of at least 80, based on four subtests (Vocabulary, Similarities, Block Design, Object Assembly) of the WISC-III (Wechsler, 1991). The children all had corrected or normal vision and had no hearing impairments.

The children with ADHD had been recruited primarily through one consultant pediatrician with a clinical practice serving a large urban population in Perth, Western Australia. The children had all been diagnosed by the Consultant Pediatrician as meeting the DSM-IV (APA, 1994) criteria for ADHD on the basis of a clinical interview and had subsequently been referred to a clinical psychologist (by the pediatrician) for the assessment of undiagnosed comorbid disorders. Also parents
completed the ADHD rating scale (Du Paul et al., 1998) that covers the DSM-IV symptoms for ADHD. Children were eligible for inclusion only if they had a confirmed diagnosis of ADHD from the consultant pediatrician, had met the clinical cut-offs on the ADHD rating scale, and had no other diagnosed comorbid conditions.

The NC group had been recruited from one local public primary school situated within the same socio-economic region of the city as the pediatrician's practice. Children comprising the NC group had no identified problems based on the annual screening conducted by the school, in accordance to criteria stipulated by the Education Department of Western Australia to identify students at risk of educational failure and reading disabilities (using the Neale Analysis of Reading Ability, Neale, 1989). None of the children had any record of problems from previous screening procedures, and had no indication of difficulties on any of their school term reports. As an additional check the school principal in consultation with the resident school psychologist confirmed the absence of learning difficulties or any other conditions.

4.2.2 Matching Procedures

Fifty boys (23 ADHD and 27 NC) had completed the two traditional laboratory tests (i.e., Stroop, WCST). Of these, 44 boys (22 ADHD and 22 NC) were successfully matched on age (within 9 months), verbal IQ and performance IQ, and thus comprised the cohort for the present study. The ADHD group was comprised of 6 boys classified as ADHD predominantly inattentive type and 16 classified as ADHD combined type as defined in the DSM-IV (APA, 1994). The mean ages, verbal and performance IQ scores for boys in the ADHD and NC groups are summarized in Table 4.1. A repeated measures MANOVA conducted on the means of age, verbal IQ and performance IQ revealed no significant group differences for
age, $F,(1, 21) = 1.44, p > .05$; verbal IQ, $F,(1, 21) = .05, p > .05$; or performance IQ, $F,(1, 21) = 2.16, p > .05$.

4.2.3 Methods and Measures

4.2.3.1 Neuropsychological Tasks: Stroop and WCST: Multiple versions of the Stroop exist, but the classic version (Golden, 1978) used in the present study consists of three conditions completed in fixed order: reading words aloud (word), naming colors (color), and the final condition of incongruent color naming of color words (interference). The word condition consists of three color words (red, green and blue) printed in black ink. The color condition consists of four letters (XXXX) printed either in red, green or blue ink. Finally, the color/word (interference) condition consists of the color words red, green and blue printed in an incongruent color. The latter condition requires the participant to name the color of the ink in which the word is printed rather than to read the word (i.e., if the word green were printed in red ink, the correct response would be red).

Stimuli for the three conditions were presented in pseudorandom order (identical items did not occur together), on separate pages (8 x 11 in.) with 100 items arranged in five columns. For each condition the participant was instructed to read the words (or name the colors) as quickly and as accurately as possible without missing any: each condition was timed to 45 seconds. Also, the participant was instructed to commence naming the words (or colors) at the top left hand side of the page, to read down the first column, and then to continue reading from the top to the bottom of each column, one at a time, from left to right of the page. Raw scores for the total number of items correctly named in 45 seconds were age corrected, and T-scores and interference T-scores were computed (Golden, 1978).
The version of the WCST used in the present study consists of 128 cards printed with geometric designs that vary according to color, form and number. The participant is given four cards and asked to sort the remaining cards using specific feedback (that indicates whether prior sorting was correct or incorrect) from the examiner. After 10 correct placements in one sorting category the examiner switches to another sorting category without informing the participant of the switch. The WCST scores of perseverative responses and perseverative errors have been widely used to index the failure to inhibit an ongoing response (Barkley, 1997; Lezak, 1995; Pennington & Ozonoff, 1996). A perseverative response is defined as persisting with a response for a particular category (e.g., color) in face of negative feedback, whereas a perseverative error is defined as a response that would have been correct during the previous sorting category (Heaton et al., 1993). In addition, the WCST number of trials required to complete the first category and number of categories completed, have been seen as evidencing both cognitive and behavioral flexibility and working memory (Barkley, 1997). Therefore, the WCST scores selected by the present study for examination of behavioral inhibition were: (a) number of perseverative responses and (b) number of perseverative errors. While (c) the number of trials (responses) to complete the first category and (d) the number of categories completed were chosen as indexing a more general executive function construct, with the latter measure analogous to the number of challenges completed in the videogame task.

4.2.3.2 Real-life Tasks: Videogame and Zoo: Timed tasks in a cognitively challenging adventure videogame (Sony PlayStation, Crash Bandicoot™: computer software) and two route tasks at the zoo were used to test behavioral inhibition and
general executive function. A brief description of the method pertaining to the present study follows; for a more detailed description, please refer to Chapter Three.

The videogame *Crash Bandicoot™* requires the participants to use response buttons (operated by the left and right thumbs) on a hand-held console to control the movement of a small, animated figure along a jungle path to a designated checkpoint. Task success depends upon being able to alternate rapidly between moving fast towards the checkpoint and inhibiting movement to negotiate the various hazards en-route, while keeping in mind specific game rules. The game tasks require the deployment of behavioral inhibition and other executive functions as specified in a current model of ADHD (Barkley, 1997, 2000). One specific game segment was used under four experimental conditions (presented in random order), which varied along two dimensions – working memory load (low, high) and distraction (low, high).

Two routes (simple, complex) were selected for the zoo component, which varied in length and the number of distracting animal exhibits, as well as in the number of designated checkpoints and tasks to be completed. The *simple route* consisted of a linear pathway between exhibit areas (Wetlands, Australian Birds) and involved one task at one checkpoint (touch signpost at designated location). The *complex route* included many auditory and visual distractors, resembling the jungle scenery in the videogame (*Crash Bandicoot™*). It comprised a circular route through four exhibit areas (Reptile House, Penguin Plunge, Wetlands, Crocodile House) and involved a different task at two checkpoints (touch snake skin on wall at designated location in Reptile House; locate and look at big crocodile in Crocodile House). Participants had to remember route instructions and to complete task requirements at the designated checkpoints en-route.
For the purpose of the present study, behavioral inhibition in the videogame was indexed by a composite score comprised of two measures. The specific event-related actions of pauses and backward pauses were selected to form a single index of the ability to inhibit prepotent and ongoing responses (as defined by Barkley, 1997, 2000). Response inhibition had to be demonstrated by a distinct and predefined movement, occurring between the appearance of a challenge (skunk, chasm, rolling wheel etc.) and the videogame character’s contact or engagement with it. This movement was defined as a sudden release of the forward movement button by raising the thumb, and in the case of backward pauses this release of the forward movement button had to be followed by a thumb shift to press one or more of the other directional movement keys. Videogame measures selected to index a more general executive function construct were the number of challenges successfully negotiated (out of a possible 28, comprised of within game distractors, obstacles and hazards); and the total task time (in seconds). The number of challenges records successful generation of timed and novel, complex motor sequences. The task time was the mean of the total task time (in seconds). The score totals were collapsed across all four video tasks (i.e., 4 tasks = 12 trials).

In the zoo component, behavioral inhibition was indexed by the measure of deviations from task. This measure indexed the ability to maintain interference control against prepotent responses to protect an ongoing response set (Barkley, 1997, 2000). Deviations were an observable and deliberate movement of more than three paces to the left or right, away from the most direct route, other than to move around an obstacle, plus an eye gaze towards a non-designated animal or location. As a measure of more general executive function the total task time (in seconds from the signal to start to reaching the designated end of the route) was selected for
examination. In the present study the totals of deviations and task time (in seconds) were collapsed across both routes.

4.2.4 Procedures

The parents of all boys gave written informed consent and all boys gave informed verbal assent. The Research Review Board of The University of Western Australia approved the research. Appointment times for the testing sessions were arranged by telephone. During the telephone conversation, parents were reminded of the section in the information letter requesting that no stimulant medication be administered to their children on the afternoon or evening prior to the testing (a minimum of 20 hours medication free). This was checked again immediately prior to testing. All boys were tested individually and completed the laboratory tasks first, then the videogame tasks, and finally the zoo tasks 6 months later in the same sequence. The Stroop and the WCST tests were administered in random order, as were the four video tasks and the two zoo route tasks.

For the neuropsychological and videogame tasks boys in the ADHD group were tested in a quiet room located in the university, and boys in the non-disordered comparison group were tested at their school, in a room designated for the study. In both settings, the room was quiet, well lit and ventilated, free of extraneous distractors, and the layout of equipment and furniture was comparable. The entire testing time for the two neuropsychological tests lasted around 45 minutes. The videogame tasks took no more than 20 minutes and the zoo tasks no more than 15 minutes to complete. The participants were observed to be comfortable and not fatigued during any testing session. All testing took place between the morning hours of 8am and 12.30pm, and the zoo testing was completed during normal zoo open hours in the summer school holidays.
4.2.5 Data Analysis

To test for differences between the ADHD and case-matched non-disordered comparison groups, a series of Multivariate Analyses of Variance (MANOVA) for repeated measures were conducted for continuous data generated from the neuropsychological, video and zoo contexts. Group (ADHD, NC) and the experimental conditions selected for examination in this study (e.g., Stroop and WCST subscales; cognitive constructs in the videogame and the zoo context) were used as repeated measures. Significant MANOVAs were followed by univariate ANOVAs to locate the source of differences. Effect sizes (ES) were ascertained by dividing the difference between the two means being compared by the standard deviation of the data, obtained by the square root of the mean square for error in the denominator of the F ratio used to test the overall hypothesis (Cohen, 1988). Pearson's correlations were conducted on raw scores to examine the relationships between the neuropsychological and real-life tasks. Statistical analyses were performed using SPSS Version 10.0.

4.3 Results

For ease of exposition, results of performance on laboratory and non-laboratory tasks are presented before the findings of the relationships between measures. Findings are summarized in Tables 4.1 and 4.2, and Figure 4.1.

4.3.1 Performance during Neuropsychological Tasks

Contrary to predictions, there were no group differences on the Stroop measure of inhibition: interference T-scores, $F, (1, 21) = 0.13, ns$. Moreover, there were no group differences on either the Stroop word T-scores, $F, (1, 21) = 2.83, ns$, or color-word T-scores, $F, (1, 21) = 2.72, ns$, which were used in this study as indices of general executive control. However, as indicated in Table 4.1, the ADHD
group was slower in color naming on the Stroop color T-scores (Effect Size, ES = 0.74).

Consistent with predictions, there were significant group differences on the WCST measures of response inhibition (perseverative responses, ES = 0.84; perseverative errors, ES = 0.96), and on one of the executive control measures (number of trials for the first category, ES = 0.76). The groups did not differ on the WCST number of categories completed, $F(1, 21) = 2.64, ns$. Extremely high scores for the number of trials to first category from two participants in the ADHD group, produced outliers that skewed the data and negated the assumption of homoscedasticity between the variables. These univariate scores were therefore adjusted by according them one unit larger than the next most extreme score in the distribution (Tabachnick & Fidell, 1996), before conducting the above reported MANOVA. The results were also significant, both with and without adjustment for outlier, using a non-parametric Wilcoxon's signed rank test.
The table below presents data on the mean and standard deviation of various measures related to ADHD. The measures include:

- **Zoo mesh time**
- **Video game trials**
- **Zoo video game passes**
- **Video game challenges**

The table contains the following columns:

- **Age (yrs)**
- **Estimated PIQ**
- **Estimated PIQ**
- **Mean of total time in seconds**
- **Mean of total number of passes**
- **Mean number of deflections on both sides**
- **Mean number of deflections on both sides of the WCS-II**
- **Mean number of deflections on both sides of the WCS-II**
- **Mean number of deflections on both sides of the WCS-II**

The table is divided into subcategories based on ADHD group characteristics and scores for ADHD and NC groups.

The table also includes notes on ADHD, attention-deficit/hyperactivity disorder, ADHD-Pi, and ADHD-CT: Combined ADHD Subtype, NC = Case.
4.3.2 Performance During Real-Life Tasks

In the videogame tasks, there was no significant group difference on the inhibition (prepotent/ongoing) measure of pauses in the videogame, $F_{1, 21} = 0.45, ns$. However, the ADHD group completed fewer challenges ($ES = 0.80$), but did not differ from the control group in terms of the time taken to complete the videogame, $F_{1, 21} = 0.55, ns$.

On the zoo measures, the ADHD and control groups did not differ on the inhibition (interference control) measure of number of deviations from task, $F_{1, 21} = 1.87, ns$. The ADHD group did, however, take a longer time to complete the zoo tasks ($ES = 0.74$).
### Table 4.2: Correlations between Neuropsychological and Real-Life Scores

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of Challenges</th>
<th>Number of Pauses</th>
<th>Task Time</th>
<th>Developments</th>
<th>Time on Task</th>
<th>Pauses</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word Color</td>
<td>1</td>
<td>0</td>
<td>0.34</td>
<td>0.38</td>
<td>0.41</td>
<td>0.39</td>
<td>0.49</td>
</tr>
<tr>
<td>Word Color - Inference</td>
<td>1</td>
<td>0</td>
<td>0.36</td>
<td>0.37</td>
<td>0.41</td>
<td>0.39</td>
<td>0.49</td>
</tr>
<tr>
<td>WCST</td>
<td>1</td>
<td>0</td>
<td>0.34</td>
<td>0.38</td>
<td>0.41</td>
<td>0.39</td>
<td>0.49</td>
</tr>
<tr>
<td>TMT (F)</td>
<td></td>
<td></td>
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<td>TMT (R)</td>
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<tr>
<td>TMT (L)</td>
<td></td>
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<tr>
<td>TMT (D)</td>
<td></td>
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</tr>
</tbody>
</table>

**Note:** All raw scores used in this Pearson 2-tailed correlation. Pearson 2-tailed correlation. Pauses = total number of pauses and backward pauses combined.

- *p < 0.05
- **p < 0.01

Video Game:

- Time on Task: 0.34
- Developments: 0.38
- Challenges: 0.41
- Pauses: 0.39
- Time: 0.49
4.3.3 Relationships between Neuropsychological and Real-Life Measures

There were no significant correlations between the neuropsychological and real-life measures of behavioral inhibition. However, inspection of the scatter plots of the zoo and WCST measures of inhibition (number of deviations; perseverative responses and errors, respectively) revealed a parallel association between the variables. Spearman’s rho correlations subsequently conducted on the rank-ordered scores, indicated that there was no significant relationship between these inhibition measures ($p = .08$ and $p = .07$ respectively). On the other hand, as shown in Table 4.2, the WCST measures of inhibition (perseverative responses, perseverative errors) were inversely related with the number of challenges completed successfully in the videogame and positively related to the amount of time taken to complete the zoo tasks. Also, the Stroop word naming and color-word naming raw scores were both positively related to the number of challenges completed on the videogame and inversely related to the time taken to complete the zoo tasks.

There were no significant correlations between any measures from the video and zoo tasks. As shown in Figure 4.1, scatter plots of the Stroop (raw scores color) and WCST (trials to complete the first category - color) revealed separate clusters of data, one consisting primarily of the NC group and the other including primarily children with ADHD. Inspection of the corresponding Stroop T-scores for the raw color naming scores, revealed that most of the children in the NC group (82%) obtained T-scores that were within 1 SD of the mean (i.e., T-scores of more than or equal to 40), and exhibited little dispersion in the number of trials to complete the first sorting category (color) on the WCST (e.g., 95% of the NC group took 10 to 12 trials). By contrast, 45% of the ADHD group exhibited markedly slowed color naming (i.e., T-scores < 40) and 36% took more than 12 trials to complete the first
sorting category (color) on the WCST. Moreover, 18% ($n = 4$) of the ADHD group, but only 0.5% ($n = 1$) of the comparison group, showed color processing problems on both the Stroop and WCST. A similar separation of data was evident for the Stroop (color) and WCST (number of categories completed). The majority of children in the NC group comprised one cluster and obtained T-scores for Stroop color naming within 1 SD of the mean (82%) as well as completing all 6 WCST categories (77%). The second cluster consisted primarily of children with ADHD, many of whom exhibited slowed Stroop color naming (45% with T-scores < 40) and completed fewer than 6 WCST categories (50%).

![Figure 4.1 Stroop Color Naming (Raw Scores) and WCST Number of Trials to Complete First Category (Color)](image-url)
4.4 Discussion

The present study examined behavioral inhibition and general executive function performance of ADHD boys and their non-disordered peers during two neuropsychological and two real-life tasks. The major findings were that: (a) there was limited evidence of behavioral inhibition deficits in the ADHD group; (b) neuropsychological and real-life measures of behavioral inhibition were not related; and (c) general executive function deficits evident in both neuropsychological and real-life tasks were related.

4.4.1 Neuropsychological and Real-Life Measures of Behavioral Inhibition

Contrary to current theory (and clinical belief), behavioral inhibition was not found to be impaired in children with ADHD on either the neuropsychological or real-life measures. Nor was there any relationship between children's performance on the neuropsychological and real-life measures of inhibition. The finding that the ADHD and comparison groups did not differ in Stroop interference is consistent with results from other studies that have controlled for speed of word reading and color naming (Houghton et al., 1999; Willcutt et al., 2001). Moreover, recent evidence that patients with frontal lobe damage exhibit color-naming problems on the Stroop, but not greater interference effects (Stuss et al., 2001), suggests either that interference control is not associated with frontal lobe dysfunction or that the Stroop measure of interference control is not sensitive to frontal lobe dysfunction. Recent attempts to explain the Stroop effect suggest that inhibitory control involves memory retrieval processes (Tipper, 2001), and neural activation (McLeod, & McDonald, 2000).

The ADHD group did exhibit more perseverative performance on the WCST, which has been interpreted as indicative of problems in inhibition and set shifting. However, the high working memory load involvement on these measures reveals the
compound nature of this performance deficit, making it insufficient as evidence for impairment unique to behavioral inhibition (Barkley, 1997, 2000; Pennington & Ozonoff, 1996).

Notably, when faced with unpredictable occurrences of various hazards (e.g., chasms, skunks, rolling wheels etc) in the videogame, the ADHD boys were as adept as their peers in terms of their ability to inhibit their forward trajectory (suddenly and completely) in pursuit of their goal. Moreover, no group differences were detected on the zoo measure of inhibition (deviations) in the present study. However, since group differences in zoo deviations were evident in the previous larger scale study (Lawrence et al., in press), it is likely that the smaller sample in the present study did not yield adequate power to detect group differences in this type of inhibition.

The limited evidence in this study of response inhibition deficits in the children with ADHD is discrepant with reported inhibitory deficits on traditional laboratory tests such as the Go/No-Go, Stop-Signal, and inhibition versions of Continuous Performance Tests (CPTs). On the one hand, different task contingencies in the videogame may have served to ameliorate any inhibitory deficits in the ADHD group, by providing: (a) sufficient (immediate and prolonged) stimulation to achieve and maintain high arousal, dopaminergic tone or both (Koepp et al., 1998), (b) more allowance for self-paced responding, and (c) in-game cues just prior to and at the point of responding which may act as prompts for working memory and the executive processes involved in motor responses. On the other hand, recent studies using the stop-signal task (Logan, 1994) - a well-established measure of response inhibition - have also failed to detect inhibitory control deficits in children with ADHD (e.g., Kuntsi et al., 2001; Scheres et al., 2001). Nevertheless, the current findings challenge the hypothesis that inhibition is a fundamental deficit in ADHD.
and suggest that previous findings of inhibition deficits in ADHD may be task specific.

By contrast to predictions, there was no evidence of any systematic relationship among the various measures of behavioral inhibition. Behavioral inhibition is a complex and multidimensional construct that is intricately linked with other executive functions (Barkley, 1997, 2000). Thus, differences in task demands among the Stroop, WCST, videogame and zoo measures of this construct would likely influence which dimension(s) of inhibition and which executive processes are engaged. For example, the participant’s responses in both the Stroop and WCST are governed by a timed impetus that is imposed and controlled by the examiner. Speeded responses are requested in the former task, while the cued and continuous impetus for responding in the latter is set and maintained by the examiner. The speeded responses necessary for success in the videogame tasks are governed by an in-game impetus promoted by an auditory soundtrack and the forward trajectory of the videogame character. The zoo tasks, in comparison, make the most allowance for self-paced responding.

4.4.2 Neuropsychological and Real-Life Measures of General Executive Control

Predicted performance deficits on general executive control measures were found on both neuropsychological and real-life tasks. Children with ADHD not only exhibited slower color naming on the Stroop than the comparison boys, but also many (50%) had scores that were more than 1 SD below the mean for age, suggesting marked impairment. The present finding of slow color naming in ADHD is consistent with findings from previous research studies that have used either the Stroop or rapid automatized naming (e.g., Houghton et al., 1999; Rucklidge & Tannock, 2001; Semrud-Clikeman, Guy, Griffin, & Hynd, 2000; Tannock et al.,
2000; Willcutt et al., 2001). Slowed color naming may reflect problems in effortful semantic processing (e.g., Stuss et al., 2001; Tannock et al., 2000). Alternatively (or additionally), it is possible that slow color naming may reflect a detrimental effect of low dopaminergic tone in the retina on visual function, including color vision.

Dopamine functions as a major neurotransmitter or modulator in the human retina and color vision impairments have been reported in several basal ganglia disorders that affect dopamine neurotransmission (reviewed by Djamgoz, Hankins, Hirano, & Archer, 1997). Specifically, perturbed color perception along the blue-yellow axis (i.e., involving blue-sensitive cones) has been found in Tourette’s Syndrome (Melun, Morin, Muise, & DesRosiers, 2001), Parkinson’s (Price, Feldman, Adelberg, & Kayne, 1992; Haug, Kolle, Trenkwalder, Oertel, & Paulus, 1995), and Huntington’s Disease (Buttner, Schulz, Kuhn, & Blumenschein, 1994). Moreover, problems in color vision and other aspects of visual function associated with normal aging have been found to impair performance on the Stroop color-word test (van Boxtel et al., 2001). Although dopaminergic dysfunction is implicated in ADHD (e.g., Barr, Swanson, & Kennedy, 2002; Grace, 2000; Krause et al., 2000; Solanto, 2002), it is not known whether ADHD is associated with low dopaminergic tone in the retina or with impairments in color perception or other aspects of visual function (but see Farrar, Call, & Maples, 2001). However, there is preliminary evidence that stimulant medication, which transiently elevates synaptic dopamine levels (Seeman & Madras, 2002), improves color naming in ADHD (Tannock et al., 2000).

Consistent with previous findings (e.g., Grodzinsky & Diamond, 1992) the present sample of boys with ADHD was also found to take significantly more WCST trials to deduce and complete the first sorting category (color). Moreover, a substantial proportion of the ADHD group exhibited both slow color naming on the
Stroop (i.e., T-scores < 40) and an unusually high number of trials to complete the first WCST sorting category (i.e. more than 12 trials). Problems with the first sorting category on the WCST may reflect the ADHD boys' difficulty in understanding the task or in utilizing the feedback. Alternatively, it is possible that color vision problems associated with low dopaminergic tone might account in part for poor performance on many tasks that require discrimination of color stimuli (specifically, blue), including the Stroop and WCST.

The ADHD group also exhibited problems in general executive functioning on the videogame and zoo tasks. Despite the ability to appropriately inhibit their forward trajectory when faced with sudden challenges, the boys with ADHD were less successful in negotiating these challenges, as evidenced by the fewer number of challenges completed in the videogame. In other words, compared to the non-ADHD peer group, the boys with ADHD did not get as far along the jungle path to reach the designated checkpoint in the videogame. That the ADHD group took comparable time to achieve fewer challenges in the videogame tasks, suggests that they used less effective game strategies in attaining the goal. Investigation of game strategies and their outcome may provide further insight into the difficulties encountered by children with ADHD in problem solving during videogames and other activities. The ADHD group also took longer to complete the zoo tasks, even though all children were given the same instructions to proceed along the routes as quickly as possible. These findings are reminiscent of those from a laboratory-based task in which children with ADHD responded more slowly than comparison boys, despite explicit instructions to go as fast as possible (Sergeant & Scholten, 1985).

Collectively, the preceding findings suggest that even on preferred activities that are intrinsically motivating, children with ADHD continue to exhibit greater
difficulty than do their peers. Moreover, the findings are indicative of decreased flexibility in adjusting to task demands. Further evidence of cognitive inflexibility in ADHD is provided by the significant inverse relationship between WCST measures of perseverative performance and successful completion of the videogame and zoo tasks, as indexed by the number of hazards (challenges) negotiated successfully and the time taken to complete the zoo tasks. Thus, difficulties in shifting mental set and using alternative strategies appear to generalize from laboratory to non-laboratory measures.

The pattern of findings in the present study is generally supportive of the hypothesis that executive functions are impaired in ADHD, but does not support the central tenet of the prevailing model: namely, that response inhibition is a fundamental deficit in ADHD. However we lack a satisfactory explanation of executive function deficits in children with ADHD across a wide range of tasks, including those that are intrinsically motivating (e.g., videogame tasks). Recent human and animal research examining the biochemical substrate of ADHD has suggested that catecholaminergic imbalances at presynaptic level may account for broadband performance deficits in ADHD (Castellanos et al., 1994; Dresel et al., 2000; Jones, Williams, & Hess, 2001; Manor et al., 2001; Oades, 2000). Inattention and impulsivity in ADHD may therefore be the result of decreased available neuronal energy (Sergeant et al., 1999; Todd & Botteron, 2001). If this is the case, and ADHD incorporates an essential difficulty in maintaining activated and balanced serotonergic and dopaminergic systems, then performance deficits would be predicted to be most clearly evident on low stimulus tasks, which require continuous and repetitive effortful cognitive processing (e.g., laboratory tasks such as Go/No-Go, stop-signal, and CPTs).
4.4.3 Limitations

The limited number and type of neuropsychological and real-life tasks investigated in this study, together with the relatively small sample size, must be considered along with the findings of the present study. The study was limited to boys and the sample size did not permit an analysis as a function of DSM-IV subtype of ADHD, so it is not known whether the findings would hold for girls with and without ADHD, or across all three subtypes. Further, the neuropsychological measures of behavioral inhibition used in this study did not reliably distinguish between children with or without ADHD. Future comparisons of neuropsychological and real-life measures of response inhibition should include measures such as the Stop-Signal task or other Go/No-Go tasks, which may have more discriminatory usefulness.

4.4.4 Clinical Implications

Notwithstanding the study limitations, the present findings have three major implications for clinicians. First, the behavioral phenomena of impulsiveness, as reported by parents and teachers, may not reflect cognitive deficits in response inhibition. The children with ADHD did not exhibit an impulsive response style on either the neuropsychological or real-life measures. On the contrary, slowed cognitive processing and poorer executive flexibility was consistently evident in ADHD under effortful cognitive demands, including those of the highly motivating videogame tasks. Second, although parents may report that their child with ADHD can play videogames for hours, this should not be interpreted as evidence that the children's videogame performance is unimpaired. The children with ADHD were far less successful than their peers in this intrinsically motivating and preferred activity. Third, the color naming problems evident in children with ADHD and preliminary evidence of visual impairments in ADHD (Farrar et al, 2001), indicate a need to
screen for color vision and other vision problems. In conclusion, the boys with ADHD did not exhibit deficits in response inhibition on either the neuropsychological or real-life tasks. There was also no evidence of association between laboratory and real-life measures of response inhibition. By contrast, other aspects of performance on the neuropsychological tasks did generalize to performance on the real-life videogame and zoo tasks. Possible problems in processing colored stimuli in the Stroop and WCST were identified, as well as generalized difficulty in the speed of processing and in cognitive flexibility in problem solving in the laboratory and real-life tasks.
CHAPTER FIVE
STUDY THREE

5.1 Introduction

The use of strategic responding entails a systematic approach to problem solving (Ellis & Hunt, 1993). This approach enables efficient performance to be repeated without trial and error. The strategy of appropriately attending selectively to a stimulus is a cognitive skill that emerges developmentally, with strategy deployment found to be more effortful for younger children (Miller, Seier, Probert, & Aloise, 1991; DeMarie-Dreblow & Miller, 1988). However, children as young as preschool and kindergarten age have demonstrated: (a) multiple- and variable-strategy use, (b) progression to more sophisticated choice and use of strategies with age, and (c) expertise in strategy use reflected in the speed and accuracy of a learnt response (Bjorklund, Schneider, Cassel, & Ashley, 1994; Bjorklund & Rosenblum, 2001; Lemaire & Siegler, 1995).

Four progressive stages in strategy utilization have been identified: introduction of new strategies, increased use of the most efficient existing strategies, improved efficiency in execution of each strategy, and more adaptive choices among strategies (Lemaire & Siegler, 1995). Inefficient use of strategy by younger children is thought to reflect a stage in strategy development when a strategy is used but with little or no benefit to performance (Bjorklund, et al., 1994; Blumberg, 2000). Strategic responding is an aspect of executive functioning, as are the abilities to rapidly vary and self-monitor one's responses to avoid repeating mistakes (Lezak, 1995). In the present study, strategic responses are defined as responses that demonstrate some degree of executive control and cognitive processing (i.e.,
involving such executive functions as behavioral inhibition, working memory and motor control, as defined by one current theory of ADHD, see Barkley, 1997, 2000).

Clinical observations of disorganization, distractibility, and forgetfulness exhibited by children with ADHD are suggestive of problems with efficient strategy use. In addition, poor cognitive performance has been demonstrated in children with ADHD in studies using a wide variety of neuropsychological tests. For example, children with this disorder have revealed perseveration, variable and inaccurate response timing, and inflexible set switching using traditional controlled-response measures. These problems appear to reflect deficits in executive functioning (see Douglas, 1999; Pennington & Ozonoff, 1996; and Tannock, 1998, for reviews). Moreover, inefficient motor responses question the extent to which children with ADHD are able to control, vary and monitor their task performance (e.g., Barkley, 1997; Douglas, 1999).

Recent explicit studies of strategy use in non-disordered participants (Gunzelman & Anderson, 2001) and children with ADHD (Cornoldi et al., 1999) have used traditional laboratory tasks such as the Tower of Hanoi. There is also some preliminary evidence that individuals with ADHD: have poorer self-organizational ability, set-shifting ability and planning ability on spatial working memory tasks (Kempton, Vance, Maruff, Luk, Costin, & Pantelis, 1999; Mehta, Calloway, & Sahakian, 2000); show deficient planned organization (August & Garfinkel, 1990); and have a poorer approach to problem solving and use less effective strategies than do their non-disordered peers (O'Neill & Douglas, 1991). The findings from these studies suggest that children with ADHD differ in strategy development from their non-disordered peers.
An important question is whether these findings from laboratory studies generalize to every day functioning in those with ADHD. One ideal medium for investigating strategy use in children with ADHD is a videogame. An adventure videogame provides a prolific supply of in-game hazards: (a) each hazard defines a problem, (b) multi-choice problem solving allows for multiple and varied strategy use, and (c) repeated encounters with hazards (problems) enables experiential learning that could facilitate within-test performance. The ecologically valid medium of adventure videogames provides a complex, multi-requirement cognitive domain (Greenfield, 1999; Greenfield & Cocking, 1994, 1996; Scriven, 1987), known to be very motivating to children including those with ADHD (Cupitt & Stockbridge, 1996; Durkin & Aisbett, 1999; Emes, 1997; Tannock, 1997). It appears logical therefore to administer cognitive tasks involving response planning and motor organization in this real-life naturalistic context (Barkley, 1991; Lorch et al., 2000; Sawyer, Taylor & Chadwick, 2001).

Adventure videogames provide controlled and timed conditions whereby children must consciously and selectively choose between strategic responses (in the presence of distractors) in order to achieve success (Brodeur & Pond, 2001; Landau, Lorch, & Milich, 1992; Milich & Lorch, 1994; Schunn, Lovett, & Reder, 2001). Videogame tasks should promote optimal performance (relative to experimental tests) in children with ADHD by providing external motivating contingencies at moments of responding over task duration (see Barkley, 1997). The stimulating nature of this medium may also optimize on-task performance of children with ADHD (Koepp et al., 1998; Kuntsi et al., 2001; Sergeant, 2000; Todd & Botteron, 2001).
In a previous study (see Chapter Three, Study One), measures of behavioral inhibition and associated executive function constructs (as defined by Barkley, 1997, 2000) were derived from an adventure videogame and route tasks at a zoo. Findings revealed that boys with ADHD demonstrated equal ability to their non-disordered peers in performance on a simple target game, however on a more cognitively challenging videogame the children with ADHD performed more poorly. In that study three strategies were discernible in the boys’ approaches to the game hazards (or problems). The strategies were pauses, prespins and backward pauses, with the ADHD group using more prespins than their non-disordered peers. These findings invited a closer examination of the use of strategy and its relation to task success in children with ADHD.

The present exploratory study examined the use of strategy by boys with ADHD and their non-disordered peers and the relationship between strategy use and overall task success. In accord with current theory, children with ADHD were predicted to (a) use fewer strategic responses (in variety and number), and (b) be less successful in their use of strategic responses than their non-disordered peers (matched on age and IQ).

5.2 Method

5.2.1 Participants

A group of 112 boys aged 6 to 12 years ($M = 9$ years 3 months, $SD = 1.76$) participated, of whom 56 had been diagnosed with ADHD and 56 were a normally developing comparison group free of any diagnosis. The children with ADHD had been recruited primarily through one consultant pediatrician with a clinical practice serving a large urban population in Perth, Western Australia. The non-disordered comparison group had been recruited from one local public primary school situated
within the same socio-economic region of the city as the pediatrician's practice. The participants had participated in a previously reported study of executive functioning during videogame play and route tasks at a zoo (see Chapter Three, Study One).

Each child had an estimated verbal or performance IQ score of at least 80, based on four subtests (Vocabulary, Similarities, Block Design, Object Assembly) of the WISC-III (Wechsler, 1991). The children all had corrected or normal vision and had no hearing impairments. Children comprising the ADHD group had to have a diagnosis for the disorder confirmed by the pediatrician, based on information derived from clinical interview and the ADHD rating scale (DuPaul et al., 1998) in accord with DSM-IV criteria (APA, 1994). The children were not to have received any additional diagnoses at that time (e.g., learning disorders, conduct disorder, anxiety disorder). All children with ADHD had been unmedicated for a minimum of 20 hours prior to administration of both the video and the zoo tasks. The latter exclusion ensured that there were no drug effects on cognitive performance. Children in the non-disordered comparison group could not have any diagnosed conditions, according to the school psychological assessments and academic records.

5.2.2 Matching Procedures

The mean ages, verbal and performance IQ scores for boys in the ADHD and NC groups are summarized in Table 5.1. A repeated measures MANOVA revealed no significant group differences for age, $F (1, 55) = 0.38, p > .05$; verbal IQ, $F (1, 55) = 1.96, p > .05$; or performance IQ, $F (1, 55) = 0.61, p > .05$. Information regarding videogame familiarity and proficiency level was obtained from the participants and their parents prior to the study. The participant's game play proficiency and eye-hand fine-motor skill coordination were also assessed immediately prior to administration.
of the cognitively challenging videogame tasks. This was assessed from their performance (using the same hand held controls) on a target game (Point Blank™).

The four tasks on this latter game each alternated in level of difficulty. Chi-square analyses of the game familiarity responses, and repeated measures MANOVAs conducted on the target game scores showed no significant group differences between the ADHD and the non-disordered control group’s performance (for more detail see Chapter Three, Study One).

Table 5.1. Sample Characteristics and Task Outcome Scores ADHD and NC Groups

<table>
<thead>
<tr>
<th>Characteristics:</th>
<th>ADHD (n=56)</th>
<th>NC (n=56)</th>
<th>Difference (df=1, 55)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>9.24 (1.76)</td>
<td>9.27 (1.68)</td>
<td>ns</td>
</tr>
<tr>
<td>Estimated PIQ</td>
<td>114.45 (18.59)</td>
<td>115.64 (16.17)</td>
<td>ns</td>
</tr>
<tr>
<td>Estimated VIQ</td>
<td>106.09 (16.42)</td>
<td>102.07 (15.58)</td>
<td>ns</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task Outcomes:</th>
<th>ADHD (n=56)</th>
<th>NC (n=56)</th>
<th>Difference (df=1, 55)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Challenges a</td>
<td>179.96 (74.50)</td>
<td>205.46 (58.99)</td>
<td>*</td>
</tr>
<tr>
<td>Time b</td>
<td>331.52 (116.20)</td>
<td>306.50 (65.58)</td>
<td>ns</td>
</tr>
</tbody>
</table>

Note: ADHD = Attention-Deficit/Hyperactivity Disorder group; NC = case-matched Normally developing Control group; PIQ = Performance IQ score, as estimated from scores on the Block Design and Object Assembly subtests of the WISC-III; VIQ = Verbal IQ score, as estimated from scores on the Vocabulary and Similarities subtests of the WISC-III.

*a Number of challenges successfully negotiated. b Mean of total time on task (in seconds). *p < .05.
5.2.3 Videogame Context

Timed cognitive tasks using an adventure videogame (*Crash Bandicoot™*) yielded measures of outcome-related task actions, task outcomes, strategy use and percentages of successful strategy use. A brief description of the method pertaining to the present study follows. More details on the methodology relating to the videogame task context are given in Chapter Three, Study One.

The game segment of the videogame *Crash Bandicoot™* used for the study requires the participants to use response buttons (operated by the left and right thumbs) on a hand-held console. Manipulation of these response buttons controls the movements of a small, animated figure (Crash Bandicoot: CB) along a jungle path to a designated checkpoint. Task success depended upon being able to alternate rapidly between moving CB fast towards the checkpoint and inhibiting movement to negotiate various obstacles, dangers and hazards en-route.

The children completed a pre-designated game segment under four different experimental conditions. The conditions were presented in random order and varied along two dimensions – distraction load (low, high) and working memory load (low, high). Children were allowed three trials (attempts) in each of the four conditions: (a) low distractor load + low working memory load, (b) low distractor load + high working memory load, (c) high distractor load + low working memory load, and (d) high distractor load + high working memory load.

The distractor condition involved a television monitor immediately adjacent to and left of the television monitor that was positioned at eye height at a comfortable viewing distance directly in front of the participant’s chair. A highly distracting recorded segment of the popular animated children’s program *The Simpsons* (Cary, 1997) was played while the children played the videogame. The distractor was then
screened simultaneously during the time taken for the participant to complete each of those two tasks. The soundtrack of the *The Simpsons* was maintained at the same audio level as that of the adventure videogame.

The high working memory condition involved the use of specific game rules while playing each of these tasks: to spin any arrow boxes they encountered, but not to touch any other boxes. One arrow box was visible on the television monitor at the start of the task and this was pointed out to the children the first time only (out of the two times) they were given this instruction. A second arrow box (not visible at the start of the task) was the eighth of the challenges (of 28 in total, that comprised within game distractors, obstacles and hazards) en-route to the checkpoint. More than 50% of both groups of children reached the second arrow box at least once during the two tasks as indicated on Table 5.3 (each task incorporating three trials or attempts).

5.2.4 Measures

Analyses of game play revealed three discernible strategies (see Chapter Three, Study One). That study focused on the frequency of responses and not on the context or success of the responses. By contrast the present study focuses on the participants' responses *immediately before* engagement with the in-game hazards that include rolling wheels, skunks, and snapping flowers. These hazards cause loss of game life if they make contact with CB. Each hazard represents a problem to be overcome. Three main strategies were discernible in the children's approach to the game problems: pauses, prespins and backward pauses.

Pausing was an observable sudden interruption in the on-screen character's forward trajectory, achieved by the sudden lifting of the left thumb from its depression of the forward movement button (requiring one response set switch). Prespins were a dynamic, whirling action made by the on-screen character, either
while moving or in a stationary position (one to three response set switches). Prespins required either simultaneous depression of both the forward movement and spin buttons by the left and right thumbs (this move could be prolonged indefinitely, from pre-engagement to post engagement with a game hazard); or release of the forward movement button by the left thumb with subsequent depression of the spin button by the right thumb with subsequent additional depression of another response button in order to engage with (and move past) a hazard. Backward pauses were exhibited on screen as a controlled sequence of movements (e.g., pause, movement sideways or backwards, pause, movement forward). This was achieved by lifting the left thumb from the depressed forward movement button (to effect a pause); thumb shift and subsequent depression of either a left, right or reverse directional button (reverse was the predominant direction however on some occasions the movements were either to the left or the right); and lift again of the left thumb from the depressed directional movement button (pause). These sequences were often repeated. The backward pause then had to be followed by subsequent depression of other response buttons (e.g., forward movement together with spin or jump) to engage with the hazard (requiring at least five response set switches). Exhibited immediately before engagement with a hazard: pausing can be considered to be more of a standard game action; while the use of prespins albeit a typical game action, at this point was a novel action; and backward pauses a completely novel action.

For the present study, two measures of outcome-related task actions were derived from the number of arrow boxes spun correctly and number of glances toward the distractor while on task. A glance was an observable movement of the eyes away from the videogame monitor with eye focus on the monitor screening "The Simpsons". In addition, two measures of task outcomes were derived from the
number of challenges successfully negotiated; and the total task time (in seconds). The number of challenges records successful generation of timed and novel, complex motor sequences. The task time was the mean of the total task time (in seconds). The score totals were collapsed across all four video tasks (i.e., 4 tasks = 12 trials).

A measure of total game strategies used was derived from the total number of pauses, prespins and backward pauses generated immediately before engagement with an in-game danger or hazard. This total score was collapsed across all four tasks (i.e., 12 trials). Strategies that did not culminate in loss of game life were deemed successful and were used to obtain a measure of a percentage of total strategy success. The children from each group who used at least one or more of the individual strategies of pauses, prespins and backward pauses (as indicated on Table 5.3) permitted analysis of percentage of individual strategy success.

Table 5.2. Task Actions and Number of Participants Who Reached the Second Arrow Boxes

<table>
<thead>
<tr>
<th>Task actions a b:</th>
<th>ADHD</th>
<th>NC</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glances at distractor</td>
<td>12.16 (12.84)</td>
<td>10.68 (11.47)</td>
<td>ns</td>
</tr>
<tr>
<td>First arrow boxes spun correctly</td>
<td>5.70 (0.76)</td>
<td>5.68 (0.66)</td>
<td>ns</td>
</tr>
<tr>
<td>Second arrow boxes spun correctly</td>
<td>3.73 (2.01)</td>
<td>4.55 (1.55)</td>
<td>5.83*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Second arrow boxes reached c:</th>
<th>Task 2</th>
<th>Task 4</th>
<th>Over both tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>64.29 (36)</td>
<td>82.14 (46)</td>
<td>.001**</td>
</tr>
<tr>
<td>Over both tasks</td>
<td>64.29 (36)</td>
<td>64.29 (36)</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>51.79 (29)</td>
<td>58.93 (33)</td>
<td>ns</td>
</tr>
</tbody>
</table>

Note. Separate repeated measures analyses of variance conducted for number of glances, and first and second arrow boxes spun correctly, with significant F values reported. Binomial tests conducted on number of participants who reached the second arrow boxes, and significance (one-tailed) based on Z approximation.

a Total number of on-task glances at distractor collapsed over all four tasks; and total number of arrow boxes spun correctly collapsed over the two relevant tasks.

b Analyses conducted on data from total sample of matched pairs (ADHD, n = 56; NC, n = 56).

c Values show percentages (with numbers in parentheses) of participants in each group who reached the second arrow boxes.

*p < .05; **p < .01.
Only those matched pairs where both individuals used the relevant strategy were included in this analysis.

Averaged across participants (with numbers in parentheses), total scores for number of pauses, presessions and backward pauses collapsed together.

Table 3: 53 Strategies used by ADHD and NC groups

<table>
<thead>
<tr>
<th>Difference</th>
<th>NC</th>
<th>ADHD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matched pairs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.2.5 Procedures

The parents of all boys gave written informed consent and all boys gave informed verbal assent. All boys were tested individually. The boys in the ADHD group were tested in a quiet room located in the university, and boys in the non-disordered comparison group were tested at their school in a room designated for the study. In both settings the room was quiet, well lit and ventilated, free of extraneous distractors, and the layout of equipment and furniture was comparable.

All boys were tested in the morning and were allowed a three minute practice time (longer for novices) prior to commencing the experimental conditions, to ensure that each boy was sufficiently competent to perform the motor skill and visuospatial aspects of the target game and to be able to maneuver CB past the fourth challenge along the route in the adventure game (necessary for an adequate measure of executive function in the previous study). Instructions for each of the four conditions were given immediately preceding the participant’s undertaking of that component. Participants were allowed only one trial for each of the four game segments in the target game; but were informed that the best time and performance would be chosen from their three attempts (for each of the four tasks) in the adventure game.

Each boy was videotaped, so that eye movements towards the distractor were recorded while on task. The videogame play was also downloaded directly onto a videocassette. The adult examiner remained out of the participant’s line of sight throughout the testing. The examiner held the controls, while giving instructions for each task. Administration of all four game conditions lasted no more than 20 minutes, and after testing the participants were allowed to play the game with no imposed rules for five minutes.
5.2.6 Data Analysis

Outliers among the scores for the strategy variables were adjusted by according them one unit larger than the next most extreme score in the distribution (Tabachnick & Fidell, 1996) before conducting the analyses. To test for differences between the ADHD and case-matched non-disordered comparison groups, a series of Analyses of Variance (ANOVA) for repeated measures were conducted for continuous data generated from task actions, task outcomes, number of total strategies used and numbers of each strategies used. Group (ADHD, non-disordered control) was used as a repeated measure. Binomial tests of proportion were used to examine differences between group percentages of participants who reached the second arrow box, and who used each strategy. Effect sizes (ES) were ascertained by dividing the difference between the two means being compared by the standard deviation of the data, obtained by the square root of the mean square for error in the denominator of the F ratio used to test the overall hypothesis (Cohen, 1988).

Pearson's partial correlations were conducted separately for the total sample, ADHD and non-disordered control groups respectively, to examine relationships between the videogame task actions, task outcomes, strategy use, and strategy success. Correlations were conducted on raw scores and percentages of raw scores. Regression analyses were conducted to identify those variables predictive of task success (i.e., the number of game challenges successfully negotiated). Statistical analyses were performed using SPSS Version 10.0.

5.3 Results

Sample characteristics of the successful group matching, and task outcomes are indicated on Table 5.1 (for more detail see Chapter Three, Study One). As shown, the ADHD group achieved significantly less overall task success in the
number of challenges achieved than did the non-disordered control group, $F(1, 55) = 4.97, p < .05$ (Effect Size: ES = 0.42), while taking an equivalent amount of time on task. The results of task actions and strategy use are summarized on Table 5.2 and 5.3, while significant relationships between the variables are summarized (on Tables 5.4 and 5.5), and predictors of task success are summarized on Table 5.6.

As indicated on Table 5.2, there were no significant group differences in terms of the number of glances at the distractor and the number of first arrow boxes spun correctly. However, the ADHD group spun significantly less second arrow boxes correctly in comparison with those spun by the control group, $F(1, 55) = 5.83, p < .05$ (ES = 0.45). Although, (as indicated in Table 5.2) significantly fewer of the ADHD group compared to the NC group reached the second arrow box on Task 2 (high working memory, low distractor condition): There were no significant group differences between the number who reached the second arrow box on either Task 4 (high working memory, high distractor condition) or overall (with the two tasks collapsed together).

There was no significant group difference in the overall total of strategies used (as indicated in Table 5.3). However the ADHD group achieved a significantly lower percent of overall strategy success in comparison with the control group, $F(1, 55) = 5.20, p < .05$ (ES = 0.43). No significant group differences were also revealed in the number of pauses and backward pauses used, however the ADHD group made significantly more prespins than did the NC group, $F(1, 55) = 5.10, p = < .05$ (ES = 0.43). In addition, as indicated on Table 5.3, there was no significant group difference between the percentages of each group who used pauses, however significantly more of the ADHD group used prespins than did the control group, while conversely significantly more of the latter group used backward pauses.
Finally there were no significant group differences revealed in terms of the percentages of success of each individual strategy.

Pearson correlation coefficients were used to examine relations among the strategy variables within the whole sample, then the ADHD and non-disordered control groups separately. As indicated on Table 5.4, prespins negatively relate to task success for both groups, albeit with marginal significance for the non-disordered control group. By contrast, a significant relationship between backward pauses and the percent of strategies successful is shown within the ADHD group. However there is no parallel relationship shown between these variables for the control group.

Pearson correlations were also used to examine relations between the variables for each strategy, task action and task outcome within the whole sample, and the ADHD and non-disordered control groups separately. As indicated on Table 5.5, an association was revealed within the ADHD group between backward pauses and correctly spun arrow boxes. This association is not evident within the control group, but is evident within the total sample. Similarly, an association between backward pauses and number of successful challenges is evident within the ADHD group and the total sample but not within the control group. Additionally, the number of glances (at the distractor) and arrow boxes spun correctly were significantly associated with the number of successful challenges within both the ADHD and total sample, while only arrow boxes showed a significant parallel relationship within the control group. The significant association evident between glances, pauses and total strategy use within the total sample was not evident within either the ADHD or control groups. While an inverse relationship between prespins and number of successful challenges was evident within the total sample as well as within the ADHD and non-disordered control groups.
<table>
<thead>
<tr>
<th></th>
<th>Pauses</th>
<th>Prescriptions</th>
<th>Backward Pauses</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Strategies successful</td>
<td><strong>31.2</strong></td>
<td><strong>22.2</strong></td>
<td><strong>21.2</strong></td>
</tr>
<tr>
<td>(Total)  N = 112</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Strategies successful</td>
<td><strong>26.1</strong></td>
<td><strong>20.1</strong></td>
<td><strong>20.1</strong></td>
</tr>
<tr>
<td>(NC)  N = 56</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>% Strategies successful</td>
<td><strong>41.8</strong></td>
<td><strong>35.5</strong></td>
<td><strong>35.5</strong></td>
</tr>
<tr>
<td>(ADHD)  N = 56</td>
<td></td>
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</tbody>
</table>

Table 5.4: Intercorrelations between Strategies for ADHD and NC Groups
<table>
<thead>
<tr>
<th>Time</th>
<th>Challenges</th>
<th>Task outcomes</th>
<th>Task actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>06</td>
<td></td>
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<td></td>
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<tr>
<td>11</td>
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<td>16</td>
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<td>22</td>
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<td>27</td>
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<td>62</td>
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<td>92</td>
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<td></td>
</tr>
<tr>
<td>97</td>
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</table>

**Note:** Pearson r-squared correlations

### Table 5.5: Inter-correlations between strategies, task actions, and task outcomes for ADHD and NC groups

<table>
<thead>
<tr>
<th>Pauses</th>
<th>Pressing</th>
<th>Backward pauses</th>
<th>Strategies total</th>
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</thead>
<tbody>
<tr>
<td></td>
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A regression analysis was conducted with the ADHD \((n = 56)\) and non-disordered control group \((n = 56)\) separately and with the total combined sample \((N = 112)\) to examine the contribution made by age, verbal IQ and performance IQ to task success (number of successful challenges achieved). Age, but not IQ scores, showed a significant contribution. Therefore age was included in the subsequently conducted hierarchical regression to examine the contribution made to success by individual strategy use.

Hierarchical regression analysis was conducted with age, backward pauses, prespins and pauses entered respectively to examine their contribution to the variance of the number of successful challenges. As indicated on Table 5.4, age is significant within each of the ADHD, control and total sample groups of scores. However, while backward pausing significantly contributes to the number of successful challenges in the ADHD group, it shows no parallel significance in the control group. Conversely, the significant negative contribution of prespins to the number of challenges within the non-disordered control group is not evident within the ADHD group. The significance for these last two variables is correspondingly replicated within the regression coefficient for the total sample.
<table>
<thead>
<tr>
<th>Step</th>
<th>Age in months</th>
<th>Pause</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3.9</td>
<td>Step 2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.38</td>
<td>Step 3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.95</td>
<td>Step 4</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>n = 112</td>
</tr>
</tbody>
</table>

**ADHD (n = 56):**

**ADHD Theory Outside the Laboratory:**

Table 3.6: Summary of Hierarchical Regression Analyses for Variables Predicting Number of Challenges Completed.
5.4 Discussion

The present exploratory study compared the strategic responding of children with ADHD with that of their non-disordered peers (individually matched on age and IQ) on cognitively challenging videogame tasks. Major findings were that (a) there were no group differences in the ability to demonstrate varied strategic responses; however, despite the highly motivating and stimulating context (b) the preferred ADHD strategy was less effective and achieved less successful task outcomes.

Success in videogame play requires executive functioning ability to (a) discriminate between the effectiveness of different strategies, (b) choose the most appropriate strategic response, (c) rapidly switch response sets (often in rapid sequence), and (d) apply a strategic response effectively in order to successfully negotiate any one of the numerous in-game hazards. The latter two abilities require controlled processing and responding, in addition to accuracy in timing (for more details see Chapter Three, Study One). For example, precise timing is essential when negotiating CB past the rolling wheels, skunks that approach in rapid intermittent succession, and flowers that lean toward CB upon his approach in order to snap.

It is important to remember that only those pauses, prespins and backward pauses generated immediately before engagement with an in-game hazard, have been included for consideration in this study. At such a point in game play: pauses are a common game strategy, prespins are a novel application of a typical game action, while backward pauses are a completely novel strategic response.

The fact that no specific strategy positively relates to the control group’s task success (as one does for the ADHD group) suggests that the control boys have no specific difficulty in any one of the abilities described above. Also, appropriately, the
control group used less of the one strategic response (prespins) that is negatively associated with their success. By contrast, ADHD success is significantly positively associated with backward pausing, and negatively associated with prespins. However, conversely the ADHD group inappropriately used less backward pausing, while using more prespins, than did the control group. That more of the ADHD group used more prespins compared to their non-disordered peers may reflect an earlier stage of strategy development in ADHD. Hence a difficulty with switching to the more effective strategy of backward pausing may either inhibit ADHD progression to the next stage of strategy development, or may simply represent an earlier stage. This contrast between the ADHD and control group’s choice of strategy makes it necessary to understand the fundamental differences between backward pauses and prespins.

Despite the busy dynamic visual display of a prespin, there is less requirement for response set switches and controlled flexibility than in a backward pause. Stationary and moving prespins may therefore be primarily reflexive movements requiring less control (Levy & Swanson, 2001). Backward pauses however, appear as reflective, calculated and controlled movements. The sequence of controlled motor movements in backward pausing strategically allows for “time-out” immediately before choosing the type of strategy and precise moment for response engagement with the particular game hazard. Tasks involving controlled processing (such as that required in backward pausing) have previously been found to differentiate between children with and without ADHD (Carte et al., 1996).

Both moving prespins and backward pauses manipulate response timing for the player, but in different ways. A moving prespin, which can be prolonged indefinitely (i.e., from pre-engagement with a danger or hazard through to post-
engagement), allows a response to be successful without precise timing and without rapid successive set switches. The present study did not differentiate between stationary or moving prespins. However the overall negative association of prespins with task success for the sample suggests the majority of prespins failed because of timing inaccuracy. For instance, stationary prespins would be most likely to fail as a result of imprecise timing of the response (a final set switch) to engage with the hazard (e.g., in initiating each jump in a series of jumps over skunks that approach in rapid succession). Moving prespins however, would most likely fail because of premature release of the spin button (e.g., before totally passing the snapping flower).

It is possible that children with ADHD choose less effective strategies over more effective strategies according to their level of effortfulness (Hoza, Pelham, Waschbusch, Kipp, & Owens, 2001; O’Neill & Douglas, 1991). Miller and colleagues (1991) determined that strategic responding is resource demanding, although the more a strategy is practiced, the more automatic and thus less effortful it becomes. Strategy use has been found to be more effortful in younger than older children. Given that executive functioning in ADHD is thought to be less efficient and mature (Barkley, 1997), it would follow that children with ADHD may choose less effortful strategies. It is important to note however, that what may appear less effortful when compared to the strategy use of non-disordered controls, would no doubt remain effortful to children with ADHD. Moreover, although fewer children with ADHD used backward pausing, those who did so were able to generate this novel and controlled strategic move as often and as successfully as their non-disordered peers.
One intriguing finding was the significant relationship between glances and task success for the ADHD group, but with no parallel association for the control group. Hence, it appears that arousal or activation obtained from the highly stimulating distractor may assist or improve performance in those with ADHD (Zentall & Zentall, 1983). It is possible that external contingencies and self-generated actions are used by children with ADHD in compensatory efforts to increase available cognitive energy. Theories of an inefficient dopaminergic system in ADHD lend support to this interpretation (Levy & Swanson, 2001; Pliszka et al., 1996; Todd & Botteron, 2001). This may also explain the ADHD preference for prespins, which produce a dynamic on-screen visual display equal to that produced by the distractor. Previous studies have also found that although children with ADHD have been distracted more by the presence of distractors than their non-disordered peers, their performance is not necessarily detrimentally affected (Brodeur & Pond, 2001; Ceci & Tishman, 1984; Karayanidis et al., 2000; Lorch et al., 2000; Landau et al., 1992).

5.4.1 Limitations

The ecologically valid context of videogame play provides an appropriate and motivating real-life medium in which to examine strategy use in children with ADHD. However, the innovative nature of this testing medium determines that this study is necessarily exploratory. The children's responses have been interpreted in view of current empirical theory on cognition, executive functioning, and ADHD, and it is acknowledged that other interpretations may be possible. Also, it is possible that the participants may have used other additional game play strategies that this study was unable to detect. It is recognized that much additional theory exists on strategy use, however the present study's focus was on how strategies were used in
the executive control approaches to problem solving used by children with and without ADHD. In addition, only boys were included in this study and so it is not known if these findings are gender specific. Further studies with other populations of children (both with and without ADHD) using this medium will be necessary in order to substantiate any findings from this study.

5.4.2 Clinical Implications

Given the high proportion of motor problems in children with ADHD (Barkley, 1997; Gillberg, 1983, 1998; Pereira, Eliasson, & Forssberg, 2000), adventure videogames provide a visuo-spatial fine-motor practice medium for children with ADHD. This novel, inductive learning activity also enables practice in planning, anticipation and timing on cognitive processing tasks that may be of benefit to children with ADHD (Blumberg, 1998; Greenfield & Cocking, 1996; Subrahmanyam Greenfield, Kraut, & Gross, 2001; Zentall & Zentall, 1983). There is some evidence of a degree of transfer of skills acquired in this medium (Greenfield & Cocking, 1994, 1996, Subrahmanyam et al., 2001). Furthermore it has been found that when children have used one type of strategic response: practice encourages the learning of that and other varied strategies (Greenfield & Cocking, 1996; Gunzelman & Anderson, 2001). With practice, strategy use becomes automatic, and thus less effortful (Miller et al., 1991), and there is some evidence that videogame play develops strategies of dual attention in children and adolescents (Greenfield & Cocking, 1996; Subrahmanyam et al., 2001).

Efficient use of strategy by children with ADHD may be undermined by a deficiency in perception or adoption of self-responsibility for either task success or failure (Abikoff et al., 1988; Douglas & Parry, 1994; Hoza, Waschbusch, Pelham, Molina, & Milich, 2000). It is not known to what extent this is a learnt defensive
response to repeated failures, or an inherent perceptual or cognitive deficit. In videogame play however, the player repeatedly observes the immediate outcome of his or her task performance equate with success or failure. The repeated immediacy of these objective performance appraisals may assist in promoting more realistic and objective self-appraisals of performance level, and thus more accuracy in judging whether performance level will equate with either success or failure (Blumberg, 1998). The virtual reality “playground” of videogames also provides for self-play, which promotes the maturation of the executive functioning processes involved in self-management of affective states (Barkley, 1997). Hence in play, one may practice subjectivity or objectivity when responding to success or failure by transference of these states to the game protagonist (just as a child has traditionally used transference through the medium of a toy in the playground for role-playing of learned adult behaviors).

In conclusion, children with ADHD demonstrated equal ability to their non-disordered peers in generating a variety of novel strategic responses on cognitively challenging videogames. However, despite the stimulating and motivating task context children with ADHD chose the less effective strategy in preference to a more effective though more difficult strategy. This resulted in less successful ADHD task outcomes. The findings provide some evidence that executive control problems in children with ADHD involving flexibility and response timing do generalize from laboratory tasks to motivating and stimulating real-life task contexts.
6.1 Review of Objectives and Synopsis of Findings

Current theory of ADHD proposes that a primary deficit in behavioral inhibition gives rise to impairments in other dependent EFs and motor performance. Support for this theory is derived almost exclusively from standard laboratory based neuropsychological tasks founded on models of adult psychology. The overall purpose of the present research was to test current theory by examining the cognitive performance of primary schoolchildren diagnosed with ADHD (two subtypes, no comorbidity, unmedicated) and their normally developing peers during challenging tasks in real-life contexts. Children’s cognitive performance was examined during two real-life activities (videogame play, route tasks at a zoo) and two laboratory based neuropsychological tasks (Stroop, WCST). The premise of the present research was that if behavioral inhibition is a fundamental deficit in ADHD, then impairments were expected to be manifest during everyday child-relevant activities that require behavioral inhibition, as well as on laboratory based measures of this construct. Operationally defined measures of specific EF (e.g., behavioral inhibition, working memory etc.) were based on one current behavioral inhibition model of ADHD (Barkley, 1997, 2000). These measures were used to examine performance during everyday activities that varied (low/high) in working memory demands and presence of distractors.

Three aspects of the results are particularly significant for the current discussion. First, there is no robust evidence for behavioral inhibition deficits across both real-life (videogame, zoo) and laboratory (Stroop, WCST) tasks in the ADHD group. For example, on the one hand, children with ADHD did not exhibit deficits in
the ability to inhibit a prepotent or ongoing response in the adventure videogame (as indexed by pauses), but did manifest inhibition deficits in terms of interference control (i.e., more deviations) during the route task at the zoo. On the other hand, the ADHD group was not impaired in the interference control aspect of inhibition as measured on the Stroop test, but did exhibit more problems on the WCST inhibition measures (perseverative errors and responses).

Second, children with ADHD did exhibit a variety of EF performance deficits across both real-life and laboratory tasks and contexts, and typically group differences were greatest under conditions of high working memory and distractor loads. For example, during the adventure videogame, children with ADHD exhibited various problems on measures of working memory (more self-talk, spinning more non-designated boxes), reconstitution (more prespins), and motor control/flexibility (fewer challenges completed). Problems in motor control/flexibility were also evident during the route tasks at the zoo (longer time to complete). Moreover, the ADHD group exhibited problems on measures of general EF on the laboratory tasks (slower Stroop color naming; more trials to complete first sorting category on the WCST). Also, although the children with ADHD demonstrated the use of a variety of game strategies in the challenging videogame, they tended to persist in using a less effective game strategy compared to normally developing peers, which likely contributed to the fewer challenges they were able to negotiate. Persistence in using a less effective strategy was also evident from their high rate of perseverative responses on the WCST, reflecting a tendency to persist with a previous but incorrect sorting category.

Third, inhibitory performance on the real-life tasks and laboratory-based neuropsychological tasks (as represented by the key measures of inhibition) was not
correlated. However, performance on other aspects of executive function measured by the neuropsychological tasks was correlated with executive function measures from the videogame and zoo tasks. For example, the number of challenges completed on the videogame tasks (an index of motor control/flexibility) was positively related to the number of items correctly named on the word and color-word subtests of the Stroop task, and inversely related to the number of perseverative responses and perseverative errors on the WCST.

Collectively, these findings provide limited support for behavioral inhibition as a fundamental deficit in ADHD, but suggest that deficits in some aspects of executive functioning may generalize across laboratory and non-laboratory contexts. Also, the findings suggest that cognitive difficulties in ADHD may be context dependent and thus amenable to improvement by environmental manipulations as well as by psychopharmacological treatment.

6.2 Limited Evidence for a Behavioral Inhibition Model

The present findings support the proposed multidimensional nature of behavioral inhibition (which is discussed more fully in the next section of this chapter). Measures of different aspects of inhibition were incorporated in this research. Specifically, the videogame tasks required sudden and complete inhibition of prepotent and ongoing responses, the zoo and Stroop tasks required interference control, whereas the WCST required the inhibition of prepotent (previously rewarded) responses.

Several major hypotheses relating to behavioral inhibition were tested in the present research. The first hypothesis was that children with ADHD would manifest deficits in various aspects of inhibition that are required by the child-oriented daily-life activities of videogame play and route tasks at the zoo, as well as by the
standardized neuropsychological tests (Stroop, WCST). Second, it was hypothesized that impairments in the various aspects of inhibition would be greatest under conditions with high demands on working memory and/or high distractor load. Third, in accordance with current theory and clinical belief (Barkley, 1997; Quay, 1997; Swanson et al., 1998; Taylor, 1998), it was predicted that inhibitory impairments would be greatest in (or even restricted to) the Combined Type of ADHD.

The first major hypothesis is not supported by the present findings. No evidence was found that deficit in any aspect of behavioral inhibition generalizes across all tasks. For example, there is evidence of deficit in interference control during the zoo tasks, but not during the Stroop. Correspondingly, while there is no evidence of deficit in the inhibition of prepotent responses during the adventure videogame tasks, deficit in this aspect of inhibition is evident in the WCST (perseverative responses and errors). The second major hypothesis is partially supported by the present findings in that impairments were greatest under conditions of high working memory and distractor loads. However, impairments included those of working memory and other EFs as well as those of inhibition. For example, under such conditions impairments in working memory and other EFs occurred in the absence of deficit in inhibition (adventure videogame), while conversely deficit in behavioral inhibition occurred in the absence of any deficit in working memory (zoo). The present findings offer no support for the third major hypothesis in that there is no evidence that impairment in any aspect of inhibition is greatest in children with the subtype ADHD-C (or restricted to that subtype) compared to those with ADHD-I.
6.2.1 Task Dependency of Behavioral Inhibition Deficit in ADHD

The pattern of inhibitory deficits evident in the performance of the ADHD group across the various tasks and contexts investigated in this research highlights the task dependency of those deficits. For example, the interference control aspect of behavioral inhibition, clearly indexed by deviations in the zoo activities, showed the ADHD group to be impaired. However the same children showed no impairment on the laboratory Stroop interference condition that also indexed interference control. Similarly, inhibition of prepotent and ongoing responses (involving reward or feedback) indexed by pauses in the adventure videogame, and in the target game (by producing limited responses of maximum accuracy in accord with task instructions) was unimpaired in the ADHD group, whereas deficits in this type of inhibition have been demonstrated fairly consistently with the laboratory-based stop-signal task (reviewed by Nigg, 2001; Oosterlaan et al., 1998). An analysis of task demands and characteristics, together with a consideration of the pattern of inhibitory deficits shown by the ADHD group, indicates why deficits in behavioral inhibition are task-dependent.

Tasks, in general, appear to have three important differences between the types of cues that influence responses. Cues vary: (a) in the time duration of their visibility or presence (e.g., transient versus sustained), (b) in the extent of their meaningfulness and saliency to children (e.g., threatening skunks or chasms versus abstract letters or auditory tones), and (c) in terms of their motivational relationship to the task goal. For example, threatening skunks and chasms clearly interfere with the salient goal of getting Crash Bandicoot along the path to the checkpoint in the adventure videogame, but aural tones and abstract letters do not appear closely related to the goals (which are also often abstract, intangible and of questionable
motivation to a child e.g., Stroop, WCST) of many laboratory tasks (e.g., a child could reason that accuracy is arguably the goal of the stop signal task).

The difference between task cues may help to explain the critical issue of why children with ADHD in the present research were able to inhibit their responses during the videogame tasks, in direct contrast to their previously demonstrated inability to do so on the laboratory stop-signal task. For example, in the stop-signal task (as in CPTs) the child is not given any advance warning of the imminent arrival of the stop tone (thus the need to stop), and also cannot stop the task to prepare for an impending stop signal. By contrast, videogames present salient visual warning cues in advance of the required pause (i.e., the child sees in advance the skunks and the rolling wheels which remain visible and highly salient). Also, the child can interrupt the game and prepare for the imminent signal to stop. Thus, the present findings suggest that if children with ADHD are given a salient, meaningful warning cue just prior to the requirement to inhibit a response, they may be able to inhibit appropriately.

In the present research, the brief, tasks such as the videogames and Stroop interference provided a continuation of salient cues in a novel or stimulating context (e.g., the conflicting word/color in the latter task may provide novelty and therefore stimulation, in addition to being both a visual clue and prompt for the correct, as well as the incorrect, response). Conversely, the tasks that extended over a period of time lacked salient task-related cues given prior to the points of critical responding (e.g., WCST and zoo activities).

The suggested task dependency of the behavioral inhibition deficit in children with ADHD supports in part current theory that these children’s behavior is more vulnerable than their normally developing peers to the effect of salient
contextual factors (see Barkley, 1997, 2000). For example, in the present research the children with ADHD appeared able to control their responses (i.e., prepotent/ongoing) with the help of salient on-task cues during videogame play, but were not able to sustain control over their responses (i.e., maintain interference control) without such cues during the zoo and WCST tasks. Hence, in accord with theory (Barkley, 1997) children with ADHD in the present research exhibited inability to self-sustain focused attention. However, as will be discussed later in this chapter, the present findings challenge the proposed hierarchical order of primary deficit in ADHD (see p.138).

An alternative neuropsychological theory proposing that delay aversion is an acquired characteristic in those with ADHD that stems from fundamental abnormalities in reward mechanisms (such as a faster decline in the effectiveness of reinforcement as the delay between the behavior and reward increases) is also partially supported by the present findings (see Sonuga-Barke, 1995, 2002). Since greater locomotor activity in those with ADHD has been found only when delays become unavoidable (Antrop, Roeyers, Van Oost, & Buysse, 2000), hyperactive and fidgety behavior may represent compensatory responses. On the one hand, the ADHD group’s deficit in sustained interference control (WCST, zoo), and preference for the less efficient (but dynamic) prespins over the more efficient (but more restrained) backward pauses during the videogame tasks is in accord with this theory. Further, the act of inhibiting responses (pauses) during the videogame could be argued to be composed of as much dynamic action as inaction (lifting the thumb from its suppression of the forward movement button for a brief duration of time). However, on the other hand, these children clearly demonstrated their ability to (a) interrupt and completely stop their ongoing forward trajectory of CB, (b) desist from
immediately re-suppressing the forward button, and (c) sustain effectively controlled pauses at critical points during game play. It is not clear whether their ability in this context is a result of (a) the active immediacy of game play reward (or failure), and the graphic, dynamic context being ideally suited to the motivational style hypothesized for those with ADHD, or (b) that such a context optimally stimulates dopaminergic substrates (Koepp et al., 1998) in which case such stimulation was unable to relieve problems with working memory, reconstitution and motor control, evident in the absence of inhibitory deficit, or (c) that there is no such hypothesized inhibitory impairment in these children, at least in this context.

Distinctions between the type of cues provided during the videogame and neuropsychological tasks (e.g., Stroop, WCST, stop-signal and CPTs) may therefore explain to some extent why children with ADHD appear inconsistent in their ability to inhibit their responses. It is also as yet unknown to what extent stress adversely affects the cognitive performance of children with a diagnosis of disordered attention (see Arnsten, 1999; Arnsten & Goldman-Rakic, 1998) when completing these abstract though obviously attention-related, laboratory based, tests.

The abstract cues provided during neuropsychological tasks also often place high simultaneous, conflicting demands on the same or similar processing area. For example, in the Stop signal the cue to go is visual whereas the cue to stop is aural. Similarly, the salient visual cues in the Stroop (colors, color names) and the WCST (colors, geometric shapes, numbers), not only create a processing conflict with each other, but also with the aural task demands (required to be held on line). This conflict demands that the individual engage an efficient gating mechanism to prioritize and filter cued information (Grace, 2001; see review by Levy & Farrow, 2002; Raye, Johnson, Mitchell, Nolde, & D'Esposito, 2000), as well as other working memory
processes to keep on line the order of that priority. Therefore, a high demand for working memory together with speeded higher order executive processing is required for such neuropsychological tasks (as these tasks are either timed e.g., Stroop, or the response impetus is beyond the participant’s control, e.g., WCST, stop-signal).

It is possible then that the memory processes required for inhibition of reflexive responding (i.e., in holding on-line a rule to inhibit specific responses) in those with ADHD may be assisted by salient, meaningful, task-relevant cues for their activation and maintenance. This is consistent with current recognition that short-term memory retention is thought to be cue driven (Nairne, 2002). This is also in accord with the pattern of deficits involving short-term or working memory exhibited by the children with ADHD under abstract or absent on-task cue conditions across the contexts of the present research (e.g., Stroop color naming; WCST; zoo deviations).

6.2.2 The Multidimensional Nature of Behavioral Inhibition

The findings from the present research support the theorized multidimensional nature of behavioral inhibition. One current theory proposes that behavioral inhibition as an executive function comprises three aspects: prepotent, ongoing and interference control (Barkley, 1997, 2000). Alternatively, inhibition has been conceptualized as comprising separate executive versus motivational processes (see Nigg, 2001), with the separation between these processes proposed to be only partially distinct on most measurement tasks and during everyday behavior.

In the present study different task demands distinguish between differing theorized dimensions of behavioral inhibition (e.g., prepotent and ongoing, and primarily motivational processes, as demonstrated during the videogame;
interference control, and primarily executive processes during the Stroop, WCST and the zoo). Hence, aspects of the construct and deficits related to the construct are not stable across all task conditions. Moreover, a lack of any significant relationship between any of the behavioral inhibition measures, either laboratory or real-life (see Chapter Four), appears to reflect this variable, multifaceted nature of the construct. Its specific nature during any task appearing to be determined by the type and extent of interaction with varying aspects of other EFs (e.g., working memory) according to task demands. For example, the inhibitory responses required in the adventure videogame and the Stroop appear to require little working memory (e.g., inhibiting a response immediately after prior salient cues to do so). Conversely, a greater degree of working memory appears demanded by the inhibitory responses required in the other tasks (e.g., zoo, Stroop, WCST). Therefore, although working memory involvement can be seen in both momentary and sustained inhibition (de Fockert et al., 2000), the memory processes involved no doubt differ. For example, controlled (prepotent or ongoing) motor responses may primarily involve processes of retrospective and prospective time estimation. This interpretation is consistent with current opinion that retrospective (sensory) working memory and prospective (motor) working memory processes enable the temporal organization of behavior (Denny & Rapport, 2001; Fuster, 2000; see review by Levy & Farrow, 2002). Whereas, the interference control enabling sustained inhibition may primarily engage short term or working memory capacity to hold information on line over time. Given that not all of the children with ADHD in the present research exhibited such deficit, it is also possible, that impaired memory processes are not distinct to all children with ADHD. Alternatively, memory and cognitive processing deficit may
only be evident in children with ADHD at times when cognitive task demands exceed the individual’s capacity.

Evidence of working memory deficit in the absence of behavioral inhibition failure during the adventure videogame challenges the present theorized hierarchy between inhibitory and working memory processes (Barkley, 1997, 2000). Further, the only behavioral inhibition impairment evident in children with ADHD in the present study (i.e., during the zoo and WCST tasks) appears to involve working memory processes. That memory processes may subserve those of inhibition, has been previously suggested (Pennington & Ozonoff, 1996; Rapport, Chung, Shore, & Isaacs, 2001), and is supported by recent evidence from animal studies (see Souza et al., 2000). Working memory processes are thought to be integral to sustained inhibition (Constantinidis, Williams, & Goldman-Rakic, 2002; Li et al., 2000; de Flockert et al., 2001; Garden, Cornoldi, & Logie, 2002).

It may also be, that working memory processes, or the neural network that subserves these processes, also play a fundamental role in the suppression of all cued responses. Previous evidence suggesting a relationship between cued prepotent responses, behavioral inhibition and working memory, was provided by a study which found antisaccade error rates increased in participants in accordance with fronto-executive demands of the response task (Mitchell, Macrae, & Gilchrist, 2002). Specifically, that study found a negative effect from working-memory load was restricted to the inhibitory component of the antisaccade task. The present findings of the ADHD group’s ability to inhibit responses during the saliently cued tasks (thus, working memory relieved tasks: videogame, Stroop) suggest that working memory processes may subserve all aspects of inhibitory deficit, including inaccurate, prepotent or ongoing responses. This interpretation is consistent with a
previous suggestion that working memory may help prevent incorrect prepotent responses (see Pennington & Ozonoff, 1996).

Finally, the interpretation of the present findings that the multifaceted and task dependent construct of behavioral inhibition reflects the working memory demands of a task, appears consistent with (a) indications from present findings that working memory processes subserve those of inhibition (b) previous hypotheses that working memory deficit may underlie impaired inhibition (Pennington, 1994; Pennington, Bennetto, McAleer, & Roberts, 1996; Pennington & Ozonoff, 1996; Rapport et al, 2001), and (c) the belief that working memory processes are task dependent (D’Esposito, Postle, & Rypma, 2000; Owen, 2000; Owen, Lee, & Williams, 2000).

6.2.3 EF and Speeded Interactive Processing

Evidence of relationships between the real-life and laboratory EF measures used in the present research appear to tap common processing networks. For example, significant positive relationships are evident between the laboratory Stroop (word and color-word) and real-life videogame (number of successful challenges) measures; and the WCST (perseverative responses) and zoo (time taken on task) measures. Moreover, the WCST (perseverative responses and perseverative errors) shows an inverse relationship to the videogame (number of successful challenges) measure. Working memory (see Pennington & Ozonoff, 1996) and speeded higher order cognitive processes may provide a common framework for this network.

The multidimensional construct of working memory used in this study was based on Barkley’s (1997) conceptualization, which differs from other current working memory models (e.g., Baddeley, 1986). Despite distinctions between models, children with ADHD in the present research demonstrated inefficiency in
Task requirements for working memory and high cognitive load appear common to the performance difficulties. For example, (a) during the videogame the children had to conceptualize and choose between strategic responses for each specific challenge, (b) while along the complex route in the zoo they had to self-direct their impetus by their own sense of time (to walk as fast as they could) while holding directions, task information and interference control in mind. (c) The Stroop naming of colors (abstractions) is thought to be more effortful than naming words or concrete semantic objects (see Tannock et al., 2000), (c) while the requirements of the WCST are understood to primarily involve the cognitive processes engaged in abstract and conceptualized thought (Lezak, 1995).

The WCST and zoo tasks demand the sustaining over time of efficient working memory and flexible cognitive processing (as in decoding abstract rules, remembering patterns and constructing meaning from abstract cues during the WCST, and remembering the correct response to highly salient distracting cues at the zoo (e.g., if a landmark, use to advance direction along the route, otherwise ignore: either way don’t waste time with it). Importantly, the cognitive processing required over the duration of such tasks must not only be efficient but also speeded, given the timing constraints on responding (set and maintained by the examiner in the WCST; and set as part of the task instructions “to walk as fast as you can” at the zoo). That is, even though both the WCST and the zoo task activities extended over a period of time, at critical points during that time the children had to process and respond quickly (and correctly) to ambivalent information.
6.2.3.1 Children with ADHD: Use of Verbalization to Self-Cue

The greater use of self-directed on-task verbalizations and affective exclamations made by the ADHD group during the videogame tasks did not prevent them from breaking a rule (of touching undesignated boxes) more so than the NC group. Similarly the greater allowance at the zoo for self-verbalizations while on task did not prevent the ADHD group from making more off-task deviations. This suggests that self-verbalizations alone, if used either as a prompt for working memory or as a self-stimulatory device to maintain attentional focus, are not sufficient to completely eradicate memory based performance problems in these children. Notable, however, is the evidence that children with ADHD make deliberate, effortful attempts to improve their performance during challenging real-life tasks. Further, the lack of performance deficit on other EF and motor control measures during the same tasks suggests that their strategic use of self-verbalizations may ameliorate performance problems to some extent.

It is possible that salient cues prompt the conscious focusing of attention in children with ADHD, which in turn activates processing areas more specific to, or efficient for, task requirements. This interpretation appears reasonable, given that: (a) it is thought that different brain regions and processing areas are activated and engaged according to task demand (Nelson et al., 2000; Owen, 2000; D’Esposito et al., 2000); (b) dissociated short-term or working memory processes are also selectively engaged according to differing task requirements (Braver & Bongiolatti, 2002; Cornette, Dupont, & Orban, 2002; Fincham, Carter, van Veen, Stenger, & Anderson, 2002; Mottaghy, Gangitano, Sparing, Krause, & Pascual-Leone, 2002); (c) consciously focused attention is thought essential in both the creation and the maintenance of effective memory processes (Wheeler & Treisman, 2002), (d) that
inefficient dopaminergic neurotransmitter systems are associated with cognitive control and working memory processes in ADHD (see reviews by Levy & Swanson, 2001; Solanto, 2002), Parkinson’s disease (Cools, Stefanova, Barker, Robbins, & Owen, 2002), and schizophrenia (Meyer-Lindenberger et al., 2002); and (e) adult males with ADHD have shown the engagement of more diffuse brain regions simultaneous with impaired working memory and inefficient strategic problem solving, compared to their non-disordered peers (Schweitzer, et al., 2000).

Alternatively, without salient cues a heavier demand is made either on working memory or on executive processes to decode inferential or abstract information. It is at this junction of interactive working memory and effortful cognitive processing, when speeded performance is required, that children with ADHD exhibited impairment in the present research.

It was recently suggested that a distinct dimension of working memory engages the supervisory and controlled executive processes associated with fluid intelligence (Primi, 2002), and specifically with speeded mental processing (see Oberauer et al., 2000). Indeed, it has been suggested that working memory capacity actually forms an essential part of fluid intelligence, and is a deciding factor in limiting an individual’s ability to control attention (Engle, 2002). This is consistent with previous research that used a videogame technique, and found two types of working memory skill deployed, one involving response timing and accuracy, the other involving the monitoring of events and strategic control (Logie et al., 1989). Moreover, a recent study found that working memory problems demonstrated by a community sample of children with ADHD were not significant once IQ was covaried (Kuntsi et al., 2001).
Debate exists among researchers regarding the role of IQ in EF processes and ADHD (see Barkley, 1997; Pennington & Ozonoff, 1996, Seidman et al, 1997). However, the present findings indicate a degree of impaired higher order intelligence or EF related to working memory deficit in children with ADHD. Moreover, recent findings from a large-scale twin study confirmed a phenotypic relationship between working memory and cognitive ability (Ando, Ono, & Wright, 2001). The findings from that study indicate a significant genetic influence on working memory storage and EF, and suggest that cognitive ability may be specific to working memory capacity. Further, working memory capacity is thought to contribute to the development of conditional (as in “if, then”) reasoning, a critical ability in logical reasoning (Markovits & Barrouillet, 2002). This accords with the posited temporal organization of behavior by working memory (retrospective and prospective) functions (see Fuster, 2000, review by Levy & Farrow, 2002).

On the one hand, the children with ADHD in the present study used strategic novel game responses during the videogame, demonstrating effortful ability to make use of past experience to create novel behaviors. However, on the other hand, processing inefficiency was evident in their reduced videogame flexibility and fewer set switches (e.g., as in the greater number of less efficient prespins instead of the more efficient more demanding backward pauses). Inherent in these inefficiencies, appear to be timing mechanisms (i.e., when to apply a response), involving prospective (sensory) and retrospective (motor) functions of working memory (see Fuster, 2000), as well as the fluid intelligence of executive judgment (i.e., conceptualization, choice and application of the most effective strategy for a specific game hazard).
The ADHD group’s accuracy in speeded motor responses during the target videogame (under low EF task demands) in the present study is in contrast to their slowed, less efficient responses during the adventure videogame (high EF task demands). This suggests that motor problems in ADHD relate to inefficient executive or cognitive processing. This interpretation is based on the ADHD group’s performance throughout the present research, whereby slowed inefficient cognitive processing during tasks was accompanied by slowed, inefficient motor performance (e.g., Stroop color naming, WCST number of trials first category).

Previous studies have reported variable and inefficient timing of motor responses in children with ADHD (Pliszka, Liotti, & Woldorff, 2000; Rubia et al., 1998; Rubia, Taylor, Taylor, & Sergeant, 1999). Although a further study by Rubia and colleagues (2001) found evidence suggesting motor processes involving inhibition, not the timing of motor responses, are impaired in children with ADHD. Other research has also found deficits in motor preparedness and motor anticipatory processes in those with ADHD (Perchet, Revol, Fourneret, Mauguière, & García-Larrea, 2001; Steger, Imhof, Steinhausen, & Brandeis, 2000). Given that working memory may be integral to the motor responses demanded in such studies, it is possible that working memory processes are partly responsible for motor performance deficit in children with ADHD. This interpretation is consistent with current suggestions that the timing of motor responses in the range of milliseconds to many seconds involves either working memory or longer term memory processes (Mangels & Ivry, 2001; Mangels, Ivry, & Shimizu, 1998). However, executive judgment or fluid intelligence also appears essential in the choosing correctly between responses and the correctly judged timing and motor application of the response, according to task demands. Hence, evidence indicates that interactive
deficits involving working memory and fluid intelligence appear reflected in slowed, inefficient motor responses of children with ADHD.

6.2.4 EF Deficit and a Biologically Based Model of ADHD

Disruption of the neural networks subserving goal-directed behavior has been shown to result in attentional lapses in healthy individuals and disorganized behavior in patients with prefrontal lesions (West & Alain, 2000). That study found evidence that attentional lapses, involving selective attention and working memory are transient in nature. Such transient lapses appear evident in the pattern of cognitive performance deficit of the children with ADHD across the tasks and contexts of the present research. This apparent inconsistency in processing deficit in ADHD is consistent with current theory that suggests possible network inefficiencies in the subserving neural transmitter systems (see Oosterlaan & Sergeant, 1996). The transient appearance of performance deficits in children with ADHD may reflect individually distinct levels of deficit. For example, deficit in an individual would only be evident when high cognitive processing demands exceed the individual's processing capacity.

The present study has, nevertheless, identified specific areas of performance deficit that appear consistently exposed under high cognitive and working memory task demands. These findings offer some support for recent hypotheses stemming from neurochemical and neurobiological findings of an inefficient neural transmitter system as a basis of the behavioral and performance problems of those with ADHD (Arnsten, 2000, 2001; Arnsten & Goldman-Rakic, 1998; Arnsten, Steere & Hunt, 1996; Levy & Swanson, 2001; Solanto, 2002). Further, the contrast between the ADHD group's ability to inhibit (prepotent, ongoing responses) during the dynamic, highly stimulating videogames compared to their inhibitory lapses (in sustained
interference control) over time during the WCST and the zoo tasks, offers support for one current model of ADHD (Oosterlaan & Sergeant, 1996; Sergeant, 2000; Sergeant et al, 1999). This model proposes that primary deficits arise from the inefficient activation of biological energy systems subserving the cognitive processes.

Findings from the present study however, question whether EF performance deficit in ADHD is dissociable from hypothesized biological efficiency. For example, if deficits in memory and cognitive processes occur as a result of neuronal inefficiencies, then no consistent pattern in the transient performance deficits might be expected, even under identical task demands and conditions. By contrast, working memory and speeded higher order cognitive processing problems appear to have been involved in all performance deficits across the tasks and settings in the present study. Further, the EF deficit evident during the stimulating videogame play specifically raises the possibility that processing deficit in children with ADHD may be dissociable from inefficiencies in underlying biological substrates.

Alternatively however, biological inefficiencies would also be logically manifest as performance problems at times of processing overload (even during optimally stimulating task contexts such as videogames). This is consistent with the slowed and inefficient performance exhibited by the children with ADHD under high simultaneous demands for working memory and speeded cognitive processing, across the tasks and contexts of the present research.

6.3 Motivation and Best Performance: EF Deficit Still Evident in ADHD

The present study examined the role that motivation plays in the cognitive performance of children with ADHD. Specifically, whether motivational bias is involved in performance problems involving response inhibition (see Nigg, 2001).
Findings from this study suggest that the role played by motivation is secondary to performance problems exhibited by children with ADHD. Despite motivating tasks and contexts, working memory, inhibitory and motor control deficits were still evident in the performance of children with ADHD. Deficits in performance of the children with ADHD across the adventure videogame and zoo contexts, suggest that levels of motivation cannot eradicate processing deficit in those with ADHD. This was particularly notable, during the intrinsically motivating videogame tasks, whereby the children with ADHD revealed poorer mental flexibility and slower, less efficient motor performance in the inefficient use of strategic responses. However, importantly, the children with ADHD consistently attended to the tasks and made effortful strategic attempts to succeed during goal-directed performance.

Motivation may, therefore, temporarily assist performance by providing arousal or activation of available resources to maintain optimal attentional focus (Casey, Durston, & Fossella, 2001; Koepp et al., 1998; Levy & Swanson, 2001; Nigg, 2001). Moreover, recent evidence indicates that emotion and higher order cognition processes are integrated and contribute equally to the control of thought and behavior (Gray, Braver, & Raichle, 2002). Motivation, therefore, takes its place as one of the various salient contingencies that may improve the task performance of children with ADHD. However, as this study demonstrates, it does not appear sufficient to eradicate higher order cognitive processing difficulty and working memory deficit in those with ADHD.

6.4 Limitations of the Research

The ecologically valid context of videogame play provides an appropriate and motivating real-life medium for assessing the cognitive performance of children with ADHD. However, the innovative nature of this testing medium and the
limitations inherent to the present research determine that this study should be considered as exploratory.

One limitation, both conceptual and methodological in nature, is that the children's responses were interpreted in view of current empirical theory on cognition, EF, and ADHD, and it is acknowledged that other interpretations may be possible. Specific actions during the videogame and zoo tasks chosen to reflect certain aspects of EF were necessarily arbitrary. These actions may reflect more than one EF, and any specific EF may be better measured by another action.

A second limitation is that there are not clear measures of every EF (or aspect of each EF) in every task or context in the present research. For example, measures of reconstitution were confined to the videogame context, while context and task demands determined what dominant aspect(s) of behavioral inhibition was measured: whether prepotent (videogames), ongoing (WCST), or interference control (Stroop Interference condition, zoo activities). Similarly, the type of working memory processes engaged was dependent on the type of task demands and context. Moreover, in both laboratory and real-life tasks it is not always possible to clearly distinguish deficits in one EF from that in other EFs. For example, the integration of behavioral inhibition, working memory and fluid intelligence is evident in deficits during the WCST and zoo. While integrated EF processes also appear evident in slowed Stroop color naming (slowed or inefficient cognitive processing/working memory), and in the prespins and backward pauses indexing reconstitution during the adventure videogame (behavioral inhibition, working memory, speeded cognitive processing, and motor control).

A third limitation concerns the use of outcome measures in the real-life contexts for which there are no data on psychometric validity. The coder, who
manually scored the videogame and zoo performance was not blind to group status, and as reliability was only coded on 10% of the sample on scoring from the videogame but not the zoo, this raises the possibility of some bias. One of the obstacles to continued use of commercially available videogames (as used in the present research) is that they do not afford precise control over the game or task parameters, nor do they permit direct measurement of performance (e.g., speed and movement patterns of the character, error types, number of challenges successfully completed, and strategy use). This indicates the need to develop innovative platforms based on videogame technology that permit precise quantification of game performance.

Fourth, the number and type of laboratory tasks (Stroop, WCST) investigated in the research were necessarily limited. However, these measures were specifically selected because previous research suggests that: (a) they measure behavioral inhibition and EF, (b) children with ADHD perform more poorly on them compared to their normally developing peers (albeit with inconsistent findings); and (c) that findings from studies using these measures with children provide the basis for much of the current theoretical knowledge on ADHD. Although the present findings indicate that these measures do not discriminate between children with ADHD and their normally developing peers in terms of behavioral inhibition, they do appear to distinguish between the children in terms of other EFs (e.g., working memory, and speeded higher or abstract cognitive processing). This finding importantly highlights a problem with many standard neuropsychological measures currently used to examine EF. Traditional neuropsychological measures may detect differences in performance, but not always the underlying processes that give rise to performance deficits. The stop signal task (Logan, 1994), which is more recently derived from the
cognitive neurosciences, indexes and measures the inhibition of an ongoing response in a way analogous to the index measure in the videogames (pauses). Thus, the stop signal task may provide a stronger comparison for the prepotent and ongoing aspects of inhibition evident during videogame play. Hence, future research needs to consider not only the ecological validity of measures, but also the use of a variety of measures and paradigms from across the broad spectrum of the research disciplines in attempting to map performance to underlying complex cognitive processes, and subserving neural networks.

Fifth, only school-aged boys without comorbidity were included in this study and so it is not known if these findings are generalizable to girls and adolescents. Further, the sample was somewhat atypical being high functioning so the findings may not be generalizable to a general ADHD or a clinical ADHD population. The research may also have had lack of power to detect differences between the ADHD subtypes. Further research involving larger sample size and contrasting clinical groups will be necessary in order to substantiate any findings from this research.

6.5 Implications for Current Theory of ADHD

The primacy and the source of the cognitive problems demonstrated by children with ADHD during the present research remain speculative. Problems with prepotent and ongoing inhibition (possibly subserved by working memory) may have been sufficiently relieved in the videogame context. If so, it is unclear whether previously reported inhibitory problems in those with ADHD primarily reflect inefficiencies in early perceptual and identification processes (Perchet et al., 2001), memory retrieval processes (Tipper, 2001), those involving neural activation (McLeod & McDonald, 2000), or a point of integration between these processes. It may also be possible that these inefficiencies in turn stem from a single
dysfunctional neurobiological source (see reviews by Levy & Swanson, 2001; Solanto, 2002).

The findings of the present research raise many critical questions and issues that should provoke and guide future research. Of these, perhaps the most critical is the challenge made to the current scientifically accepted assumption that children’s impaired performance during laboratory measures is a benchmark for their impairment during real-life tasks and contexts. Given the present findings, this assumption appears not always correct and should be further tested by similar studies that examine children’s task performance over a broad range of cognitive tasks and differing contexts.

6.5.1 Heterogeneity in ADHD

Heterogeneity appears evident in ADHD along three distinct categories or levels: (a) at group level in that not all children with ADHD exhibit the same deficits, (b) at sub-type level, and (c) at sample level (e.g., community versus clinic samples). Heterogeneity poses a major obstacle to investigations aiming to delineate primary deficits in ADHD, and in turn, questions the searching for homogeneity in this disorder where it may not exist - at least not as currently conceptualized.

6.5.1.1 Heterogeneity at Group Level

At group level, the continuum nature and heterogeneity of deficit demonstrated in those with ADHD are reflected clearly in the highly functioning sample of children with ADHD of the present research. This is despite the efforts taken to ensure as homogenous an ADHD sample as possible. Although performance deficit distinguished the ADHD group from a normally developing peer group, not all of the children with ADHD showed the same degree of cognitive processing deficit or working memory failure. For example during the videogame, those
children from the ADHD group able to conceptualize and execute the more sophisticated and effective strategy of backward pauses, used this strategy more than their equivalent number among the controls. Similarly not all of the children with ADHD made more deviations at the zoo, demonstrated slower color naming in the Stroop, or had problems during the WCST. It was beyond the scope of the present research to determine the pattern of deficits distinct to each child.

6.5.1.2 Heterogeneity at Subtype Level

Difference in deficit between the subtypes ADHD-C and ADHD-I was not detected in this study, which suggests common degrees and types of cognitive deficits between the two subtypes (ADHD-C and ADHD-I). On the one hand, this study may have lacked power to detect possibly existing differences. Also, the type of tests used (predominantly requiring nonverbal performance) may not have been sensitive to other deficits more dependent on verbal abilities. On the other hand, it is important to recognize that any comparison of cognitive abilities between the ADHD-I and ADHD-C subtypes carries the implicit assumptions that: (a) the cognitive deficits will be associated with the hyperactivity/impulsivity dimension, and/or that (b) the inattention problems manifest in ADHD-I are fundamentally different from those manifest in ADHD-C, as proposed by Barkley (1997). Conversely, one recent family based twin study (Willcutt, Pennington & DeFries, 2000) indicates that the hyperactivity of the ADHD-H subtype differs from that exhibited by the ADHD-C subtype. Moreover, previous research findings have indicated that the subtypes ADHD-I and ADHD-C are more alike than different in EF deficit (e.g., Houghton et al., 1999), with no difference in cognitive performance and with deficits associated with the dimension of inattention not hyperactivity/impulsivity (Chhabildas et al., 2001).
The two main behavioral symptom clusters of inattention currently used to define ADHD (i.e., hyperactive/impulsive as in ADHD-C, and disorganized as in ADHD-I, APA, 1994; see Nigg, 2000, 2001), may then be different behavioral manifestations of the same area and type of deficit. These salient disparate attentional behavioral symptoms may therefore be more evident of individually distinct biopsychosocial factors, than evidence of different types of deficit (White, 1999).

6.5.1.3 Heterogeneity at Sample Level

It would be expected that behavioral inhibition performance deficit, as indeed any performance deficit exhibited by such an ADHD sample as the present, would be less severe (e.g., as in symptoms and comorbidity) than that exhibited by certain clinical samples. For example, the present sample was recruited through a general pediatric clinic rather than through a specialty ADHD or psychiatric clinic, which typically see more complicated cases. The findings of the present research are consistent with those of a previous study that found no evidence of inhibitory failure in a community sample of children with ADHD on the stop task (Kuntsi et al., 2001). This further supports hypotheses of the continuum nature of ADHD symptoms, indicating the importance of not confusing the level of deficit evidenced in clinical samples with the level of deficit in community samples of children with ADHD. Indeed, the inconsistency among findings from all research with children with ADHD (whether from clinical or community samples), questions whether a benchmark of deficit is at all possible, or feasible, given the heterogeneity of the disorder.

Findings, therefore, in support of the well-documented heterogeneity of ADHD symptoms, prompt the question of whether one looks to find homogeneity in
this disorder where it may not exist? If, for example, the cognitive, affective and behavioral symptoms associated with ADHD do in fact stem from biological imbalance in an individual, then cognitive deficit would logically be manifest according to each individual's (genetically and environmentally influenced) cognitive characteristics. Therefore, homogeneity of cognitive deficit demonstrated by any group of such individuals would be dependent on similarly shared cognitive features, and could be expected to be evident only to a degree.

A large body of empirical literature traces concurrent investigative attempts to unravel the etiologies of other psychiatric disorders (often with strikingly similar symptoms as ADHD) such as autism, and schizophrenia. Much can be learnt, however, from the theoretical advances and perspectives of such research. Particularly, the realization that symptom heterogeneity may be better examined in terms of a disorder syndrome, rather than of a disorder entity (Braver, Barch, & Cohen, 1999; Carpenter, Arango, Buchanen, & Kirkpatrick, 1999). Hence, rather than looking for a single etiological cause or source of the disorder, it may be more effective to examine the syndrome from a multi-source perspective (Tannock, 1998).

Much evidence already exists across the broad areas of investigative research into ADHD, indicating that many risk factors are influential in the incidence of the disorder in children. The sum of this evidence appears to point to trauma or inefficiency at a biological level in an individual (e.g., see Werry, 2001), although the extent to which any one risk factor alone (e.g., genetic makeup) is able to explain a biological state distinct to ADHD is as yet questionable. This, in turn, raises the question as to whether a common conceptualization and taxonomy of ADHD is possible, unless it is first recognized that ADHD is a syndrome of commonly occurring disorders or difficulties instead of a disorder entity (Tannock, 1998).
6.5.2 EF in Real-Life Contexts: Dynamics of Children’s Cognitive Performance

The present investigation during real-life tasks revealed evidence that may help to explain the dynamic nature of cognitive performance in children. These dynamics are not revealed during static laboratory based neuropsychological measures. The nature of the transient performance problems in children with ADHD requires contrasting cognitive levels of task demand, and contrasting context contingencies to be revealed. Thus, testing for best performance emphasizes the importance of a simultaneously broad though detailed research focus in the study of ADHD. The use of a variety of measures, tasks and contexts is essential in order to find any patterns in performance, given the heterogeneity of the disorder.

The susceptibility demonstrated by children with ADHD to differing levels of working memory load in task and context during the present research, makes it essential that future research further test contextual effects on performance. Importantly, further examination of the dynamic cognitive processes involved in children’s performance during real-life tasks and contexts may reveal other facets of inhibition, working memory, and integrated processes, not yet identified.

The interaction between developmental level, salient task and context contingencies, and task demands is inherent in these children’s everyday cognitive performance. So it is during these tasks and contexts that performance needs to be examined. Accurate assessment of children’s performance level in their daily cognitive functioning is beyond the measurement scope of current laboratory neuropsychological tasks of pre-designated narrow focus and static nature (Tannock, 1998). It is only by building a thorough global account of children’s performances across a range of cognitively demanding tasks and contexts and a broad range of
investigative disciplines: that greater understanding of the cognitive underpinnings of ADHD may be achieved.

6.6 Implications for the Education of Children with ADHD

An important finding of the present research was that the children with ADHD did demonstrate cognitive deficits in everyday contexts. Hence, cognitive problems in these children are not restricted to performance during laboratory based tasks in psychology clinics and research offices, but would be manifest in the course of everyday life, including the classroom. This highlights an urgent need to reconceptualize ADHD from being a behavioral disorder to a more accurately described conceptualization, such as a syndrome of behavioral problems arising from a variety of cognitive, particularly EF, difficulties (Tannock, 2000).

6.6.1 Improving the Efficacy of Self-Help Attempts by Children with ADHD

The present research revealed that children with ADHD actively generated attempts to improve performance during real-life tasks. For example, self-generated actions in the videogame (prespins, backward pauses) and zoo (deviations) and on-task self-verbalizations appeared to reflect active and effortful (albeit inefficient) attempts at strategic engagement during performance. This indicates that children with ADHD make conscious and deliberate attempts to improve their task performance. Also, there is other evidence that those with ADHD attempt to use available resources to improve cognitive efficiency (e.g., finger counting, self-talk, use of nicotine). This is important, given current belief that (a) conscious awareness in the planning of cognitive and motor responding may facilitate activation and utilization of the most effective processing areas of the brain (see Baars, 2002; Stephen et al., 2002); (b) that working memory has capacity limited direct access,
and requires focused attention (Oberauer, 2002); and (c) there are individual limits to the capacity of directly accessed working memory processes (Ando et al., 2001).

Although children with ADHD actively attempt to improve their performance, they appear to use less efficient behavioral and meta-cognitive strategies. It is possible that their lack of knowledge and experience in planning strategies results in turn in their recruitment of less effective neural networks. Teaching these children how to deliberately deploy simple meta-cognitive skills may enable them to develop the use of more effective cognitive and neural processes.

Recent evidence suggesting that: (a) working memory span is not solely dependent on capacity, but may be increased by prior learning (Lustig, & Hasher, 2002), (b) training and practice in logical reasoning may improve higher order cognitive and working memory processes (Pfeiffer & Czech, 2002), and (c) that conscious and deliberate use of strategy assisted working memory and improved task performance in patients with mild traumatic brain injury (Cicerone, 2002), invites further examination of the possibility of teaching children with ADHD more efficient cognitive strategies. It has been suggested that the neural connections in working memory processes are formed and developed on an accumulative basis, requiring associative learning (Jani & Levine, 2000).

Teaching children with ADHD deliberate use of efficient organizational strategies may stimulate more self-cued activation of more efficient neural networks, and thus less vulnerability to contextual contingencies. The learning and use of these strategies could be supplemented by the associated use of efficient and non-invasive, mechanical aids and memory prompts that are motivating for children to use. Mechanical salient reminders and time prompters were found effective with a child with ADHD in a study by Fraser, Belzner, & Conte (1992). Such suggested
mechanical aids, similar to calculators, could be modeled on the small portable, 
hand-held computer games that are popular with children. It is recognized that any 
intervention is ideally tailored to the needs of an individual. However, similar to a 
common calculator, such mechanical aids may be able to assist the cognitive 
performance of vast numbers of individuals of diverse cognitive ability. Importantly, 
any increase in a child’s sense of self-efficacy, and hence self-esteem, will have all 
the recognized attendant benefits on the individual’s affective and cognitive realms.

There is also some evidence that teaching inductive reasoning strategies 
improves fluid intelligence (Klauer, Willmes, & Phye, 2002). Improved strategy 
selection in problem solving in healthy adults has been shown to rely on either an 
individual’s inductive reasoning ability or the giving of explicit instructions (Schunn, 
Lovett & Reder, 2001). That study found evidence suggesting that the explicit 
awareness of an individual is influenced by conscious experiential learning, and may 
play a role, independent of working memory capacity, in improved strategy 
selection. Thus, the teaching and fostered practice of simple, organizational and 
problem solving strategies may encourage regular, and hence over time, automatic 
activation of more appropriate brain neural pathways in children with ADHD. These 
skills may be taught using resources that are highly motivating to children such as 
computer games (Amory, Naicker, Vincent, & Adams, 1999). Such games appeal to 
all children not just those with ADHD, and it has been found that such games use 
and promote inductive reasoning and cognitive skills with some degree of transfer 
(see Greenfield & Cocking, 1996). Educational games, modeled on video games, can 
be structured according to differing cognitive, age, and gender requirements. 
Educators are desperately in need of interventions that are effective for all students 
(Gersten, Chard, & Baker, 2000), especially given the recent emphasis on inclusive
education. Educative videogames can be readily and conveniently implemented (computers are prevalent in most schools) as part of the school curriculum, with supervised home use directed as a motivating supplement or alternative to homework.

6.6.2 Cognitive-Behavioral Interventions: Teaching Children Deliberate Use of Cognitive Strategies

The teaching of self-management strategies in planned and organized approaches to problem solving may increase the effectiveness of these children’s own inefficient attempts at self-help. The teaching approach used is crucial, with short, dynamic, highly structured and cued lessons essential. This approach could learn much from the platformed, inductive learning structure of the adventure videogame itself. Such games provide a continuation of visually graphic cues at points immediately relevant to performance, and immediate feedback over the duration of the learning experience. Importantly the children are actively engaged and instrumental in their own learning.

Almost every child in the present research responded to the question of why they liked playing adventure videogames with an answer that emphasized the importance of their being actively engaged, and feeling effective. The inductive learning nature of such games are designed to appeal to, and motivate, a vast range of individuals with differing cognitive abilities from unpracticed beginner players to experienced highly skilled players. Current pedagogical approaches in education emphasize the effectiveness of students’ active engagement in the learning process (Barry & King, 1999). Importantly, although adventure videogame contingencies offer continued feedback and rewards encouraging progress, the player sets his own pace and is active in self-learning. This is important when one considers the wide
range of distractors present in the populated context of classroom learning. For example, there is some evidence that eye contact and the visual processing of an instructor's face hinders children's processing of visuospatial information (Doherty-Sneddon, Bonner, & Bruce, 2001). In addition, given that computer assisted learning has shown some evidence of benefit to children with autism (Williams, Wright, Callaghan, & Coughlan, 2002), this resource invites further examination as a possibly valid instructional resource for children with attentional difficulties.

The findings of the present research lend some support to the existing literature on the benefits of motivating, stimulating, structured, and cued task contingencies. However, a multimodal approach geared to each individual's specific needs appears currently to be the most efficacious approach to treatment. Such an approach could combine optimized task contingencies, guided practice in simple meta-cognitive skills and strategies, and judicious use of medication.

The development of more effective interventions for children with ADHD necessitates further such child-oriented research as is described here. Developmental and contextual influences and the dynamic nature of cognitive task performance are important considerations in the assessment of all children (see Tannock, 1998). In particular, developmental influence on children's ability in comparison to the nature and demands of assessment tasks is of importance in future studies with children with ADHD (Hale, Bronick, & Fry, 1997; Rabinowitz, Howe, & Saunders, 2002; Tannock, 1998).
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APPENDIX A

DSM-IV Diagnostic Criteria for Attention-Deficit/Hyperactivity Disorder

A. Either (1) or (2):

(1) six (or more) of the following symptoms of **inattention** have persisted for at least 6 months to a degree that is maladaptive and inconsistent with developmental level:

**Inattention**
(a) often fails to give close attention to details or makes careless mistakes in schoolwork, work, or other activities
(b) often has difficulty sustaining attention in tasks or play activities
(c) often does not seem to listen when spoken to directly
(d) often does not follow through on instructions and fails to finish schoolwork, chores, or duties in the workplace (not due to oppositional behavior or failure to understand instructions)
(e) often has difficulty organizing tasks and activities
(f) often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (such as schoolwork or homework)
(g) often loses things necessary for tasks or activities (e.g., toys, school assignments, pencils, books, or tools)
(h) is often easily distracted by extraneous stimuli
(i) is often forgetful in daily activities.

(2) six (or more) of the following symptoms of **hyperactivity-impulsivity** have persisted for at least 6 months to a degree that is maladaptive and inconsistent with developmental level:

**Hyperactivity**
(a) often fidgets with hands or feet or squirms in seat
(b) often leaves seat in classroom or in other situations in which remaining seated is expected
(c) often runs about or climbs excessively in situations in which it is inappropriate (in adolescents or adults, may be limited to subjective feelings of restlessness)
(d) often has difficulty playing or engaging in leisure activities quietly
(e) is often "on the go" or often acts as if "driven by a motor"
(f) often talks excessively
Appendix A continued

**Impulsivity**
(g) often blurts out answers before questions have been completed
(h) often has difficulty awaiting turn
(i) often interrupts or intrudes on others (e.g., butts into conversations or games)

B. Some hyperactive-impulsive or inattentive symptoms that caused impairment were present before age 7 years.

C. Some impairment from the symptoms is present in two or more settings (e.g., at school [or work] and at home).

D. There must be clear evidence of clinically significant impairment in social, academic, or occupational functioning.

E. The symptoms do not occur exclusively during the course of a Pervasive Developmental Disorder, Schizophrenia, or other Psychotic Disorder, and are not better accounted for by another mental disorder (e.g., Mood Disorder, Anxiety Disorder, Dissociative Disorder, or a Personality Disorder).

**Code** based on type:

314.01 **Attention-Deficit/Hyperactivity Disorder, Combined Type:** if both Criteria A1 and A2 are met for the past 6 months

314.00 **Attention-Deficit/Hyperactivity Disorder, Predominantly Inattentive Type:** if Criterion A1 is met but Criterion A2 is not met for the past 6 months.

314.01 **Attention-Deficit/Hyperactivity Disorder, Predominantly Hyperactive-Impulsive Type:** if Criterion A2 is met but Criterion A1 is not met for the past 6 months.

**Coding note:** For individuals (especially adolescents and adults) who currently have symptoms that no longer meet full criteria, "In Partial Remission" should be specified.

*Source: DSM-IV, APA (1994)*
PARTICIPANT INSTRUCTIONS: VIDEOGAME TASKS
The examiner had previously established the participant’s videogame play proficiency. Accordingly, novice players or players who had not previously used the Sony handheld control panel were given instructions and several minutes practice until they demonstrated proficiency in using the directional buttons and the button for “firing” required for the target game. This procedure was repeated prior to administration of the adventure videogame to ensure that all players demonstrated proficiency in the appropriate use of the run, jump and spin buttons.

Target Videogame (Point Blank™)
“What I want you to do now is to play four target games. The targets will appear on the (TV) screen and they are round black and white circles: bullseye targets. You only get a short time to hit as many of them as you can, as they don’t stay on the (TV) screen for very long. The game rule is that you must make every shot count. You are not allowed to waste shots. (The game won’t let you score if you use too many shots per target.)”

Adventure Videogame (Crash Bandicoot™)
“Now I want you to play Crash Bandicoot. But I want you to play by special game rules. After you play the game by my rules, then you can play it your way for a while.”

Task One: “What I want you to do now is take Crash from the starting point here (points to the path position on the screen where Crash stands) as quickly as you can as far down the path as you can to the first checkpoint. The game rule is that Crash must not touch any boxes. When you get him to the checkpoint, stop there. Try to reach the checkpoint but don’t worry if you don’t, just take him quickly and as far along the path as you can. You have three lives so you get three goes, and we’ll use your best one (where you get the furthest and the quickest) out of the three for scoring.”

Task Two
“This time, I want you to take Crash as far down the path to the first checkpoint as you can, as quickly as you can. But this time, Crash has to spin open any boxes marked with an arrow, like this one (points to the arrow box visible on the screen). He must spin them open, not jump on them, and he is not to touch any other boxes. You have three lives so you get three goes, and we’ll use your best one (where you get the furthest and the quickest) out of the three for scoring.”

Task Three: Directions as per Task One. (Examiner turns distractor on at start of game play)

Task Four: Directions as per Task Two. (Examiner turns distractor on at start of game play)
APPENDIX C

PARTICIPANT INSTRUCTIONS: ZOO TASKS

The following verbal instructions were given to each child immediately prior to starting the relevant route.

"Do you remember when we played Crash Bandicoot? What we are going to do today is a bit like what Crash Bandicoot does in that videogame we played. Like Crash, I want you to go from a starting place to different checkpoints, and back to the starting place as quickly as you can. Walk as quickly as you can, but it is not a race and you are not allowed to run."

Complex Route

"Go from this starting place (points to the ground where standing)"
Appendix C continued

into the Reptile House (*points to the Reptile House which is visible and also shows photo*) to the far end where the big skin is up on the wall (*shows photo of the large crocodile skin on wall*).

When you get there I want you to touch the rail (*points to the rail in Photograph*). That is the first checkpoint. Then come back out and go into the Wetlands (*points*) and go past the penguins (*points in the direction and then shows photo of glass enclave with penguins visible swimming within*)
Appendix C continued

to the far end of the Wetlands to the Crocodile House (waves arm in an arc indicating the general direction of the path). Go into the Crocodile House and have a look at the big crocodile (shows photo of close profile of large crocodile inside glass enclave), that is the second checkpoint, and then come straight back to this starting place.

Remember to walk normally, but go as quickly as you can. I'll be following behind you with the camera but just ignore me. Do you know what to do? (The Examiner repeats instructions, until the boy says he knows what to do. The Examiner then tells the boy to start.)
Appendix C continued

Simple Route
“What I’d like you to do now is to go as quickly as you can from this Starting Place (points to the ground where standing) to the end of this path (points to path) to the checkpoint which is this bird sign (shows relevant photo).

Touch the bird sign and then stop there. Don’t forget, don’t run it is not a race, but walk as quickly as you can. I’ll be following behind you with the camera but just ignore me. OK... Do you know what to do?” (When the boy says he knows what to do, the examiner tells him to start.)