

**Response Inhibition, Working Memory, Attention, and Concept of Time
as Executive Functions in boys diagnosed with ADHD**

by

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Abstract

The purpose of the present research was to examine the current conceptualisation(s) of Attention-Deficit/Hyperactivity Disorder (ADHD), and to further contribute to the development of theory about the disorder, by way of a systematic empirical investigation. Initially, a comprehensive review of the literature was undertaken which served to establish the theoretical framework within which the subsequent research could proceed. Those issues which arose from the literature that required further clarification were explored in more detail in a series of semi-structured interviews with six leading international authorities in the field of ADHD research. The results obtained revealed that the current understanding(s) of ADHD appears to rely largely on the prevailing theoretical models of the disorder, and in particular, Barkley's (1997a) Unifying Theory of ADHD. In addition, the interview participants posited that four executive impairments are demonstrated by children with ADHD, namely, impairments in: response inhibition, verbal and non-verbal working memory, selective and sustained attention, and concept of time.

The present research set out to systematically examine the nature of these predicted impairments with ADHD ($n = 68$) and non-ADHD Control boys ($n = 67$). All of the ADHD participants had been diagnosed by a consultant paediatrician as meeting DSM-IV criteria for ADHD, and were selected because they had not been identified with any diagnosed comorbidity. In order to address other potentially confounding factors, the ADHD participants received no stimulant medication for a minimum period of 20 hours prior to testing, and the ADHD and Control participants were individually matched on Age. However, satisfactory Age-matching (i.e., to within three months) could only be achieved at the expense of a reduced sample size, and the matched sample

consisted of 50 ADHD boys (14 ADHD Predominantly Inattentive Type and 36 ADHD Combined Type) and 50 Control boys. In addition, the present research sought to address the issue of poor construct validity, by employing instrumentation specifically designed to be sensitive to the predicted impairments of boys with ADHD.

The data obtained were examined using multivariate analyses of variance and revealed that the ADHD boys were significantly impaired on measures of verbal memory, attentional switching, and time reproduction, relative to individually Age-matched Control boys. However, no significant differences were observed on the measures of response inhibition, non-verbal memory, or selective attention. In addition, no significant differences were observed according to ADHD subtype, although this might be attributable to the limited size ($n = 14$) of the ADHD-PI sample, and it is suggested that this result be interpreted with caution. However, the finding of slower overall reaction times, and modality-specific impairments in verbal memory and visual time reproduction tasks, provide clear directions for further research.

In conclusion the present study has confirmed the executive impairments that were identified in Study One, and has provided evidence pertaining to the suitability of the instrumentation.

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Declaration

In accordance with the regulations for presenting theses and other work for higher degrees, I hereby declare that this thesis is entirely my own work and that it has not been submitted for a degree at this or any other university.

John West

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Note: This thesis has been formatted in accordance with modified American Psychological Association (1995) publication guidelines.

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CHAPTER ONE

Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is the current diagnostic label for the clinical syndrome that is now recognised as one of the most common neurobiological/developmental disorders of childhood. Children with ADHD present with a persistent pattern of hyperactivity-impulsivity and/or inattention "that is more frequent and severe than is typically observed in individuals at a comparable level of development" (American Psychiatric Association [APA], 1994, p. 78). Although estimates of its prevalence vary considerably, ADHD is thought to affect between 3% and 9% of the school-age population, and approximately three times as many boys as girls (American Psychiatric Association, APA, 1994, 2000; Mental Health Division of Western Australia, 2000; National Institute of Health, 2000).

Children with ADHD are at an increased risk of a range of adverse outcomes, including low academic achievement, poor school performance, grade retention, suspension, and expulsion (Barkley, 1997a, 2001a). In addition, as many as 50% to 80% of children with ADHD will carry the symptoms into adolescence, and between 30% and 50% into adulthood. Where ADHD persists into adolescence and adulthood, it is associated with greater risk for poor peer and family relations, anxiety, depression, aggression, conduct problems, delinquency, early substance experimentation and substance abuse, driving accidents and speeding violations, as well as difficulties in adult social relationships, marriage, and employment (Barkley, 1997a, 2001a).

Furthermore, ADHD rarely occurs in isolation, with evidence from research indicating that as many as 50% to 80% of children with ADHD also meet the

diagnostic criteria for other disorders (Tannock, 1998). The presence of comorbidity (i.e., two or more disorders which occur at one point in time; Clarkin & Kendall, 1992) can complicate the assessment, diagnosis, and treatment of ADHD, and may result in increasingly adverse outcomes. A recent study by Langsford (1999) found that ADHD was the most comorbid of the 20 school-age disorders most commonly referred to school psychologists. While the most frequent comorbidity is with other disruptive behaviour disorders (i.e., Oppositional Defiant Disorder and Conduct Disorder), there is also evidence to suggest that ADHD children are at an increased risk of mood disorders, anxiety disorders, and specific learning disabilities, compared to non-ADHD controls (Langsford, 1999; Tannock, 1998).

Despite the considerable amount of research has been conducted on ADHD since it was first described as a clinical syndrome by Still in 1902, researchers and clinicians continue to challenge the conceptualisation of ADHD (Tannock, 1998). Thus while ADHD is one of the most extensively researched syndromes of child psychopathology, it remains one of the most controversial. While the key characteristics of ADHD have remained relatively constant, the conceptualisation of the disorder has continued to evolve as new research findings have challenged the prevailing construct (Tannock, 1998). Thus, over the years children with ADHD have been given any number of labels, suggesting that their disorder is the result of: a deficit in moral control, biological causes (such as minimal brain damage/dysfunction), hyperactivity and poor impulse control, a deficit in attention, and more recently, impaired response inhibition.

The evolving conceptualisation of ADHD

Until recently, most of the research conducted on ADHD since 1994 has relied on the conceptualisation that was established with the publication of the DSM-IV (i.e., the fourth edition of the Diagnostic and Statistical Manual of Mental Disorders; APA, 1994; Text Revision, APA, 2000). While there continues to be some disagreement among researchers as to the exact nature of ADHD, the DSM-IV arguably represents the most widely used international diagnostic standard. Thus the DSM-IV diagnostic criteria (presented in Table 1 of the following chapter) were adopted as definitive for the purposes of the present research.

The DSM-IV conceptualises ADHD as a multiaxial disorder which comprises an inattentive and a hyperactive-impulsive symptom dimension (Lahey et al., 1994). Although most individuals with ADHD display symptoms of both inattention and hyperactivity-impulsivity, there are some individuals in whom one or the other pattern is predominant. Thus the DSM-IV delineates three behavioural subtypes of ADHD: ADHD, Predominantly Inattentive Type (ADHD-PI); ADHD, Predominantly Hyperactive-Impulsive Type (ADHD-HI); and ADHD, Combined Type (ADHD-CT).

In recent years, however, the limitations of the DSM-IV criteria have become increasingly apparent. In 1997, Barkley suggested that a new theory of ADHD was needed because the existing model (i.e., based on the DSM-IV) was purely descriptive and largely atheoretical, and provided little direction for research or treatment (Barkley, 1997a). Instead, Barkley (1997a) argued that a theory of ADHD should serve as a scientific tool that could explain the findings of previous research and make explicit predictions about new phenomena that

might be observed and tested, thus advancing the understanding of ADHD. Furthermore, Barkley (1997a) posited that a theory of ADHD should link the disorder to an abnormality in normal human development, and advance a range of specific and testable hypotheses that will give rise to further research and provide a means of falsification.

Barkley (1997a) subsequently drew together the earlier work of Quay, Bronowski's theory of human language, and Fuster's theory of prefrontal functions, to construct a Unifying Theory of ADHD. In this Barkley argued that the primary impairment in ADHD was one of response inhibition, and that this in turn resulted in secondary impairments in four executive functions (i.e., those self-directed behaviours that are responsible for self-control). These executive functions were non-verbal working memory, verbal working memory, the self-regulation of emotion, and reconstitution (i.e., behavioural analysis and synthesis). According to Barkley, the successive chain of impairments in response inhibition and the executive functions give the appearance of poor sustained attention in children with ADHD, when in fact the disorder actually represents a reduction of the control of behaviour by internally represented information (i.e., self-control).

A range of other theories have, over the years, been proposed in an attempt to best account for the observed manifestations of ADHD. Zentall's (1985) optimal stimulation theory, Sergeant's (2000) use of the cognitive-energetic model developed by Sanders (1983), and Sonuga-Barke, Saxton and Hall's (1998) notion of delay aversion in ADHD children, are among the most prominent. However few, if any, of these theories are as comprehensive or testable as the model proposed by Barkley (1997a). Whilst most of these models have sought a single unitary cause - whether biological, neurological, or genetic - which now

appears increasingly unlikely (Tannock, 1998), they have also served to provide a focus for research.

The limitations of previous research

The recent development of theories that focus on the component problems which underlie ADHD represents a significant advance in the field (Tannock, 1998). Previously, most of the research conducted on the nature of ADHD was exploratory and descriptive, rather than theoretically motivated (Taylor, 1996). In addition, the existing research in this area has been weakened by the incessant changes in the conceptualisation of ADHD, and hampered by a number of confounding factors. That few studies have attempted to control for these factors might help to explain the inconsistent findings across studies (Tannock, 1998). These factors include:

Limited sample sizes

Many previous studies of children with ADHD have been conducted using small sample sizes, which limits their statistical power and hence the generalisability of their findings. The reliance on small samples also demands that the findings of such studies be interpreted with caution until the results can be replicated with larger samples. Due to the over-representation of boys among the ADHD population, few studies have been conducted involving girls (e.g., Houghton et al., 1999; Seidman, Biederman, Faraone, Weber, & Oullette, 1997).

In addition, few studies have included sufficient numbers of ADHD-PI children to permit comparisons to be drawn between the different ADHD subtypes, despite evidence to suggest that the developmental course of the hyperactive-

impulsive and inattentive symptom clusters might differ (e.g., Lahey et al., 1994). Yet recent genetic research (Willcutt, Pennington, & DeFries, 1999) has suggested that the two ADHD symptom clusters might be etiologically distinct. In a study of 373 twins, selected because one twin showed evidence of learning difficulties, Willcutt et al. (1999) found that whilst extreme inattention was highly heritable regardless of the presence of hyperactivity-impulsivity, the same was not true for hyperactivity-impulsivity in the absence of inattention. This result appears to be in line with Barkley's (1997a) suggestion that the ADHD-PI might represent a different disorder entirely, with a qualitatively different impairment in attention. However, since the risks associated with ADHD are generally thought to reside with the hyperactive-impulsive symptom cluster (Tannock, 1998), a number of current theories (e.g., Barkley, 1997a) have focused on this to the exclusion of the ADHD-PI subtype.

Inadequate controls

The failure to adequately control for a number of factors that relate to the samples of ADHD and control children being studied may also have served to confound the results of earlier research. These include the use of now superseded diagnostic criteria (such as DSM-III or DSM-III-R), an insufficient number of control children, or the use of poorly matched control groups. Although Barkley (1997b) argued that matching the ADHD and control groups on IQ may be inappropriate since slightly depressed IQ might be characteristic of the ADHD population, there is no similar argument against matching on age. Indeed, given that the DSM-IV (APA, 1994; Text Revision, APA, 2000) requires ADHD symptoms to be of "a degree that is maladaptive and inconsistent with developmental level" (p. 83 and p. 92 respectively), the use of appropriate age controls would appear essential in this and subsequent research.

In addition, while stimulant medication has been found to improve aspects of executive and attentional functioning (Barkley, 1990), thereby giving rise to a potential medication effect (Houghton et al., 1999), many previous studies have failed to adequately control for the use of stimulant medication (Barkley, 1997b). For example, in a naturalistic study of neuropsychological functioning in 118 boys with ADHD, Seidman, Biederman, Faraone, Weber, and Ouellette (1997) reported that 68% of the ADHD participants were medicated at the time of testing.

Comorbidity

Comorbidity, whether diagnosed or undiagnosed, has also been identified as a frequent confounding factor in the existing research. While this may, at least in part, be due to the extensive comorbidity between ADHD and other disorders (see Tannock, 1998; Langsford, 1999), the present study sought to examine only those ADHD boys who had no diagnosed comorbidity. In order to achieve this, the ADHD participants used in the present study were drawn from a larger sample of approximately 3500 children with ADHD, of whom only 122 were identified as having no diagnosed comorbidity. This appears to be in line with recent evidence from Barkley (2001a) which has suggested that approximately 3% of ADHD children have no diagnosed comorbidity. Alternatively, the high rates of comorbidity in general, and evidence suggesting that comorbidity occurs more frequently than the component disorders alone occur by chance (e.g., Langsford, 1999), might suggest a need to develop new diagnostic constructs (Tannock, 1998).

Poor construct validity

In addition to the changing conceptualisation of ADHD, research has also been hampered by the inability of researchers and clinicians to reach a consensus on the definition and operationalisation of constructs such as attention and the executive functions. For example, while there is strong agreement that the concept of “executive function” does not refer to basic cognitive processes such as sensation, perception, motor activation, attention, and memory, a precise definition has yet to emerge (Tannock, 1998). Without this, the logic of many studies that have examined executive functioning in ADHD children appears almost circular, with the construct under examination effectively being defined by the measures used to assess it. However, in the present study, the information obtained from a series of semi-structured interviews with leading professionals in the field of ADHD research served to define the constructs being examined, and to inform the selection of instrumentation used to assess them.

Aims of the research

The overall aims of the present research, therefore, were to: (i) examine the current conceptualisation(s) of ADHD and its associated cognitive impairments; (ii) systematically examine these predicted impairments empirically; (iii) address the acknowledged limitations of previous research; and (iv) to further contribute to the development of theory about ADHD. The present study also sought to extend current understanding by verifying or challenging aspects of the existing theoretical models of ADHD (e.g., Barkley, 1997a), and suggesting modifications where appropriate. A particular aim of this research was to examine cognitive impairments among ADHD boys who had no diagnosed comorbid conditions and who were unmedicated at the time of testing, since

these were identified as frequent confounding factors in previous research with this population.

The present study also sought to address the issue of construct validity and the inconsistent results obtained in earlier research, by employing recently developed instrumentation specifically designed to be sensitive to the predicted impairments of children with ADHD. Thus it is anticipated that this research will also prove to be a valuable source of additional psychometric data for these measures. A final aim of this study is the dissemination of the research findings to the widest possible audience, with the aim of increasing the understanding of ADHD, and in doing so to facilitate improved outcomes for children with the disorder. Therefore, the publication of the findings of this research in a leading international journal was a desirable outcome of the present study.

Original contribution of this research

It is anticipated that this research will provide a significant contribution by developing a clearer understanding of the current conceptualisation(s) of ADHD, which is considered essential given the continuing evolution of the disorder. Study One is exploratory and will involve a comprehensive review of the theoretical and research literature, the prevailing theoretical models of the disorder (e.g., Barkley, 1997a), and a series of semi-structured interviews with leading professionals in the field of ADHD research. Study One will also serve to identify any predicted executive impairments of ADHD children and their observable manifestations, thereby ensuring that the subsequent empirical investigation of these impairments (i.e., Study Two) will be adequately operationalised. In particular, the results of Study One will guide the selection of instrumentation (to be used in Study Two) sensitive to the predicted impairments of ADHD children. In contrast, many studies of ADHD to date

have relied upon poorly defined constructs (such as the executive functions), or the instrumentation used to assess them, with the result that the findings of such studies have appeared inconsistent, thereby raising concerns as to the construct validity of the applied instrumentation.

Study Two will also attempt to address the range of methodological limitations that were identified in the review of previous research on ADHD. These included: limited sample sizes, inconsistent diagnostic procedures, poor age-matching between groups, and failure to control for comorbid disorders or medication status at the time of testing. In addition, while many current theories of ADHD are restricted to those children who present with symptoms of both inattention and hyperactivity-impulsivity (e.g., Barkley, 1997a), the present investigation also included those ADHD children who display symptoms of inattention only (i.e., ADHD-PI). While it is acknowledged that the size of the ADHD-PI sample employed was only limited ($n = 14$), their inclusion in the present study may provide an indication of whether the existing theories of ADHD can be extended to accommodate them, or the development of a new theory is warranted.

Chapter summary

Although a considerable amount of research has been conducted on ADHD since the syndrome was first identified, much of this research has been confounded by the evolving conceptualisation of ADHD and a number of methodological flaws. The present study seeks to address these limitations by way of an empirical investigation of the current conceptualisation(s) of ADHD. The results of this research will also serve to verify or challenge certain aspects of the existing theories of ADHD (and suggest modifications where

appropriate), and in doing so contribute to the further development of understanding about ADHD.

The following chapter describes the review of literature which served to provide the theoretical basis for the subsequent research. Those issues that arose from the review of literature which required further clarification were explored in more detail in semi-structured interviews with leading professionals in the area of ADHD research. The data obtained from these semi-structured interviews are presented in Chapter Three and discussed in Chapter Four, where they serve to inform the selection of instrumentation to be applied in Study Two. Chapter Five provides details pertaining to the design of the empirical investigation of the predicted executive impairments of ADHD children, and extends hypotheses to be tested. The results of the subsequent empirical investigation of the executive functioning of boys with ADHD are presented in Chapter Six. Finally, Chapter Seven attempts to reconcile the results of Study One and Two with the review of literature, and the aims of the research. This chapter also discusses the reconceptualisation of ADHD that is suggested by these data and provides directions for further research.

CHAPTER TWO

Literature Review

The critical review of literature presented in this chapter serves to provide the theoretical basis for the subsequent research, which examined the current conceptualisation of ADHD and its associated impairments. Initially, the rationale for the current research is presented, and the conceptualisation of ADHD that was established with the publication of DSM-IV (APA, 1994) is discussed. Current information pertaining to diagnostic procedures, developmental course, comorbidity, prevalence, and intervention strategies for ADHD is provided, and the limitations of the DSM-IV formulation are considered. The need for a new theory of ADHD is then examined within the context of the evolving understanding of the disorder. The role of the present study in contributing to the extension and modification of the current theory of ADHD is then illustrated with reference to the impairments of ADHD children that were identified from the literature (i.e., response inhibition, working memory, attention, and the concept of time).

Attention-Deficit/Hyperactivity Disorder: Diagnostic criteria

Attention-Deficit/Hyperactivity Disorder (ADHD) is the current diagnostic label for the cluster of hyperactive, impulsive and inattentive symptoms that is now recognised as one of the most prevalent disorders of childhood (Tannock, 1998). The fourth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) lists the defining feature of ADHD as a “persistent pattern of inattention and/or hyperactivity-impulsivity that is more frequent and severe than is typically observed in individuals at a comparable level of development” (American Psychiatric Association [APA], 1994, p. 78).

The DSM-IV criteria currently used by professionals were developed through a lengthy process involving field trials, expert consultations, and the examination of published literature (Baxter, 1995; McBurnett, Lahey, & Pfiffner, 1993). Factor analyses conducted on empirical data gathered during these field trials suggested that ADHD comprises "two separate dimensions of symptoms - one composed of inattention symptoms and a second dimension composed of excessive motor activity and impulsivity" (Lahey et al., 1994, p. 1674). From these two symptom clusters, which are thought to be distinct in their etiology, course, response to treatment, and outcome, three ADHD subtypes are delineated: the Predominantly Inattentive Type (ADHD-PI), Predominantly Hyperactive-Impulsive Type (ADHD-HI), and the Combined Type (ADHD-CT) (Tannock, 1998).

The DSM-IV diagnostic criteria, which are reproduced in Table 1, consist of a schedule of nine inattentive symptoms and nine hyperactive-impulsive symptoms. Six (or more) of these inattentive symptoms are required for the diagnosis of ADHD-PI, whereas six (or more) hyperactive-impulsive symptoms are required for the diagnosis of ADHD-HI. At least six symptoms from each cluster are required for the diagnosis of ADHD-CT. In addition, symptoms must cause impairment in two or more different settings (i.e., symptoms must be pervasive), some symptoms must have been present before age seven, and should not be better accounted for by another disorder.

Table 1

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

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)
-

Table 1 Continued

-
- 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)

Developmental course of ADHD

Whilst the DSM-IV criteria require that some symptoms causing impairment are present before age seven, DuPaul, Guevremont, and Barkley (1994) noted that "the majority of children who will be identified as having ADHD begin to manifest significant overactivity, noncompliance, and short attention span by 3 years of age" (p. 237). In addition, the DSM-IV diagnostic requirements are that the behaviours associated with ADHD must be present to a degree that is maladaptive and inconsistent with the child's developmental level (APA, 1994).

The present study therefore sought to account for these developmental differences by examining the performance of ADHD boys relative to a sample of individually Age-matched Control boys.

In the majority of cases, the symptoms of ADHD persist into adolescence, although there may be some attenuation of symptoms with age (Searight, Nahlik, & Campbell, 1995). Barkley (1997a) cited research that suggested 50%-80% of ADHD children exhibit symptoms into adolescence and between 30%-50% into adulthood (Barkley, Fischer, Edelbrock, & Smallish, 1990; Klein & Mannuzza, 1991; Weiss & Hechtman, 1993). There is also evidence to suggest that ADHD is associated with higher risks for “low academic achievement, poor school performance, retention in grade, school suspensions and expulsions, poor peer and family relations, anxiety and depression, aggression, conduct problems and delinquency, early substance experimentation and abuse, driving accidents and speeding violations” (Barkley, 1997a, p. 65). As adults, children with ADHD are also more likely to experience difficulties with adult social relationships, marriage, and employment (Barkley, 1997a).

In a number of models of ADHD (e.g., Barkley, 1997a; Quay, 1997), the risks associated with ADHD have been linked to the hyperactive-impulsive (HI) symptom cluster, and there is some evidence to suggest that its developmental course might differ from that of inattention (Lahey et al., 1994). Barkley (1997a) has even proposed that the ADHD-PI subtype might represent a separate disorder entirely. A recent study has provided added support for this conjecture, suggesting that the HI and inattentive dimensions might be etiologically distinct. In a community sample of 373 same-sex twins aged between 8 and 18 years, selected because at least one twin showed evidence of learning difficulties, Willcutt, Pennington, and DeFries (1999) concluded that

extreme ADHD scores, as assessed by the Diagnostic Interview for Children and Adolescents, Parent Report Version (DICA; Reich & Herjanic, 1982), “were almost entirely attributable to genetic influences” (p. 154). In addition, while the heritability estimate (h^2 , that is, the proportion of the variance in the ADHD symptoms that is attributable to genetic factors) obtained for inattentive symptoms ($h^2 = 1.10$) was extremely high, the same was not true for HI symptoms without inattention ($h^2 = 0.08$). However, given that the heritability estimate for inattention exceeded the theoretical limit of 1.00, these results should be interpreted with caution. Nevertheless it is possible this result simply reflects sampling error around the true value (95% confidence interval = 0.65 - 1.55) since heritability estimates calculated in this way are unconstrained (Wilcutt et al., 1999).

Prevalence of ADHD

In a recent report pertaining to the Mental Health of Young People in Australia, Sawyer et al. (2000) found that approximately 14% of 4 to 17 year olds had indications of mental health problems, and that of these ADHD was the most prevalent. However, the determination of accurate prevalence figures for ADHD has been confounded by several factors, including the shifting labels and definitions that have been applied to the disorder, the different diagnostic criteria utilised (e.g., DSM versus ICD-10), and failure to account for comorbidity. Whilst prevalence estimates for ADHD have varied widely, with some studies suggesting rates as high as 15% to 24% (Zentall, Harper, & Stormont-Spurgin, 1993), large scale epidemiological studies have produced more conservative estimates of between 3% and 9% of the school-age population (Barkley 1997a; Mental Health Division of Western Australia, 2000; National Health & Medical Research Council [NHMRC], 1996; National Institute of Health, 2000).

In Western Australia, recent research using the Australian Child and Adolescent Disorders Screening Inventory (ACADSI; Langsford, Houghton, & Douglas, 2000) has estimated the prevalence of ADHD at approximately 7.4% in a sample of 823 school-age children. However, it must be acknowledged that the ACADSI is not a diagnostic instrument, and although it was based on DSM-IV criteria, a positive screen is not necessarily indicative of the presence of a disorder. Nevertheless, the ACADSI was designed to be sensitive to the 20 school-age disorders most commonly referred to school psychologists, and has the particular strength of integrating parent, teacher, and self-report data.

ADHD also affects proportionately more males than females, occurring in approximately three times as many boys as girls (Barkley, 1997a, 2001a; Tannock, 1998). In addition, ADHD is more common in first-degree biological relatives of children with the disorder (APA, 1994, 2000), which is consistent with the notion of genetic heritability. ADHD also occurs across a range of cultures and geographical regions (Tannock, 1998), with figures that suggest it affects 6.7% of children in New Zealand, 4.2% of children in Germany, 6-9% of children in China, 7.7% of children in Japan, and 9.5% of children/adolescents in Puerto Rico (Barkley, 2001b).

Comorbidity of ADHD

Comorbidity refers to the simultaneous occurrence of two or more disorders in the same individual at the same time (Clarkin & Kendall, 1992). Whilst prevalence estimates vary considerably, as many as 50% to 80% of children presenting with ADHD also meet the diagnostic criteria for other disorders (Tannock, 1998). The most frequently documented comorbidity is between ADHD and the other disruptive behaviour disorders, with oppositional defiant disorder and conduct disorder occurring in as many as 40% to 90% of children

with ADHD (Jensen, Martin, & Cantwell, 1997). However, a comprehensive review of the published literature on comorbidity (1997 - 1999) conducted by Langsford (1999) revealed a greater prevalence of ADHD amongst individuals with learning disabilities, disruptive behaviour disorders, mood and anxiety disorders, eating disorders, autistic and tic disorders, than in the general population.

There is also some evidence to suggest that the two ADHD symptom dimensions differ with respect to comorbidity, with the hyperactive-impulsive cluster more likely to be linked with oppositional or antisocial behaviour (Lahey et al., 1994), and the inattentive cluster more likely to be associated with specific learning disabilities (Stanford & Hynd, 1994). The recent findings of a genetic study by Willcutt, Pennington, and DeFries (2000) also appear to provide some support for this claim. Willcutt et al. (2000) again used the DICA (Reich & Herjanic, 1982) to assess ADHD symptoms in a community sample of 313 eight to 16 year-old same-sex twins, who were selected because at least one twin met the criteria for Reading Disability (RD). Willcutt et al. (2000) found that individuals with RD were significantly more likely than individuals without RD to exhibit elevated scores on both the hyperactive-impulsive and inattentive symptom dimensions. However, the bivariate heritability of RD and inattention was significant ($h^2 = 0.39$) whereas the heritability of RD and hyperactivity-impulsivity ($h^2 = 0.05$) was not. Furthermore, the etiology of this overlap appears to differ for the two symptom dimensions with 95% of the overlap between RD and inattention being attributable to common genetic factors, whereas only 21% of the overlap between RD and hyperactivity-impulsivity was attributable to genetic influences.

The presence of comorbid disorders may complicate the assessment, diagnosis, and treatment of ADHD, and is a frequent confounding factor in experimental research. Comorbid conditions are thought to result in increasingly adverse outcomes for children with ADHD, and the recent findings of Langsford (1999) have suggested that ADHD is the most comorbid of the 20 school-age disorders most commonly referred to school psychologists. Langsford subsequently devised and administered a screening device specifically designed to examine the pattern of comorbidity in school-aged students to a sample of 823 school children. The findings revealed that as the number of positive screens for disorders increased, there was a corresponding decrease in the mean level of self-control. The present study therefore sought to control for comorbidity by investigating only those children with ADHD and no diagnosed comorbid conditions. In this manner, any significant differences found between the ADHD and Control participants are more likely to be associated with ADHD itself and not attributable to comorbid influences.

Intervention strategies

Although this thesis is not primarily concerned with intervention strategies for ADHD it is necessary to include a brief description to develop a clearer understanding of the condition. The management of ADHD may be divided into two broad categories consisting of pharmacological and non-pharmacological interventions. Whilst few controlled studies have examined the longer-term efficacy of these interventions, a growing body of literature has until recently suggested that a multi-modal approach was more effective than either method individually (DuPaul et al., 1994; NHMRC, 1996). However, a recent 14-month clinical trial of stimulant medication and/or behaviour therapy found that a combined approach failed to yield significantly greater benefits than medication alone in 579 children with ADHD (MTA Cooperative Group,

1999). Nevertheless, the study also revealed that all four of the treatment groups (including a community care group) showed sizeable reductions in symptoms over time, albeit with significant differences in the degrees of change (MTA Cooperative Group, 1999).

While a range of unproven therapies have been applied to the treatment of ADHD, including diet management, sensory integration training, chiropractic skull manipulation, psychotherapy, EEG biofeedback, self-control (i.e., cognitive) therapies, and social skills training, in many cases there remains little or no empirical evidence to support their use as effective treatments. In contrast, there is considerable empirical evidence to support the use of certain specific medications, parent management training, family therapy, teacher education about ADHD, and classroom behaviour modification, in the treatment of ADHD (Barkley, 2001a). Whilst the medications most commonly used in the treatment of ADHD are the psychostimulants dextro-amphetamine sulphate and methylphenidate hydrochloride (known under the trade names Dexedrine and Ritalin respectively; NHMRC, 1996), noradrenergic medications, tricyclic anti-depressants and anti-hypertensives have also been proven effective (Barkley, 2001a).

The psychostimulant medications act on inefficient or immature neurotransmitter pathways “to mainly influence prefrontal, frontal, and limbic systems with benefits on behavioural inhibition, impulse control, selective attention, active working memory and executive functioning” (NHMRC, 1996, p. 21). Furthermore, “dexamphetamine appears to release newly synthesized dopamine and block uptake postsynaptically, while methylphenidate releases stored dopamine” (NHMRC, 1996, p. 21). Although side effects may include insomnia and loss of appetite (in 50% of cases), headaches and stomach aches

(20%-40%), irritability (10%), nervous habits (10%), mild weight loss, and increased heart rate and blood pressure, stimulant medications may be effective in as many as 90% of children with ADHD (Barkley, 2001a). Unless used improperly, stimulant medications are not addictive and can result in significant benefits including increased concentration and persistence, decreased hyperactivity and impulsivity, increased work productivity, better emotional control, decreased aggression and defiance, and improvements in working memory (Barkley, 2001a).

The non-pharmacological interventions focus on education and training for parents and teachers of children with ADHD. However, while behaviour management training for parents and behaviour modification training for teachers have proven effective (DuPaul et al., 1994; NHMRC, 1996), the use of cognitive (i.e., self-control) therapies for children with ADHD has proven largely ineffective (Barkley, 2001a). Barkley has argued that the efficacy of cognitive-based interventions for children with ADHD will be undermined by impairments in the underlying cognitive processes. Nevertheless, a number of studies have suggested that cognitive-behavioural interventions may have some (albeit limited) beneficial effects, particularly when used as part of a multi-modal treatment regime (Miranda & Presentacion, 2000; MTA Cooperative Group, 1999; NHMRC, 1996). Other effective non-pharmacological interventions include: parent training (Pelham, Wheeler, & Chronis, 1998), training in problem solving (Robin, 1988), the use of a mentor system (Barkley, 2001a), peer tutoring (DuPaul, Ervin, Hook, & McGoey, 1998), token reinforcement and response costs (McGoey & DuPaul, 2000), and the use of weekly assignment sheets (Barkley, 2001a).

The evolving conceptualisation of ADHD

Since the characteristic cluster of hyperactive, impulsive, and inattentive symptoms that is now recognised as ADHD was first discussed as a behavioural syndrome by Still in 1902 (DuPaul et al., 1994), the understanding of ADHD has continued to evolve. In particular, researchers and clinicians have struggled with the conceptualisation of ADHD as new research findings challenged the prevailing construct (Tannock, 1998). Differences have also emerged between the North American and the European formulations of ADHD, with the European formulation recognising only those children with symptoms of hyperactivity, impulsivity, and inattention, as ADHD (Tannock, 1998). To this point this thesis has reviewed the conceptualisation of ADHD that was established with the publication of DSM-IV (APA, 1994), which represented the culmination of many years of research. However, the understanding of ADHD has continued to develop and as a consequence, the limitations of DSM-IV have become increasingly apparent. In particular, the DSM-IV criteria are descriptive, and fail to account for the many cognitive and behavioural deficits associated with ADHD (Barkley, 1997a). Furthermore, the DSM-IV formulation is largely atheoretical, and provides little insight into the nature of the disorder (Barkley, 1997a), or directions for its treatment (Power & DuPaul, 1996).

Barkley (1997a) subsequently argued that a new theory of ADHD was needed that could: address the findings of previous research; link the disorder to a defect in normal human development; and make explicit predictions about new phenomena that can be tested empirically. Although various theories have been proposed to account for ADHD, most notably Zentall's (1985) optimal stimulation theory, Sergeant's (2000) cognitive-energetic model, and Sonuga-

Barke's notion of "delay aversion" in children with ADHD (Sonuga-Barke, Williams, Hall, & Saxton, 1996), Barkley's (1997a) Unifying Theory appears to be the most scientific conceptualisation to date. Barkley (1997a) drew together literature from the fields of developmental psychology, neuropsychology, and neurology, to construct a theory of ADHD which linked the disorder to an irregularity in the development of self-control. According to Tannock (1998) the recent development of theoretical models that focus on the component processes which underlie ADHD represents a significant advance in the field. Whilst it is beyond the scope of this thesis to provide a full historical account of ADHD, key historical developments will be detailed so that the emerging models can be placed into context of the conceptualisation of ADHD to date.

1900 to 1949: Historical origins

Although the symptoms of ADHD may have been first identified as early as the 1860's (DuPaul et al., 1994), the first clinical descriptions of the disorder were presented by Still in 1902 who described children with what he termed morbid defects in moral control. Using the theories of William James as a basis, Still postulated that the deficits in inhibitory volition, moral control, and sustained attention associated with this condition were due to an underlying neurological deficiency (Barkley, 1990). During the 1930s, links were beginning to be established between brain injuries and a number of cognitive and behavioural impairments such as ADHD, which was then known as organic drivenness or restlessness syndrome (Barkley, 1990). Although several researchers attributed the ADHD symptoms to a frontal lobe dysfunction in the brain, the prevailing consensus during this era was that hyperactivity was the result of psychological causes such as poor parenting or a poor family environment. Another significant development that occurred during this era was the discovery of

amphetamines as an effective intervention for children with the disorder (Barkley, 1990).

1950 to 1959: An era of “Minimal Brain Damage/Dysfunction”

Over the course of the next decade, the conceptualisation of ADHD evolved once again and by the 1950s symptoms were being attributed to minimal brain damage. By the late 1950s and early 1960s, the lack of corroborating evidence, in the form of actual central nervous system damage in children with this condition, forced the concession that although the disorder was neurologically linked, it was not the result of neurological damage (Barkley, 1990). This shift in emphasis was reflected by the change in terminology from minimal brain damage to minimal brain dysfunction. A number of studies conducted during the 1950s also referred to ADHD as “hyperkinetic impulse disorder,” postulating that the condition was due to cortical overstimulation, and the result of inadequate sensory filtering. However, no mention was made of ADHD in the inaugural edition of the DSM published in 1957 (McBurnett et al., 1993).

1960 to 1969: Hyperactivity

The understanding of ADHD further evolved in the 1960s when the concept of hyperactive child syndrome appeared. In 1960, Chess emphasised that the key feature of the disorder was hyperactivity, and her conceptualisation of the condition distinguished it from a brain damage syndrome and removed the blame from the child’s parents (Barkley, 1990). During this era, the concentration on the hyperactivity component of ADHD to the exclusion of the impulsive and inattentive components may have resulted in the disorder becoming known as hyperactivity or hyperkinesis (DuPaul et al., 1994).

Hyperactivity also began to be viewed as a behavioural syndrome that could occur both in the presence or absence of a biological cause (Barkley, 1990). This view began to gain wider endorsement prior to the publication of the DSM-II in 1968, which was the first edition to incorporate ADHD under the name Hyperkinetic Reaction of Childhood (McBurnett et al., 1993). By the end of this decade, the prevailing view was that although ADHD was still considered a brain dysfunction syndrome, it was less severe in nature than previously suspected and was no longer linked to brain damage. Instead, the focus had shifted to brain mechanisms (Barkley, 1997b).

1970 to 1979: The era of the “Attention Deficit”

The 1970s saw a vast amount of research conducted into the disorder and with in excess of 2000 studies published, the literature abounded. Ironically the increased scientific and professional (as well as public) attention focused on the disorder coincided with the emergence of the concept of the Attention Deficit. Early in the 1970s it became clear that the exclusive focus on hyperactivity had obscured other key characteristics of the disorder such as: impulsivity, distractibility, short attention span, aggressiveness, and low frustration tolerance. Douglas (1972) stressed the role of deficits in sustained attention and impulse control over hyperactivity as the key features of the disorder. Douglas also reported that children with ADHD were not necessarily reading or learning disabled and that they were no more distractible than other children, but linked the observed lack of moral development to the deficiencies in attention and impulse control (Barkley, 1990).

The 1970s also saw a profound increase in the use of stimulant medication in the treatment of ADHD. The view that hyperactivity was the result of food additives (and later sugar), and could thus be alleviated by diet modification,

gained popularity which persisted long after these claims were refuted. The views that ADHD was the result of environmental overstimulation or poor parenting also resurfaced. For a time, in the mid 1970s, the research focused on the psychophysiology of children with ADHD, with variables such as galvanic skin response being measured. By the end of the decade, it was clear that inattention and impulsivity were important in explaining the problems of children with the disorder. The focus on the cause of the disorder had shifted from brain damage to other brain mechanisms such as underarousal, underactivity, brain neurotransmitter deficiencies, or neurological immaturity (Barkley, 1997b). The recognition of environmental variables as a causal factor in the disorder led to the ratification of a range of treatment strategies including behaviour modification and parent training.

1980 to 1989: The development of diagnostic criteria

During the 1980s Douglas (1980, 1983, cited in Barkley, 1997a) reformulated her theory of ADHD, arguing that it comprised major deficits in: attention and effort, impulse inhibition, arousal modulation, and an increased need to seek immediate reinforcement. The profound impact of Douglas' research may have been partly responsible for the renaming of the condition as Attention Deficit Disorder (ADD) in the DSM-III. Of further importance, the DSM-III (1980) introduced a multiaxial assessment system comprising two behavioural subtypes: ADD with hyperactivity (ADD/H or ADD/+H), and ADD without hyperactivity (ADD/WO or ADD/-H) (Morgan, Hynd, Riccio, & Hall, 1996). During the 1980s the concept of an underlying attention deficit as the cause of ADHD was replaced by other ideas, including that of a dysfunction in the effort/activation system (Sanders, 1983). Zentall (1985) also proposed an optimal stimulation theory of ADHD, postulating that hyperactivity is a form of self-stimulation used to maintain an optimal arousal level.

However, the main advances in research during this decade were due to the emergence or application of new scientific techniques including regional cerebral blood flow/computed tomography (rCBF/CT) and magnetic resonance imaging (MRI) in the study of ADHD. These new techniques revealed regions of reduced prefrontal lobe activity in the brain and the widely held view that ADHD was the result of neurotransmitter deficiencies was established. The efficacy of psychostimulant medications in the treatment of ADHD was understood and explained in terms of their ability to target inefficient or immature neurotransmitters (NHMRC, 1996). With the advent of the DSM-III-R in 1987 came the current terminology of Attention-Deficit/Hyperactivity Disorder (ADHD) (Morgan et al., 1996). The DSM-III-R returned to a unidimensional syndrome comprising 14 symptoms, the presence of eight of which were required for diagnosis (McBurnett et al., 1993). The additional category of Undifferentiated Attention Deficit Disorder (UADD) was included for children with prominent inattentive symptoms only (Morgan et al., 1996) or attention deficit disorders not specified by the ADHD criteria (McBurnett et al., 1993).

1990 to 1999: The era of the “Executive Functions”

The publication of the DSM-IV (APA, 1994) represented a major advance, with several major changes to the ADHD criteria including the return to a multiaxial assessment and the reinstatement of behavioural subtypes. Whilst the existence of distinct behavioural subtypes of ADHD is now generally acknowledged, there continues to be disagreement as to their composition. The 1990s also saw an increase in the research on comorbidity and a focus on the “executive functions”. However, much of the research in these areas was confounded by poorly defined constructs, and a precise definition of executive function (EF) is yet to emerge (Tannock, 1998). While Welsh and Pennington (1988) defined EF

as “the ability to maintain an appropriate problem-solving set for attainment of a future goal (Bianchi, 1922; Luria, 1966)” (p. 201), Eslinger (1996) reported that the National Institute of Child Health and Human Development working group on EF generated 33 different definitions.

However, while there is strong agreement that the construct of EF does not refer to basic cognitive processes such as sensation, perception, motor activation, attention, and memory, a precise definition has proven elusive (Tannock, 1998). Without this, the logic of many EF studies appears almost circular, with the construct under examination effectively being defined by the measures used to assess it. Tannock (1998) stated that EF is typically used to refer to the psychological processes involved in one or more of the following capacities: self-regulation, sequencing of behaviour, flexibility of thinking or responding, response inhibition, planning, and organisation of behaviour. In 1996, Pennington and Ozonoff conducted a review of studies of EF in four developmental psychopathologies: ADHD, conduct disorder, autism, and Tourette’s syndrome. Pennington and Ozonoff (1996) concluded that EF deficits were consistently found in both ADHD and autism but not in conduct disorder or Tourette’s syndrome. Research by Seidman, Biederman, Faraone, Weber, and Oulette (1997) with 118 boys with ADHD demonstrated significant impairments on the Stroop Task (Trenberry, Crosson, DeBoe, & Leber, 1989) and the Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtiss, 1993), both of which are measures of EF according to Pennington and Ozonoff (1996). A subsequent study by Seidman, Biederman, Faraone, Weber, Menin, and Jones (1997) found no significant differences between the neuropsychological performance of ADHD and Control girls. It is worth noting however that neither study controlled for stimulant medication status or comorbidity.

A recent study by Houghton et al. (1999), which controlled for these factors, also reported significant EF impairments amongst a sample of 94 ADHD children compared to non-ADHD Controls. Houghton et al. also found significant impairments on the Stroop and WCST (particularly amongst the ADHD Combined Type), although no gender effects were observed. However, whilst there is sufficient evidence to suggest that EF is impaired in children with ADHD, these deficits do not appear to be specific to ADHD (Pennington & Ozonoff, 1996), or primary to the disorder (Pennington, Bennetto, McAleer, & Roberts, 1996). A new model of ADHD was therefore needed that could drive new research initiatives (Barkley, 1997a), and link the observed impairments in EF to problems with sustained attention, hyperactivity, and impulse control.

Sergeant's Cognitive-Energetic Model

In recent years, Sergeant has utilised the cognitive-energetic model described by Sanders (1983) to direct research into ADHD. The cognitive-energetic model suggests that whilst there may be certain aspects of inhibition that are deficient in children with ADHD, this may also depend on the energetic state of the child (Sergeant, 2000). This model conceptualises information processing as involving three distinct levels: a set of lower cognitive processes (i.e., encoding, central processing, and response organisation); the three energetic pools of arousal, activation and effort; and the management or executive function system (Sergeant, 2000).

To date research conducted at the level of the lower cognitive processes has suggested that there are no apparent deficits in encoding or central processing, but that motor organisation is impaired in children with ADHD (Sergeant & Van der Meere, 1990a, b). At the second level, the primary deficits of ADHD children are thought to be associated with activation (which is concerned with

the control of motor readiness) and effort (which is influenced by motivational factors, such as knowledge of results, and self-regulation) (Tannock, 1998). At the management or executive level, it is suggested that inadequate activation of the inhibitory mechanism in ADHD children results in the secondary deficiencies in the other executive functions described by Barkley (1997a) (Sergeant, 2000). However, the results of a meta-analysis by Oosterlaan, Logan, and Sergeant (1998) suggested that this explanation was not specific to ADHD, but also applied to children with oppositional defiant disorder and conduct disorder.

Sonuga-Barke et al.'s Delay Aversion Model

Alternatively, Sonuga-Barke, Saxton, and Hall (1998) have argued that the impairments seen using standard tests of impulse control amongst hyperactive children might be an artefact of the laboratory situation itself. Sonuga-Barke et al. (1998) observed that in situations where the length of the task is dependent on the delay prior to responding, choosing the more immediate and lesser reward, or responding more quickly, results in shorter trials and less delay overall. Thus according to Sonuga-Barke, "impulsive" behaviour might in fact represent a situation-specific attempt to reduce the subjective perception or experience of delay, and hyperactive children can in fact withhold responses, but choose not to do so in order to minimise time in the laboratory (Tannock, 1998). The delay aversion theory therefore challenges the notion that behavioural inhibition is an underlying impairment in ADHD. Instead, the inhibitory problems are viewed as indicative of a deviation in motivational attitude, and the central construct in the model is a specific aversion to delay or the suppression of responses over time (Tannock, 1998).

Recently Kuntsi, Oosterlaan, and Stevenson (2001) attempted to address this issue by testing the predictions made by three theories of ADHD: the response inhibition deficit (e.g., Barkley, 1997a; Quay, 1997), working memory/executive impairment (Pennington & Ozonoff, 1996; Pennington, Bennetto, McAleer, & Roberts, 1996), and delay aversion (e.g., Sonuga-Barke et al., 1998). Kuntsi et al. (2001) examined 51 ADHD children and 119 control children using the Maudsley Index of Childhood Delay Aversion (Kuntsi, Stevenson, Oosterlaan, & Sonuga-Barke, in press), the Stop Task (Logan & Cowan, 1984), the Delayed Response Alteration Task (Carpenter & Gold, 1994), and Sentence Span (Siegel & Ryan, 1989). Kuntsi et al. (2000) found that children with ADHD performed worse than controls on the measure of delay aversion (in which participants have to choose between a small immediate reward and a large delayed reward) and some of the working memory tasks (which are reviewed later in this chapter). While no significant differences were found on the measures of inhibition derived from the Stop Task, the ADHD children were found to be more variable than controls in terms of their response speed, and generally slower and less accurate in their responding (Kuntsi et al., 2001).

In recent years, Sonuga-Barke, Williams, Hall, and Saxton (1996) have advocated a modified formulation in which delay aversion and impulsiveness are thought to result from impairments in temporal processing. While this appears to be in conflict with Sonuga-Barke et al.'s earlier non-deficit model (Tannock, 1998), Barkley (1997a) has also suggested that the concept of time might be impaired in children with ADHD. Barkley, Koplowitz, Anderson, and McMurray (1997) examined this issue in more detail in two studies using a time reproduction task. While this (and other) studies of concept of time in children with ADHD are reviewed in more detail later in this chapter, the findings of Barkley et al. (1997) suggest that time reproduction may be impaired in ADHD

children. However, given the small amount of research in this area to date and its acknowledged limitations (including small sample sizes, comorbidity, and issues of motor control and persistence) further research is clearly necessary.

Barkley's Unifying Theory of ADHD

Barkley (1997a) subsequently proposed a theoretical model of ADHD (which is reproduced in Figure 1), designed to apply to the Hyperactive-Impulsive and Combined Types (i.e., those subtypes characterised by Hyperactive-Impulsive behaviour), which posited that the central impairment in the disorder was one of behavioural (or response) inhibition. Whilst the notion of a deficit in behavioural inhibition in ADHD is not new, but builds on earlier work of Douglas (1988), and Quay's (1988) use of Jeffrey Gray's model of anxiety applied to ADHD, Barkley's (1997a) model predicts that it is the central impairment in ADHD. In addition, Barkley (1997a) predicted that secondary impairments in four specific EFs would result from the ADHD child's essential inability to inhibit and postpone responses. These four EFs are: the operation of working memory (including hindsight and forethought); the internalization (or self-direction) of speech; the self-regulation of mood, motivation and arousal; and reconstitution (the ability to analyse and synthesise novel sequences of behaviour).

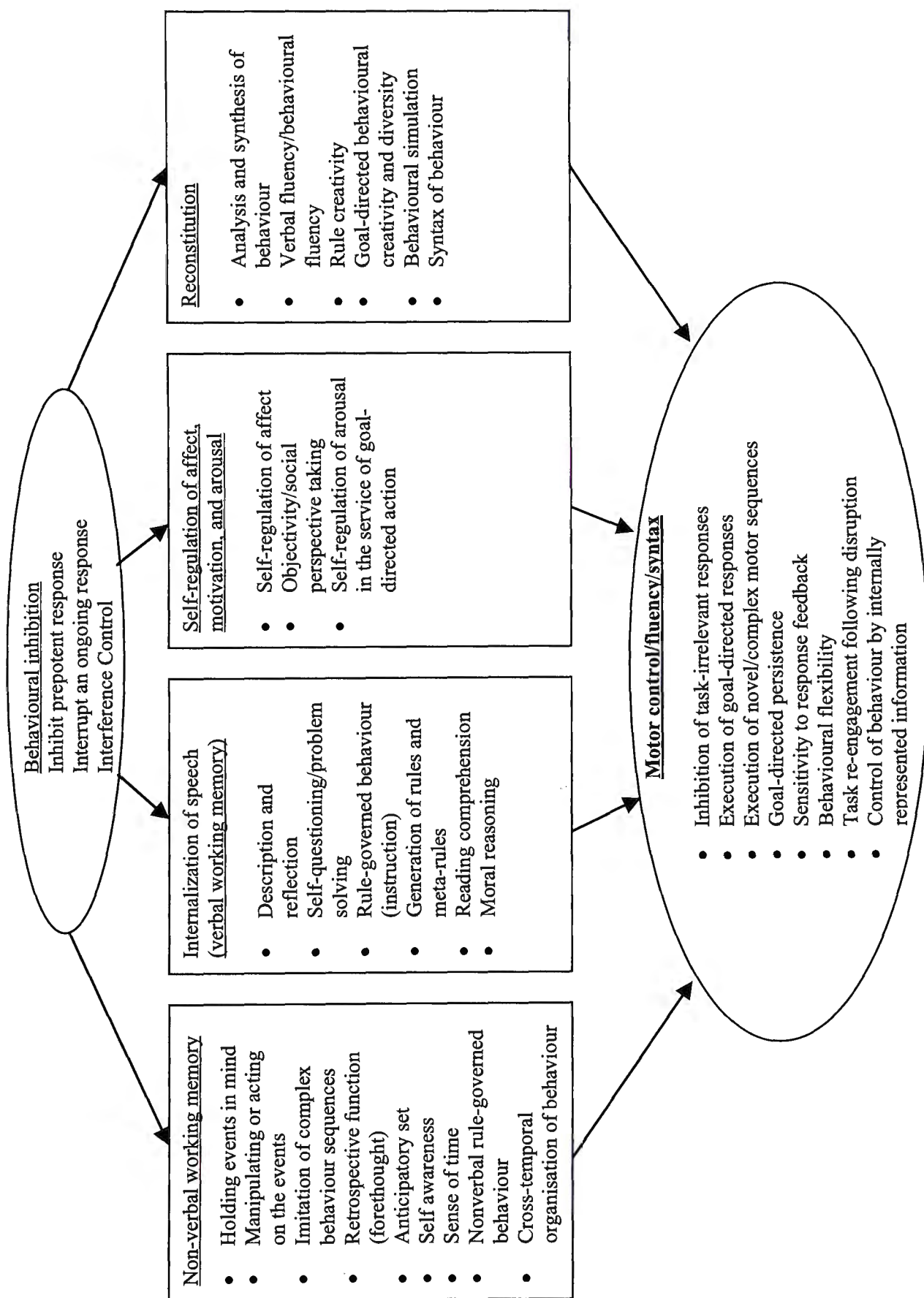


Figure 1. Barkley's Unifying Theory of ADHD. From Barkley (1997b).

According to Barkley (1997b) the EFs are those self-directed actions that begin as public behaviours and are gradually privatised over the course of development, becoming increasingly responsible for self-control as the public aspects of these behaviours are inhibited. Thus Barkley (1997b) predicted that the EFs are dependent on behavioural inhibition for their effective development. Furthermore, whilst the successive chain of impairments in the EFs creates the appearance of poor sustained attention in those with ADHD, Barkley (1997b) argued that it actually represents a reduction in the executive control of behaviour (i.e., control by the internally represented information that is afforded by the EFs). Therefore, Barkley predicted that individuals with ADHD will be less proficient in the self-regulation of their behaviour and more susceptible to control by the immediate external environment.

A number of specific predictions have been advanced by the Barkley model that have served to stimulate research (Tannock, 1998). According to Barkley (1997a), poor behavioural inhibition results in secondary deficiencies in working memory and its subfunctions in children with ADHD. In particular, Barkley predicted that impairments in verbal working memory would lead to difficulties with reading comprehension and adherence to verbal rules or instructions, while deficiencies in non-verbal working memory would result in an impaired concept of time. Furthermore, Barkley (1997b) suggested that as a consequence of this chain of impairments, children with ADHD will manifest difficulties with goal-directed persistence and sustained attention.

The predicted impairments in each of these areas are of particular relevance to the present research since they were also identified in the review of literature and the semi-structured interviews in Study One. The present research sought to contribute to the ongoing development of theory pertaining to ADHD by

extending the findings of previous research in each of these four domains. The following sections therefore review previous and concurrent research relating to each of these four areas of executive functioning.

Response inhibition

Given Barkley's (1997a) contention that response inhibition is the central impairment of children with ADHD, the effective measurement of a deficit in behavioural inhibition in ADHD is crucial to current theories of the disorder (Nigg, 1999). However, there is also considerable evidence to suggest that response inhibition is a multifaceted construct (Barkley, 1997a; Nigg, 2000). In 1997, Barkley described a three phase model of inhibition which comprised three interrelated processes: inhibiting the initial prepotent response; stopping an ongoing response, which permits a delay in the decision to respond; and interference control, which protects this period of delay from disruption by competing events and responses (Barkley, 1999). In contrast, Nigg (2000) identified eight kinds of inhibition that have been applied across different tasks and measurement paradigms, that can be broadly grouped into executive, motivational and automatic inhibitory processes.

Evidence of poor inhibition in ADHD children has been established using paradigms such as the go/no-go task (e.g., Casey et al., 1997; Iaboni, Douglas, & Baker, 1995), the change task (Schachar, Tannock, Marriott, & Logan, 1995), and the stop signal task (Oosterlaan & Sergeant, 1995, 1996; Schachar, Mota, Logan, Tannock, & Klim, 2000). In the go/no-go task, participants are required to respond (e.g., press a key) when a frequent stimulus appears, but to make no response when an infrequent stimulus appears. In contrast, the stop signal task (Logan, 1994) has the advantage of being based on a well-established theory of response inhibition (Nigg, 1999), which unlike other measures permits the

measurement of the underlying inhibitory process (Oosterlaan, Logan, & Sergeant, 1998).

The stop signal paradigm is based on the race model (Logan & Cowan, 1984), in which response inhibition is conceptualised as a race between competing stop and go processes (Nigg, 2000). According to this theory, poor inhibitory control could result from extremely fast response processes or from very slow inhibitory processes (Tannock, 1998). There is also evidence from an increasing body of research that suggests that the latter is in fact the case (Oosterlaan et al., 1998; Pliszka, Borcharding, Spratley, Leon, & Irick, 1997; Schachar et al., 1995). Aman, Roberts, and Pennington (1998), Purvis and Tannock (1997), and Schachar and Logan (1990) have also shown that children diagnosed as ADHD have slower stop signal reaction times than non-ADHD controls. Using a new tracking procedure for assessing stop signal response time, Nigg (1999) also demonstrated that ADHD was associated with slower stop signal response time, and that taken as a whole the results “bolster the idea that deficits in motor inhibition processes are associated with the DSM IV ADHD combined type” (p 399).

Recently, Leth-Steensen, Elbaz, and Douglas (2000) described this pattern of longer overall response times and increased variability of responding amongst ADHD children as “the most consistent finding in the ADHD cognitive literature” (p. 168). Leth-Steensen et al. subsequently demonstrated that the response time distributions of boys with ADHD were distinguished from those of age-matched Control boys by an increased number of abnormally slow responses, resulting in a larger tail of the distribution. However, given the limited sample size of Leth-Steensen et al.’s (2000) work ($n = 17$), caution is advised in the interpretation of these findings until such time they can be

replicated with a larger sample. Whilst it is anticipated that the response time data gathered in the present study will be examined using a similar distributional approach, providing a useful extension to Leth-Steensen et al.'s (2000) work, such analyses are beyond the scope of the present research.

However, evidence from research also suggests that children with conduct disorder show similar impairments to those seen in ADHD (Oosterlaan, Logan, & Sergeant, 1998; Oosterlaan & Sergeant, 1996; Schachar et al., 2000), and therefore impairments in response inhibition might not be specific to ADHD. Nigg (2000) argued that if an inhibitory deficit is not specific to ADHD, it cannot be a necessary and significant cause of the disorder. It may be, as suggested by Oosterlaan et al. (1998), that deficits in response inhibition might characterise that wider group of children with disruptive or externalising behaviour problems, although similar findings have also been found in children with reading disability (Purvis & Tannock, 2000). The present study will examine whether deficient inhibition is characteristic of boys with ADHD who have no diagnosed comorbid conditions (including other disruptive or externalising behaviour problems). The individual matching of the ADHD and control group to within three months of age will also address the potential developmental variations in inhibitory functioning suggested by Williams, Ponesse, Schachar, Logan, and Tannock (1999) in their cross-sectional study of inhibitory control across the life span.

Working memory

According to Denckla (1996), working memory refers to the ability to represent and hold in mind visual or verbal information for the duration of a task. Furthermore, Denckla suggested that "working memory entails the ability to behave on the basis of represented rather than immediately presented

information/knowledge” (Denckla, 1996, p. 116). This is consistent with Barkley’s (1997a) notion that the development of self-control represents a shift from the external control of behaviour to control by internally represented information (i.e., the EFs, and in particular, working memory). However, whilst impairments in working memory are central to the current theories of ADHD (e.g., Barkley, 1997a; Kuntsi, Oosterlaan, & Stevenson, 2001), systematic investigations of working memory in ADHD are sparse (Tannock, 1998).

The limited research in this area has suggested that children with ADHD perform poorly on tasks of working memory, including repetition of digits forwards and backwards (Barkley, Murphy, & Kwasnik, 1996), mental arithmetic (Zentall & Smith, 1993), the Freedom of Distractibility Scale of the Wechsler Intelligence Scale for Children (Third Edition; Wechsler, 1991) (Anastopoulos, Spisto, & Maher, 1994), and the Tower of Hanoi (Pennington, Grossier, & Welsh, 1993), compared to non-ADHD control children. In addition, children with ADHD appear to have difficulties in adjusting their subsequent responding, despite feedback pertaining to the ineffectiveness of their performance (Houghton et al., 1999; Sergeant & Van der Meere, 1988). In line with this, it has been suggested that failure to adjust performance may reflect an interaction between behavioural inhibition and the retrospective-prospective functions of working memory (Barkley, 1997a).

Kaplan, Dewey, Crawford, and Fisher (1998) examined verbal and non-verbal memory in 53 ADHD, 63 RD, 63 ADHD+RD, and 112 control children using the Wide Range Assessment of Memory and Learning (WRAML; Sheslow & Adams, 1990). The WRAML is a standardised test of memory function in children between five and 18 years of age and consists of nine subtests that between them assess verbal memory, visual memory, learning, and memory

retention. The analyses revealed a multivariate main effect for group on the verbal memory subtests (Story Memory, Sentence Memory, and Number/Letter Memory) which was supported by univariate main effects for Sentence Memory and Number/Letter Memory. A multivariate main effect for group was also observed on the visual memory subtests (Picture Memory, Design Memory, and Finger Windows) which was supported by a univariate main effect for Finger Windows, in which participants must point their finger through a series of “windows” in sequential order. Post hoc comparisons of these univariate effects revealed that the ADHD, RD, and ADHD+RD groups scored significantly lower than the control group on all three of these subtests (Kaplan et al., 1998).

In addition, all three disordered groups performed significantly worse than controls on the overall measure of general memory. Kaplan et al. (1998) also found that the RD and ADHD+RD groups scored significantly lower than either the ADHD or control groups on the overall measures of Verbal Memory and Learning, and had forgotten more information from the Story Memory subtest at delayed recall. However, no significant differences were found on the measures of Visual Learning, or the other measures of memory retention. Kaplan et al. (1998) concluded that these data were consistent with Barkley’s (1997a) model of ADHD and provided support for the notion of working memory deficits in ADHD. However, it should be noted that there were significant differences in the mean age, estimated IQ, and socio-economic status of the groups being compared. In addition, while the difference in sex distribution across the four groups was non-significant, the proportion of females ranged between 15.2% to 50%, and 54.7% of the ADHD participants and 49.2% of the ADHD+RD participants were medicated at the time of testing (Kaplan et al., 1998).

In another study, Oie, Sundet, and Rund (1999) compared the memory function of 19 adolescents with schizophrenia (aged 13-18 years), 20 with ADHD (aged 11-18 years), and 30 control children (aged 12-18 years). The WISC-R Digit Span subtest (Wechsler, 1974), California Verbal Learning Test (Delis, Kramer, Kaplan, & Ober, 1987), Kimura Recurring Figures test (Kimura, 1980), and the Digit Symbol Location task (Oie et al., 1999) were chosen to assess visual and verbal memory, short and long term memory, and recall and recognition memory. The results revealed that relative to the controls, the schizophrenia group showed significant impairments in both visual and verbal memory, while the ADHD group only showed significant impairment on measures of verbal memory and learning. While these findings appear to be consistent with Kaplan et al. (1998), Oie et al. failed to control for comorbid RD in the ADHD sample, which was an acknowledged limitation of the study. Thus it is possible that the verbal memory impairments of the ADHD children might have arisen from the known comorbidity with RD (Oie et al., 1999), since Kaplan et al. (1998) also found that children with RD and ADHD+RD performed worse than ADHD children on Verbal Memory and Learning.

More recently Kuntsi et al. (2001) used three working memory measures with a sample of 51 pervasively hyperactive children aged between seven and 11 years. The Delayed Response Alteration Task (Carpenter & Gold, 1994) was utilised, in which participants must choose between two boxes that are presented on a computer screen; each individual is told whether his or her response is correct. The child's task is to determine the rule the computer uses to decide which box is correct. If the child does not find out the rule (which consists of choosing the coloured and uncoloured box on alternate trials), the rule is explicitly taught by the researcher. The second measure utilised was the Sentence Span task (Siegel & Ryan, 1989) in which the child is read several

sentences and then asked to supply the missing last word in each sentence. At the end of each set of sentences, the child is asked to recall all of the words that he or she had supplied, in the correct order. The third measure, the Counting Span task (Case, Kurland, & Goldberg, 1982), is analogous to the sentence span task except that the child is asked to count the number of dots on a series of cards instead of supplying words. Significant group differences were found on the post-instruction phase of the delayed response alteration task and both the sentence span and counting span measures, although these differences became non-significant after controlling for IQ.

In line with the recent findings of Willcutt et al. (2000) which suggested considerable genetic overlap between inattention and RD, Tannock (2001) postulated that a deficit in working memory might be characteristic of both ADHD and RD. According to Tannock (2001) a common impairment in verbal working memory might also help to explain the frequent comorbidity between ADHD and RD. Although it is not possible to examine this assertion directly in the present study, evidence of impairment on measures of verbal and non-verbal memory, immediate and delayed recall, or working memory, may be provided by the Children's Memory Scale (CMS; Cohen, 1997). This recently developed and validated instrument was utilised in the present research.

Attention

Despite considerable research, attempts to characterise the exact nature of the attention deficit associated with ADHD have proven largely inconclusive. In many cases, the inconsistent research findings might be attributed to methodological limitations such as small sample sizes, substantial variation in diagnostic procedures, and failure to control for the use of stimulant medication, ADHD subtype, and comorbidity (Barkley, 1997b; Houghton et al.,

1999). In addition, whilst there appears to be general agreement that attention is multifactorial, there remains a bewildering array of subdivisions of the attentional construct (Denckla, 1996). Various theories have proposed the delineation of attention into the following components: selective and divided; automatic and effortful; and focus, shift, sustain, and encode (Denckla, 1996). Posner and Peterson (1990) argued that attention consists of at least three separate systems: a selection system responsible for selecting relevant stimuli; a vigilance system, responsible for maintaining readiness to respond in the absence of external cues; and an orientation system, responsible for engaging, moving, and disengaging attention.

Typically measures of selective attention involve the visual search for predetermined targets against competing and irrelevant foils (e.g., locating the knife-and-fork symbols which represent eating facilities on a road map; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1996). In contrast, Continuous Performance Tests (CPTs), which demand sustained attention and vigilance, have been the most widely used measure of sustained attention deficits in children with ADHD (Denckla, 1996; Lin, Hsiao, & Chen, 1999). The CPT is a paradigm in which a series of stimuli (usually digits or numbers) are presented, and participants are required to respond to infrequent, randomly presented targets (Swaab-Barneveld et al., 2000). The dependent measures taken are the number of commission errors (i.e., failures to respond to the target signal, for which a response is required) and the number of omission errors (i.e., failures to withhold a response when no response is required). While commission errors (i.e., missed target signals) are generally attributed to failures of sustained attention (Robertson et al., 1997), omission errors are considered to reflect impulsivity (Swaab-Barneveld et al., 2000).

The results of studies using CPTs, however, have been equivocal with some investigations demonstrating significant deficits in sustained attention and vigilance (e.g., Aylward, Verhulst, & Bell, 1990; Barkley, Grodzinsky, & DuPaul, 1992) while others do not (e.g., Schachar, Logan, Wachsmuth, & Chajczyk, 1988; Van der Meere & Sergeant, 1988a, b). In a meta-analysis of 26 CPT studies, Losier, McGrath, and Klein (1996) found that children with ADHD performed significantly worse than non-ADHD controls in terms of both commission and omission errors. Oades (2000) also reported similar results with a sample of 14 ADHD children, 11 children with a tic syndrome, and 14 healthy controls, using two versions of the CPT (the standard paradigm, and the CPTax in which each target “x” must be preceded by an “a”). However, the limited size of the sample employed in this study would suggest that further research is necessary. Research by DeWolfe, Byrne, and Bawden (1999) has also examined the performance of 25 preschool children with ADHD using visual and auditory forms of the CPT. DeWolfe et al. (1999) found that although the ADHD children made significantly more commission and omission errors on the visual CPT, no significant differences were observed on the auditory CPT.

Swaab-Barneveld et al. (2000) used a visual CPT to study the performance of boys with a range of psychiatric diagnoses (including 52 ADHD boys and 55 healthy controls, 29 boys with oppositional defiant or conduct disorder, 29 boys with anxiety or dysthymia, and 43 boys with pervasive developmental disorder). The results revealed that ADHD children were slower, less accurate, more impulsive, less likely to adjust their behaviour in response to feedback, and showed a larger decrease in vigilance over time compared to normal controls. However, although the ADHD children were the only psychiatric group to be characterised primarily with an “attention deficit”, Swaab-

Barneveld et al. (2000) found that deficits in sustained attention deficits were not specific to the ADHD group.

Attentional switching is measured using tasks that require an individual to frequently shift the focus of his/her attention, such as changing the direction of counting, in tasks which in themselves are relatively undemanding (Robertson et al., 1996). However, only a very limited amount of research appears to have examined this construct in ADHD children in recent years. Recent research by Cepeda, Cepeda, and Kramer (2000) for example used the task switching paradigm to examine attentional switching in 16 ADHD and 16 Control children (aged 6-12 years) matched on age and IQ. In the task switching paradigm, participants perform two simple tasks such as deciding whether a letter is a vowel or consonant or deciding whether a number is odd or even. In the baseline condition, participants perform the same task a number of times, whereas in the second condition they must switch between one task and the other. The increase in the response time provides a measure of the time required for the executive control processes to switch from one task to another. Cepeda et al. (2000) found that these "switch costs" were significantly larger in unmedicated ADHD children than in non-ADHD Controls, although their performance normalised on resumption of their normal medication regime. Furthermore, the performance of the ADHD children did not differ significantly from Controls on the non-switch trials regardless of stimulant medication, suggesting that these trials place only minimal demands on the executive processes.

A recent study using the Test of Everyday Attention for Children (TEA-Ch; Manly, Robertson, Anderson, & Nimmo-Smith, 1999), found significant differences in sustained attention, attentional switching, and dual task

performance, between 24 ADHD children (mean age 10.0 years) and similarly aged Controls. However, no significant difference were found on the measures of selective (or focused) attention, and Manly et al. (1999) did not examine the relationship between attentional performance and ADHD subtype. Whilst the attentional characteristics of the ADHD subtypes have yet to be examined systematically, research to date intimates that the ADHD Predominantly Inattentive child may have more problems with focused or selective attention, information processing, and memory retrieval. In comparison, the ADHD Combined Type child may have more problems with persistence, working memory, and inhibition (Barkley, 1997b). However, as Barkley (1997b) pointed out, the results of such studies are not sufficiently consistent to conclude unequivocally that these two subtypes have a different attentional disturbance or different patterns of associated cognitive deficits.

The TEA-Ch was used in the present study since it provides measures designed to be sensitive to three types of attention in children (i.e., selective or focused attention, sustained attention, and attentional switching/dual task performance). This permitted the examination of a number of hypotheses pertaining to the nature of the attentional impairment(s) in unmedicated boys with ADHD (and no comorbid conditions), according to subtype and relative to Age-matched Control children. Further information about the TEA-Ch is provided in Chapter Four.

Concept of time

According to Bronowski, the basis for a sense of time derives from the ability to hold a sequence of events in working memory. By comparing these events against each other in any sequence, a sense of time and temporal duration arises (Barkley, 1997a). Barkley (1997b) subsequently predicted that as a consequence

of their hypothesised deficiencies in working memory, children with ADHD should manifest impairments in their sense of time and its associated retrospective (sensory) and prospective (motor) functions.

Evidence for impairment in the concept of time of ADHD children has been demonstrated in a number of studies using various paradigms and a variety of time durations. Typically, researchers have required participants to: (a) produce a verbally presented time interval by signalling the start and finish of the interval (such as by turning a light on and then off), (b) verbally report the duration of a previously presented time interval, and (c) reproduce a previously presented time interval in a similar manner. According to Barkley et al. (1997), it is this last paradigm (time reproduction) which is the most difficult to perform and may be the most rigorous means of testing the construct of time (see Barkley et al., 1997, for a more detailed description). Furthermore, these kinds of tasks place heavier demands on working memory (Barkley et al., 1997) and may thus more accurately represent the subjective sense of time (Zakay, 1990).

Cappella, Gentile and Juliano (1977) used durations varying from 7 seconds up to 60 seconds in their earlier time estimation studies with hyperactive and normal children. Results indicated that all children made larger errors as the time durations increased, but that hyperactive children made significantly larger errors in time production than Controls, and that the magnitude of these errors increased with the length of the duration to be reproduced. These findings were subsequently replicated by Walker (1982) who found that boys diagnosed as impulsive made significantly more errors in a time reproduction task.

More recently Barkley et al. (1997) conducted two studies to compare sense of time in children with and without ADHD. In a preliminary study, 32 unmedicated ADHD children aged 8 to 13 years were presented with time reproduction tasks in which they were required to replicate a given time interval using a flashlight. In one type of treatment condition a distractor (a Jack in the Box) was presented since such events have been shown to decrease the accuracy of time reproduction by children in comparison to non distractor periods (Zakay, 1992). The results indicated that ADHD children made significantly larger time reproduction errors than Controls at the 6 and 10 second durations with no distractor and at the 10 and 16 second durations with a distractor. Both groups increased the magnitude of their errors with increasing duration. The Jack in the Box served as both a visual and auditory distractor and while these had an effect on participant's performance no conclusions can be drawn as to which specific component (i.e., visual or auditory) was the effective distractor. The present research therefore attempted to address this issue by employing separate visual and auditory distractors.

Using the same testing procedure over five time durations (12, 24, 36, 48, and 60 seconds) Barkley et al. (1997) tested an additional 12 ADHD children and 26 Controls. Results revealed that the ADHD group made significantly larger errors of time reproduction, and that the magnitude of these discrepancies was increased by the presence of a distractor, particularly at the 12 to 36 second durations. Furthermore, the discrepancies increased with the length of the duration to be reproduced. Barkley et al. (1997) commented that the ADHD children appeared to be making larger time reproduction errors than Controls, but that the direction of these errors was quite variable. In conclusion it was suggested that ADHD children are more variable or erratic in their time reproductions than Controls.

Dooling-Litfin (1997) compared the performance of 16 ADHD children and 14 Controls aged between 8 and 11 years on a simple time reproduction task. During this study, the examiner demarcated six time intervals ranging from 2 to 60 seconds using simple verbal cues at the beginning ("Go") and end ("Stop") of the interval to be reproduced. Participants were then asked to reproduce the interval by saying "Go" and then "Stop" when he or she thought that the same amount of time had passed. Results demonstrated that ADHD children showed significantly larger absolute discrepancies (i.e., the magnitude of errors regardless of direction) than Controls. However Dooling-Litfin qualified these findings by suggestion that the lack of significance in direction of errors (that is, over- versus underproduction) may have been due to the greater variability in accuracy amongst the ADHD group.

More recently, Rubia, Taylor, Taylor, and Sergeant (1999) examined the motor timing synchronisation of boys with ADHD using motor timing anticipation and motor timing synchronisation tasks. In the anticipation task used by Rubia et al. (1999), participants were required to monitor the inter-stimulus interval between a stimulus (an airplane) which appears three times on a computer screen, and press a response button in anticipation of the appearance of the fourth and subsequent airplanes. In the motor timing synchronisation task, participants were required to synchronise their motor response (i.e., a button press) to the appearance of the stimulus airplane, which was presented at regular intervals on the computer screen. Whilst Rubia et al. found no significant differences between the ADHD and Control boys in their perception of time (as measured by the anticipation task), they reported that the boys with ADHD were impaired in the timing of their motor output (as measured by the synchronisation task). In particular, these boys were found to be more inconsistent in anticipating, self-regulating, and synchronising their motor

output to external visual stimuli. However, it is important to note that only 11 ADHD and 11 Control boys participated in this study and that the time discrimination task used simply involved deciding whether a five-second interval was followed another five second interval, or a shorter interval of three seconds' duration.

Although the findings from studies to date have suggested an impaired sense of time in children with ADHD, a number of issues may have confounded these studies and hence these need to be addressed in future research. For example, all of the studies to date appear to have involved small sample sizes which potentially limits their generalisability. Furthermore, as Barkley (1997a) suggested, since ADHD children have problems with motor control and persistence, requiring ADHD children to press and hold an activation button on a flashlight over long time durations might be problematic. In addition, order effects might exist since in most studies time durations were presented in a standard sequence. Finally, since research has suggested extensive comorbidity with ADHD (25%-30%, Barkley, 1997a; 38%, Langsford, 1999) this may confound any explanation linking impairments in sense of time with ADHD.

The present investigation sought to address these issues and to extend the work of Barkley et al. (1997) by using a larger sample of ADHD and Control boys matched for age and with no diagnosed comorbid conditions. The current research also used shorter time intervals to reduce demands on persistence, and used a new measure of time reproduction, which is described in detail in Chapter Four. Furthermore, the accuracy of time reproduction of ADHD and Control boys was evaluated using separate visual and auditory modes of presentation of the time reproduction tasks, and in the presence (and absence) of distractors.

Chapter summary

In summary, this literature review has shown that ADHD is a pervasive and impairing neurobiological/developmental disorder that affects between 3%-5% of the school-age population (although reported prevalence figures have been found to range from 1% to 25%). This literature review has also shown through historical developments that response inhibition and not attention appears to represent the central impairment in ADHD. Evidence from the literature has also suggested that an impairment in working memory might play a significant role in ADHD (e.g., Denckla, 1996; Barkley, 1997a). Barkley (1997c), for example, has suggested that the delayed internalisation of speech and attainment of rule-governed behaviour seen in ADHD children may occur as a result of deficient verbal working memory, and that impairments in sequencing and sense of time may result from impairments in non-verbal working memory. Thus, deficiencies in verbal and/or non-verbal working memory might account for many of the practical difficulties observed in ADHD children, including poor organisation of behaviour with respect to time, problems integrating temporal and spatial concepts, failure to apply past experience and knowledge in new situations, and dual task performance.

In Study One, these issues will be examined in further detail through a series of semi-structured interviews with leading international researchers in the field of ADHD research. These interviews will examine the current conceptualisation(s) of ADHD, the predicted executive impairments of ADHD children, and the types of instrumentation that might be sensitive to these impairments. This information will then guide the current research in a second major study in which the predicted executive impairments of children with ADHD will be identified and systematically examined using instrumentation specifically

designed for this purpose. It is anticipated that the results of this investigation will contribute to and extend current theoretical understanding of ADHD.

Research questions

The present research therefore sought to examine the current conceptualisation(s) of ADHD, arising from the theoretical and research literature and subsequently from interviews with leading international professionals in this field of research. From the literature reviewed and commensurate with the aims of the present research, the following research questions were formulated:

1. What are the current theoretical and clinical conceptualisation(s) of ADHD and its subtypes?
2. What are the predicted executive impairments of ADHD children and their observable manifestations?
3. What types of instrumentation are sensitive to these executive impairments?
4. To what extent can these predicted executive impairments be verified empirically?
5. How might this information be used to contribute to, challenge or extend the current conceptualisation of ADHD?

CHAPTER THREE

Study One: An exploratory study in the conceptualisation of the executive functions in ADHD

Methodology and Results

This chapter describes the methodology and results of Study One, the purpose of which was to establish a conceptual framework within which the subsequent phase of the research (Study Two) could proceed. Thus, Study One served to define the parameters in the search for the central executive impairments exhibited by children with ADHD. This process comprised a number of distinct, yet inter-related, phases. Initially, a comprehensive and critical review of the theoretical and research literature was undertaken (presented in Chapter Two). This was followed by a series of exploratory semi-structured interviews with leading international researchers in the fields of education, psychology, psychiatry, and paediatrics. The data obtained from these semi-structured interviews are reported here and discussed in further detail in the following chapter.

Participants

Participants in the semi-structured interviews which comprised Study One included six influential and highly regarded scholars within the field of ADHD research. Participants were purposefully chosen to ensure that they had extensive clinical and research experience of children with ADHD and included senior academics and paediatricians, many of whom have published extensively. The professionals interviewed in Study One were:

Russell Barkley, PhD

Dr Barkley is Professor of Neurology and Psychiatry and Director of Psychology at the University of Massachusetts Medical Center. Professor Barkley is a much sought-after keynote speaker at international conferences and an internationally-recognised authority on ADHD, with over 100 publications to his credit, including several books. He has published in many leading international journals including the Journals of: Abnormal Child Psychology, Child Psychology and Psychiatry, Developmental and Behavioral Pediatrics, Learning Disabilities, and the American Academy of Child and Adolescent Psychiatry. Professor Barkley has won numerous grants from many external sources including the National Institute of Mental Health (NIMH) and is a past president of the International Society for Research in Child and Adolescent Psychopathology (ISRCAP).

Rosemary Tannock, PhD

Dr Tannock is an Associate Professor at the University of Toronto and The Hospital for Sick Children, Toronto. In addition to her membership of ISRCAP, Associate Professor Tannock has also served on the review board of the NIMH, and is a sought-after keynote speaker at international conferences. She has in excess of 50 publications to her credit, including several book chapters and articles in leading international journals including the Journal of Abnormal Child Psychology, the Journal of Child Psychology, the Journal of the American Academy of Child and Adolescent Psychiatry, the Journal of Clinical Child Psychology, and Clinical Psychology Review.

Thomas Brown, PhD

Dr Brown is Associate Director of the Yale Clinic for Attention and Related Disorders at the Yale University School of Medicine. Dr Brown has presented papers, workshops and symposia at national meetings of the American Psychological Association, American Psychiatric Association, American Academy of Child and Adolescent Psychiatry, and the International Neuropsychological Society. Dr Brown has also published articles in a number of professional journals and is author of the Brown Attention Deficit Disorder Scales published by The Psychological Corporation. Dr Brown's research interests include the assessment and treatment of ADHD (especially the Predominantly Inattentive Type) and executive function and memory impairments in ADHD.

Annemaree Carroll, PhD

Dr Annemaree Carroll is a Senior Lecturer and Registered Psychologist at the Schonell Special Education Research Centre, University of Queensland, Brisbane, Australia. She has published articles in a number of leading international journals including the Journal of Child Psychology and Psychiatry, the Journal of Educational Psychology, and Clinical Psychology Review. Dr Carroll has won early career research awards and been a recipient of grants totalling over \$1 million. In addition, Dr Carroll is a member of the professional advisory boards of the Queensland ADHD and Tourette's Syndrome support groups.

Dr Christopher Green

Dr Green is a consultant paediatrician based in Sydney, Australia, who has extensive clinical experience of children with ADHD and developmental

disorders. Dr Green is the author of a number of influential books including "Toddler Taming" and "Understanding ADHD" and has been instrumental in raising public awareness about ADHD worldwide through numerous radio and television appearances. Dr Green has also been the keynote speaker at a number of international conferences. Until recently, Dr Green was a Clinical Lecturer at the University of Sydney and Head of the Child Development Unit at the Royal Alexandra Hospital for Children, before having to step down due to illness.

Dr Trevor Parry

Dr Parry is a consultant paediatrician with extensive clinical experience of children with ADHD. Dr Parry is also Director of Community Paediatrics for Princess Margaret Hospital, Perth, Western Australia. In addition, Dr Parry is Director of the State Child Development Centre, where he is responsible for the assessment and diagnosis of children with ADHD and other developmental disorders. Dr Parry's own particular speciality is the ADHD Predominantly Inattentive Type. Furthermore, Dr Parry has been a member of various state and federal committees pertaining to ADHD.

Settings

The location for the interviews was arranged by prior agreement with participants. Individuals were interviewed at the New York Hilton and Towers, the venue of the Tenth Annual Children and Adults with Attention Deficit Disorders (CHADD) Conference in New York City, 15-17 October, 1998, with the following exceptions. Dr Trevor Parry was interviewed at the State Child Development Centre, located in Perth, Western Australia, and Associate Professor Rosemary Tannock and Dr Annemaree Carroll were interviewed at

the Centre for Attention and Related Disorders, The Graduate School of Education, The University of Western Australia. During the interviews, the interviewer sat on the opposite side of a small table to the participant, with a portable audio cassette recorder placed on the table between them to record the interview.

Instrumentation

Semi-structured interviews were utilised in the present study which sought to elicit new information that has not been reported in the available literature to date. The use of open-ended interview questions allows participants to formulate their own answers, and to disclose their own opinions and feelings, thus reducing the potential for interviewer bias. The semi-structured interview questions systematically addressed those pertinent issues which arose from the initial review of literature. A copy of the semi-structured interview questions is included as Appendix A.

Participants were first asked to describe how they conceptualised ADHD. Their views were then sought pertaining to the nature and composition of the ADHD subtypes, with particular regard to the differential characteristics of these subtypes and the nature of any associated attentional problems. Participants were also asked to respond to suggestions that only two subtypes of ADHD may exist in practice (due to the virtual absence of the ADHD-HI diagnosis in clinical settings), and that the ADHD-PI and ADHD-CT subtypes may in fact represent two inherently different disorders (Barkley, 1997a). Subsequent questions examined participants' understandings of ADHD, inquiring as to whether they viewed attentional impairment as central to the disorder, and the mechanism by which such an impairment interacts with the executive functions (EFs). Feedback was also sought regarding Barkley's (1997a) prediction that a

deficit in response inhibition represents a central impairment in ADHD, which in turn affects the effective deployment of specific EFs.

The tendency of ADHD children to perseverate, despite the presence of corrective feedback (Houghton et al., 1999), was discussed with a view to eliciting examples of situations in which such behaviour is likely to occur. Impairments in working memory were also advanced for discussion and participants were asked to comment on this and the way(s) in which working memory might be impaired or otherwise manifest in ADHD children. Feedback was also sought pertaining to Barkley et al.'s (1997) prediction that a deficiency in non-verbal working memory might also manifest as an impaired concept of time in ADHD children, with particular regard to the cross-temporal organisation of behaviour. Attention was drawn to ADHD children's supposed use of past knowledge and experiences (hindsight) in novel contexts (forethought), the integration of time and space, and dual task performance.

In line with Barkley's (1997a) predictions of impairments in verbal working memory, delayed internalisation of speech, and thus rule-governed behaviour, participants were asked to describe what they perceived as the role of language in children with ADHD. Finally, participants were asked whether they viewed the current terminology (ADHD) as an appropriate diagnostic label, and whether its placement amongst the Disruptive Behaviour Disorders category of DSM-IV is warranted. At the conclusion of the interview, participants were given the opportunity to comment, qualify their statements, or provide additional information.

Procedure

Participants were initially contacted via e-mail (international and national) or by telephone (local) and informed of the purpose of the present research, and then e-mailed (or telephoned) to arrange mutually acceptable times and locations for the interviews. At the commencement of each interview, it was reiterated to the participant that the interview would be recorded, subject to their approval. None of the participants had any objections to the recordings being made.

During the course of the interviews, every effort was made to ensure the homogeneity of the interviews by following a written standardised administration format. However, the open-ended nature of the questions afforded participants considerable latitude in their responses. If particular topics of interest were raised during the interview, the researcher probed with further questions in order to elicit as much relevant information as possible. The moderator subsequently guided the participant back to the pre-designed format of the questions. In some cases, participants' responses pre-empted subsequent interview questions. In these instances, the moderator allowed the participant to finish speaking before asking the next question, thereby allowing participants to elaborate on their previous response should they wish, but emphasising that the participant may have already answered the question.

Data analysis

The transcripts obtained from the recorded interviews were analysed using procedures similar to those used by Zemke and Kramlinger (1985). This involves generating a list of key ideas, words, phrases, and verbatim quotes; using these ideas to formulate categories and placing ideas and quotes in

appropriate categories; examining the contents of each category for subtopics; and selecting the most frequent and most useful illustrations for the various categories.

Results

The data presented here are discussed in further detail in the following chapter, where they also serve to inform the selection of instrumentation to be used in the subsequent phase of the research (Study Two). Participants' responses were arranged into five sections comprising: (1) The nature of ADHD and its subtypes; (2) The characteristic impairments of ADHD children; (3) The role of response inhibition and the executive functions (EFs); (4) Verbal and non-verbal working memory; and (5) Further comments and unresolved issues. For the purposes of analysis, each of these broad categories (or themes) was divided into a number of sub-categories or questions. (Copies of the interview transcripts have been reproduced as Appendices B through G.)

(1) The nature of ADHD and its subtypes

Moderator (M): Briefly, how would you describe your conceptualisation of ADHD?

Whilst this question received a range of individual responses, the prevailing consensus among all six participants appeared to be that ADHD represents a problem of self-regulation, which manifests as impairments in the executive functions (i.e., those organisational processes mediated by the frontal lobe). Some of the responses were as follows:

"I think the problem is largely one of the development of self-regulation... I suggested I think there were four major forms of behaviour that start out as

public, are then turned on ourselves as a means of controlling us, and then gradually are made private. Specifically, the four things are: the ability to sense privately to ourselves, primarily including visual imagery - but other senses also being capable of private use without others seeing us. This allows us to simulate information mentally without actually having to test it out in the real world first. The second one is language - that's a very Vygotskian view of language - turned on the self, made private. The third is emotional behaviour that is then made private - the individual uses emotions to themselves. And then lastly is this concept of reconstitution, which I think is probably most akin to play - a child who takes apart and rebuilds blocks and designs and manipulates the environment - and then gradually is able to do this not only with symbols and language but then can do it internally as well" (Professor Russell Barkley).

"I would differentiate my point of view from that of Russ Barkley on the grounds that I think of his model as a very good one in terms of describing executive function except when he gives primacy to the specific function of behavioural inhibition... with that modification I would pretty much join him in thinking of this as Attention Deficit Disorder as being essentially developmentally impaired executive function" (Dr Thomas Brown).

"ADHD appears to be a disorder of response inhibition. Whilst it was once thought that attention was the key element of the disorder, it is now more likely that response inhibition is the key element with other features being hyperactivity, impulsivity, inattention plus problems with self-regulation" (Dr Annemaree Carroll).

"ADHD is a frontal lobe problem. A problem of self-monitoring, self-monitoring behaviour, self-monitoring learning, causes children to be out of

step in their behaviour and out of step in their learning” (Dr Christopher Green).

“I would see ADHD, by DSM-IV criteria, as a developmental, genetic, neurobiochemical disorder of organisational processes” (Dr Trevor Parry).

“It’s most likely I think... a neurodevelopmental problem, so although we still define it behaviourally, I believe that’s just the observable consequences if you like, of some underlying problems in dealing with information processing... I think it really is a manifestation of a complex system of cognitive impairments - difficulty processing information - that in turn give rise to some of these observable behavioural symptoms that we see like inattention, disorganisation, the so-called behavioural impulsiveness et cetera” (Associate Professor Rosemary Tannock).

M: Please describe your view of the ADHD subtypes.

Although it was clear that participants had differing views about the ADHD subtypes, it seemed that the majority of them viewed inattention as a characteristic that is pervasive across the ADHD subtypes. Participants described the inattentive symptoms as a central characteristic of both the Predominantly Inattentive Type and the Combined Type. Responses were as follows:

“I think that the Combined Type is an output disorder, meaning that there is no problem with how information is being perceived and processed but that the problems come in when behaviour must be organised and executed, or when strategies must be applied to the information coming in to organise it better... In the inattentive children, I think it is an input problem. I think it does have to do with the initial perceptual, selective, and processing aspects – the front end

of an information processing model. And so I think it's a different attentional mechanism - I would say that they are focused or selective attention problems and the other is an executive/behaviour control problem. That's how I would conjecture that they differ" (Professor Russell Barkley).

"The first thing I think it's important to note is the division of the two symptom clusters... I think this has been a useful advance in conceptualisation in the field... And what becomes difficult now is when you say theoretically these two clusters may give rise to three subtypes - and that is where I think you run into problems. And why is that? Because essentially how it's operationalised in DSM is that you've got to have at least six of the inattentive and fewer than six of the hyperactive-impulsive to be called the Predominantly Inattentive Type. But in reality, you're going to get kids who have six of the inattentive and five of the hyperactive-impulsive. It also depends which informant you're going to base that on" (Associate Professor Rosemary Tannock).

"The way I see it is that the PI type symptoms are present in those that we would diagnose as Predominantly Inattentive Type but they also are present in virtually all of the people who have the Combined Type. And really the Predominantly Hyperactive-Impulsive Type is essentially a category for talking about preschoolers who aren't expected to be able to attend very much anyhow" (Dr Thomas Brown).

"I would recognise the Combined - where you've certainly had an early history of some kind of kinesis or Barkley's inhibitory/impulsivity and that is no longer current in the primary school child as he gets older, and inattentive disorganisation is. So you would see that. But none of that allows for more widespread developmental disorganisation which is frequently in partnership with just those learning and attentional aspects that Barkley speaks about. So I

guess that though the Barkley theory fits well for classical hyperkinetic disorder which is not necessarily associated with these other areas of disorganisation, that's fine, but it doesn't allow for what I think actually in our experience is probably a much larger group of kids who have the ADHD part without hyperkinesis as a component" (Dr Trevor Parry).

"All ADHD - there are very few pure one or others - most are a mix and most of the mixes are different to other mixes - so it is a very varied thing. I see the majority are a mix of behaviour and learning but the balance of whether it is more behaviour or more learning varies dramatically from child to child. And I see that there are very, very, very few pure ADHD inattention only... There is probably a very great number of those who've got a predominantly learning problem - the ADHD Predominantly Inattentive - but they've nearly all got a little bit of impulsivity and 'stupid' behaviour with it" (Dr Christopher Green).

M: What are your views on the suggestion that only two subtypes of ADHD may exist (i.e., the ADHD-CT, which subsumes the ADHD-HI, and the ADHD-PI)?

While the majority of participants appeared to agree with the delineation of the ADHD-PI and ADHD-CT subtypes, there was little support for the suggestion that only two subtypes of ADHD may exist, as the following responses illustrate:

"In examining the most recent research in this area it would seem that the Predominantly Hyperactive and Combined Type children are on the same continuum or display similar features compared with the Predominantly Inattentive Type children" (Dr Annemaree Carroll).

“The Predominantly Hyperactive-Impulsive Type is essentially a category for talking about preschoolers who aren’t expected to be able to attend very much anyhow” (Dr Thomas Brown).

“I suspect there are probably four or five subgroups... You know kids where there is no evidence clinically at all at any time of there having being a hyperkinetic component... certainly there is a group of - I believe of - what might be called if not have to be called Inattentive ADHD that are not just a burned out Combined” (Dr Trevor Parry).

“I actually think that - we certainly see kids with hyperactive-impulsive only. Even when we take into account information from parents and teachers. They are relatively few sure, and they’re not always the young kids. So it’s not that they’re just up to six and seven year olds, we also see some of the nine, ten and eleven year olds like this too” (Associate Professor Rosemary Tannock).

M: How would you respond to the suggestion that the ADHD Predominantly Inattentive and the ADHD Combined Type might represent separate disorders?

The range of responses provided by participants revealed that further research is necessary to clarify the nature of the ADHD subtypes and their characteristics. All but one of the participants were inclined to agree that the ADHD-PI and ADHD-CT represent two qualitatively different disorders. Responses were as follows:

“I would certainly hold that view, at least that view that you know kids where there is no evidence clinically - at all - at any time of there having been a hyperkinetic component... certainly there is a group of... inattentive ADHD that are not just a burned out Combined. And I think that the nearest that you

get to that... [is] Gillberg's concept of what he calls DAMP, by which he means disorders of attention, motor control, and perception" (Dr Trevor Parry).

"Given that the features of the Predominantly Inattentive children are so different in many aspects (e.g., daydreamers) from the Hyperactive and Combined, then yes, this could well be a likely view" (Dr Annemaree Carroll).

"If the Predominantly Inattentive type is being conceptualised as not having problems with inhibition, which is how we conceptualise it, and my model places inhibition at a key point in the development of these other functions, then there's no way that my model could speak to the Inattentive type" (Professor Russell Barkley).

"I think there are some intriguing genetic findings - or findings from twin studies - that do suggest that there may be something important to take into account that these clusters of symptoms may differentiate... It brings to mind a recent study by Willcutt and Pennington... they showed that... individuals who have extreme levels of inattention, show high heritability, irrespective of what their level of hyperactivity-impulsivity is. On the other hand, in that sample, individuals who showed extreme levels of hyperactivity-impulsivity, that was not highly heritable if it did not occur with a lot of inattention, which suggested that hyperactive-impulsivity alone may be something completely etiologically distinct from the hyperactivity-impulsivity that occurs with inattention" (Associate Professor Rosemary Tannock).

"I disagree sharply with Russ Barkley when he talks about how those Predominantly Inattentive Type are a whole different thing - I think that's something which is central to both subtypes" (Dr Thomas Brown).

(2) The characteristic impairments of ADHD children

M: What are the key features of ADHD?

The majority of participants described impairments with cognitive functioning. In particular, participants frequently cited difficulties with organisation and executive functioning. The comments received from participants included:

“I think probably it’s most useful to begin by saying I think of the cognitive impairments associated with ADHD as the central impairments... the main things are problems with being able to get organised and get started, problems with being able to stay tuned and screen out distractions, problems with being able to sustain alertness and effort, processing speed to complete tasks in a reasonable time, being able to manage affect so that it doesn’t interfere too much, and problems with short term working memory. And I see these as a cluster of functions that I think of as important in executive function” (Dr Thomas Brown).

“Whether or not I think it’s any specific one deficit, no is the answer. I don’t think we can really narrow it down and adopt this reductionist position that it can be a single, fundamental deficit. That’s too simple. I think that we’re going to have a group of them - in my head right now I would say I could think of about four or five difficulties with processing information” (Associate Professor Rosemary Tannock).

“I think the key one is the issue of difficulty with organisational processing... of course the classical difficulties are with concentration, impulsivity, and distractibility... But I suppose the kinds of things that we are much more aware/alert to these days is the issue of underachievement compared to known ability for no other identifiable reason... there is in other words an amalgam, an

interplay, of disorganisational, developmental delay, of which attentional deficiency, and to use Barkley's concept of executive decision or function, is the key" (Dr Trevor Parry).

"The main problem with ADHD is that it varies dramatically from child to child and the key features, if you're looking at behavioural presentation in the school age child, are impulsivity - why does such a clever child do such stupid things? - and insatiability - demand - the mosquito that buzzes you and doesn't give you space. Those would be the key things that are not present in other conditions. And the learning ones are a circling brain which is self-distraction, a problem of getting the focus on the right thing, a problem of moving focus from one thing to another, a problem of an over-focus, a problem of short term memory, and a problem of organisation" (Dr Christopher Green).

M: Do you think attentional impairment is central to ADHD?

Participants provided a range of responses to this question. Whilst some rejected the notion of attentional impairment as central to ADHD, others were inclined to accept a more broader definition of "attentional impairment" as characteristic of ADHD. The responses obtained from participants were as follows:

"No, no I don't. I think disorganisation is" (Dr Trevor Parry).

"No. I would see that behavioural inhibition is the central component of ADHD" (Dr Annemaree Carroll).

"I think that attention is a bad word - like hyperactivity. I think it is the self-monitoring, which means it is the control of the attention (that is, the coming in and out of attention, moving focus from one thing to another, regrouping after

a distraction) - it is the moving of attention - it isn't inattention. It isn't that they don't concentrate, it's that they find it hard to select - home in on - and keep homing in on the right thing - that's where it's all at" (Dr Christopher Green).

"Yes. But I also would say that it's attentional impairment broadly defined. If you take a look at the cluster of symptoms under attention what you see is that there is a wide range of cognitive impairments associated with them. It's not just paying attention in the sense of listening to a speaker, but it involves - you know - being able to get organised, being able to activate - that certain energetic, affective component to it, and modulating that affect, and there's a problem with short term memory that's a crucial element of it" (Dr Thomas Brown).

"Yes, absolutely... these symptoms of the inattention - if we look at the actual symptoms, they incorporate many critical cognitive - or suggest or reflect critical cognitive processing. And we know that they persist into adolescence and adulthood, whereas the kinds of fidgety/restless behaviours typically decline... And if we look at the comorbidity, that may also be informative. The comorbidity that's associated with the hyperactive-impulsive only type and the combined type is typically Oppositional Defiant Disorder and Conduct Disorder. By contrast learning disabilities typically go across the board" (Associate Professor Rosemary Tannock).

M: In particular, how would you distinguish the nature of any attentional problems between the subtypes?

This question also received a range of responses from participants who conceptualised the attentional impairments associated with the ADHD-PI and ADHD-CT subtypes in a number of different ways. For example:

“The Predominantly Inattentive children appear as daydreamers, with high levels of inattention, and in particular poor sustained attention. In contrast, the Combined Type have problems with withholding responses, and are often hyperactive, clumsy, with problem solving difficulties, inattention, problems with sequencing and time concepts, and distractibility... Where the Combined type may rapidly flit from one task to the other (i.e., selective attention difficulties) and may have problems screening out unnecessary information and are easily distractible, the Inattentives have more difficulties with sustained attention” (Dr Annemaree Carroll).

“I think that the Combined Type is an output disorder, meaning that there is no problem with how information is being perceived and processed... the problems come in when behaviour must be organised and executed, or when strategies must be applied to the information coming in to organise it better... the attentional problems there are: one, resistance to distraction, which is the interference control/inhibition problem; and an inability to guide behaviour by internal information, which is the sustained attention/sustained effort problem... So I think that their sustained attention and distractibility problems are due to the working memory deficits and the inhibitory deficits. In the inattentive children, I think it is an input problem... And so I think it's a different attentional mechanism - I would say that they are focused or selective attention problems. I think it does have to do with the initial perceptual, selective, and processing aspects - the front end of an information processing model” (Professor Russell Barkley).

“Not clearly. We've actually tried this by looking at just what I call the behavioural phenomenology. In other studies, where we were looking at an objective measure of activity - so we were using actigraphs. We didn't find on this measure, any difference between the Predominantly Inattentive Type and

the Combined Type. And it's puzzling because you'd assume if everybody's describing that the Combined Type are the fidgety/restless ones, that should be picked up on an actigraph, which measures movement... But we also looked... at the sustained type of attention and the selective, focussed attention - and in terms of just the symptom count and what's been endorsed, we really didn't see any difference there. But I think that's because we're just looking at these surface behaviours. So I think the next step is we clearly need to be looking at more of the cognitive processes, and this is where I think we're beginning to get some evidence of some separation. As soon as we go to the cognitive processing, then I think we might be seeing some differences for example in working memory" (Associate Professor Rosemary Tannock).

(3) The role of response inhibition and the executive functions (EFs)

Participants were invited to share their views on Barkley's (1997a) recent Unifying Theory of ADHD, which has response inhibition as the core deficiency in ADHD, which in turn leads to secondary impairments in four specific EFs. In particular, Barkley refers to four EFs that are gradually internalised over the course of normal human development. Specifically, these four EFs are: the ability to sense privately to ourselves (primarily visual imagery), the internalisation of language (i.e., the development of private speech), emotional behaviour that is then made private, and reconstitution (i.e., the analysis and synthesis of behavioural sequences). When interviewed, Professor Barkley himself outlined his theory in some detail, clarifying the role he hypothesises that response inhibition plays in the development of self-control. It is Barkley's (1997a) contention that the normal development and deployment of these executive functions is contingent upon response inhibition, which effectively provides the delay needed for these executive functions to develop.

Furthermore, Barkley predicts that an impairment in response inhibition in children with ADHD compromises the normal development (i.e., internalisation) of these executive functions, thus affording these children considerably lower levels of self-control.

“I think that over development those four behaviours slowly become private and as they do they take over the guidance of public behaviour, so that public behaviour is being guided by private information... this means that over the course of child development there is a shift between external control to internal control, of control by the temporal moment to control by the conjectured future... and from public observed self-control to private self-control that’s no longer observable” (Professor Russell Barkley).

M: [Question posed specifically to Professor Barkley.] As I understand it, the inhibition actually provides the time for these processes to occur?

“It gives you the time for it, but the other thing which I don’t think came across quite so clearly in the book [i.e., ADHD and the nature of self-control; Barkley, 1997c] is it is the mechanism that privatises the behaviour. You can’t privatise a public behaviour if you don’t inhibit the public manifestation of it. So not only does it give you the time to do these things because it’s delaying the prepotent response, it’s also precluding the public aspects of these private activities while you’re thinking about it. And because ADHD is disrupting this inhibitory mechanism, not only are more prepotent responses being released, but more behaviour is being engaged in publicly that others would have been doing in private” (Professor Russell Barkley).

All of the other participants were familiar with the theory and were very positive about the contribution that Barkley’s (1997a) model has made to the theoretical understanding of ADHD. Whilst participants’ comments were

largely favourable, they nevertheless raised a number of significant issues that they suggested should be addressed in subsequent research.

M: A recent theory by Barkley (1997) has response inhibition as the core deficit in ADHD, which in turn leads to impairment in specific EFs. What is your view on this theory?

“This has truly been a major, major advance in the field because it’s put out a model - and a model is there to be tested empirically, to be supported, or challenged... from the neuropsych findings to date it lent itself to the notion that inhibition may be the core feature...and whereas this has certainly been within our group, believed to be a major component of ADHD, our recent findings are really challenging that... we have not found robust differences between the Predominantly Inattentive and Combined Type in terms of behavioural inhibition, yet according to both Barkley’s model and the model proposed by Quay based on Gray’s model, they both argue that in fact the inhibition-impulsivity - the inhibitory control problems - would be restricted to this Combined Type, and primarily that’s therefore being accounted for by the hyperactive-impulsive symptom clusters. And we don’t find evidence for that” (Associate Professor Rosemary Tannock).

“Yes. This sounds very plausible and again in examining empirical evidence on the neuropsychological functioning of individuals, it seems that the ability to inhibit responses to a task is a central problem in children with ADHD” (Dr Annemaree Carroll).

“Yes, I am familiar with that and I think that that’s appropriate for hyperkinetic forms of ADHD and of course that’s all that Barkley explained - and in that context I am comfortable, but I am not comfortable in that where either of the

other groupings are not allowed in the spectrum and that clearly is meant to transpose across because I clinically don't think you'd see it" (Dr Trevor Parry).

"I think of his model as a very good one... except when he gives primacy to the specific function of behavioural inhibition... My model... needs to have his behavioural inhibition added to it and I think his model needs to be levelled so that you don't have that behavioural inhibition as the chief among equals" (Dr Thomas Brown).

M: How do you conceptualise the EFs, their range and their role?

While a precise definition of the executive functions continues to elude researchers even after many years of study, there appeared to be a general consensus among the participants that the construct refers to those higher-order cognitive processes responsible for the organisation and self-regulation of thought and behaviour.

"Executive functions are basically those strategies or processes that exist to help us self-regulate our behaviour - our ability to problem solve, shift from one thing to another, self-monitor, inhibit responses, sustain attention, and set maintenance" (Dr Annemaree Carroll).

"Well, executive function is the business of frontal lobe - it is the business of self-monitoring - that is absolutely central to ADHD" (Dr Christopher Green).

"I think the most important is working memory... and then problems with activating and organising as probably most central - and most frequently neglected in most of the formulations" (Dr Thomas Brown).

“The ultimate function I believe is the maximisation of future over immediate consequences... if you read Leda Cosmides’ work on social exchange... her paper with John Tooby lists the mental mechanisms that would need to be in place to allow social exchange to occur. And if you read the list it is: sense the past, project to the future, evaluate the changing value of a consequence over a period of time, and enter into a commitment with another person and then follow the commitment. You’ve just described each of the executive systems” (Professor Russell Barkley).

“The executive functions is a woolly concept - fuzzy. You can’t define it - nobody can agree on what they are. Rather I think we assume that executive functions are the superordinate processing involving wide distributive networks - neural networks - that integrate a whole range of more basic processes - like perception and so on... And I think that what we may be detecting is evidence of developmental anomalies in the networks that support constructs like inhibition or like working memory” (Associate Professor Rosemary Tannock).

M: Children with ADHD (and in particular, the Combined Type) appear to have difficulty inhibiting their immediate responses even when deferral of the response would lead to future gratification. Can you give some examples of where this may happen?

Participants described a range of situations in which this phenomenon might be observed in children with ADHD. However, Professor Barkley identified that the establishment of a competing schedule of rewards appears to be common to these tasks:

“The most immediate examples that come to mind are the ones I cite in the book which is Campbell’s cookie delay task and Joel Newman’s delay of gratification software program... But any task that sets up a competition between two schedules of reward, one involving an immediate and the other involving a delayed but larger one. Now what examples in life might that pertain to? Well anything that involves a reinforcer being available, but socially you have to wait for it” (Professor Russell Barkley).

This was supported by Dr Trevor Parry who commented:

“In the younger child particularly, who has great, great difficulty understanding in a formal way of what is anticipated, which might be going to the pictures - you know - having a reward, waiting for a birthday, having a holiday, or playing Nintendo - if it’s got to be in two days’ time rather than now... you see a very characteristic feature of all of the groups but particularly the inattentive of an over-focusing on the issue of the now to the exclusion of all other things” (Dr Trevor Parry).

“Often they’ll say the first thing that comes to mind in a conversation, and in the process sometimes even interrupt people because what they’ll tell you is that if they don’t say it when they think of it, they’re not going to remember it later... it’s part of their cognitive style - they tend to often think quickly and be thinking about a lot of different things all at one time... And in some tasks, where you need to be able to think in this multi-tasking way, their ADHD style is really an asset” (Dr Thomas Brown).

“Yes. An example of this would be if they were told they could play on the computer for five minutes now or if they waited until after lunch they could play for half an hour. Examples of interference might be: giving a set of instructions and then someone saying something which throws out the ability

to complete what has been asked. Inhibition: not being able to stop yourself calling out, hitting the person next to you, or throwing the rubber” (Dr Annemaree Carroll).

“Well if you were to listen to parents, probably the number one thing that they would tell you - of certainly young ADHD children - is an inability to take frustration... when things don’t go well, we can walk away from them. When the ADHD child’s brother takes their toy, they wallop them. When things don’t go to plan - when it’s raining and they can’t play - they can’t take that. It is that business of inability to take frustration that would be one of the classic things that you would see” (Dr Christopher Green).

“With difficulty these days. I think at one time I would have said yes. I’m really struggling with this notion - do they really have difficulty withholding responses? I look at these youngsters in our laboratory situation, and I look at them doing any of our so-called tasks - they don’t actually seem to have difficulty withholding - in fact they’re often slow to respond. And I can’t find many instances where they respond too quickly. On the other hand, a child who is anxious can often respond too quickly. So I’m not really sure what I’m seeing any longer” (Associate Professor Rosemary Tannock).

M: Many ADHD children may persist in giving incorrect responses (perseverate) even when corrected. Can you think of any examples where this may occur?

All participants provided examples and generally attributed the problem of perseveration to the inability to switch between two competing tasks or to inhibit an ongoing response. The comments received included:

“The Wisconsin Card Sort is a classic example of that where a reinforced pattern of behaviour is occurring, a shift occurs in the strategy, the rule, the concept that must now be applied and the individual must use their errors to detect that a change has occurred and then analyse those errors for a possible strategy... that would be perseveration on a psychological task. Now in the real world, what would it be? You’re engaged in an academic task in school and the sign or the symbol of your math problems change and you start to get errors” (Professor Russell Barkley).

“The perseveration is part of their demand-insatiability and also part of their problems of focus... Some of these children have got not an attention deficit but in fact they’ve got attention surpluses - i.e., they get an idea in their mind and they’re like a dog with a bone you can’t budge them... And also with ADHD there is this insatiability of not knowing when to back off - you know ‘Can we have it, can we have it, can we have it?’ - when most people look their mother in the eye and think ‘This is inappropriate, back off!’” (Dr Christopher Green).

“Yes, they’ll sometimes get stuck on things and I think sometimes it’s just the ADHD and sometimes they’ve got an unrecognised OCD problem... But there again you’re talking about a dimensional variance of executive function which has to do with being able to shift gears, which you could subset under prioritising, or you could deal more specifically with it in terms of Russ Barkley’s notion of reconstituting - of being able to shift from one task to another” (Dr Thomas Brown).

“Parents find it in their parenting. You know, ‘Can I buy such and such?’, ‘No, you can’t’, and it goes on and on and on and on... Or again, just a concept, just something they’ve seen or something which has happened. An injustice that has been done for the older child when they’ve reached that sort of moral stage

of awareness of that which is just and unjust and will be exaggerated in their sense of affront, without any awareness of what they their participation in that issue might be" (Dr Trevor Parry).

"Oh, frequently. In some ways it's a fascinating issue - because to what extent are perseveration and inhibition related - if you fail to inhibit, you'll continue doing the same thing... if I looked in a classroom situation, I can recall clearly one child who had a topic on his mind. And he kept reintroducing this topic over and over again at the most bizarre moments and he couldn't let it go. Parents likewise often tell us that they often - although the kids don't seem to pay attention - they'll suddenly get stuck with something and won't let go of it and it can go on and on and they don't want to stop, which to me is that perseveration. And yet is that also a failure to inhibit? I don't know" (Associate Professor Rosemary Tannock).

(4) Verbal and non-verbal working memory

M: It appears that working memory may also play a significant role in ADHD. What are your thoughts on this?

The consensus among participants appeared to be that an impairment in working memory may indeed play an important role in ADHD. However, participants were also careful to stress that problems in working memory are not necessarily the result of an underlying deficit in memory itself.

"I think that it is central... I think that the aspect of working memory that's most important for most people is verbal working memory... we are using the Children's Memory Scale and find that if we use the Story Memory there that we often get better registration of short term working memory impairments in

people with ADHD than we do if we were using digit span alone" (Dr Thomas Brown).

"I do believe it plays a major role - and in fact many of the tasks that we use to measure inhibition and a whole range of other more complex processes, for children - if you take a developmental perspective - make heavy demands on working memory... It could be that we've got an impairment first of all just in the amount of information one could hold momentarily - the span - and it also could be in fact manipulating information. What seems to be the problem with ADHD that's emerging in the literature now is that if we take the verbal span (that ability to hold a certain amount of information on-line - verbal information), it doesn't seem to be a problem - when we manipulate it in some way, there is a problem... there is evidence in the literature... that the ability to hold and represent spatial information and manipulate it seems to be quite impaired in ADHD" (Associate Professor Rosemary Tannock).

"Working memory - short term memory is a symptom that parents talk of and working memory is a major problem with the learning part of this which teachers complain about. But not all ADHD children necessarily have problems with working memory - most probably do - but it certainly causes problems with reading... you see the words but you've forgotten by the time you get to the end of the page. It causes problems with mental arithmetic. So in many ways it is causing problems" (Dr Christopher Green).

"We see it when the kids get into trouble with school for disciplinary reasons and they're absolutely outraged or even just confused and puzzled as to why something which was last Tuesday which they've now not remembered is having to have its detention Friday, or not being allowed to go on the school trip or the school camp or whatever else" (Dr Trevor Parry).

"I would say that while they have the capacity for recalling the past - that is to say that there is not a memory deficit - the past has been processed and stored, maybe not as well or as efficiently or as organised, but they have a past and it's there. And on cued recall they can tell you about the past. What happens however, is at the point where a response must be initiated, that response is not inhibited to allow time for this recall of the past back into working memory in order for the results of that analysis of the past to then decide the response" (Professor Russell Barkley).

M: It has been suggested that children with ADHD may be less proficient at analysing their previous experiences, and using this information to formulate appropriate responses in new situations. Have you seen any evidence of this?

"Well that depends on what they're doing. If it's one of those domains in which they have special interest they often make very good use of their past experience. And if it's something where there's been a big jolt of positive or negative reinforcement on it they may very well remember - it's the routine stuff they have trouble with. And often they don't remember the stuff that's not dramatic" (Dr Thomas Brown).

"Children with ADHD will often make the same mistake over and over again although they have had negative consequences given to them. So basically they either forget this has happened or don't learn from the mistakes they have made" (Dr Annemaree Carroll).

"Sometimes they can be remarkably sensible... the problem with ADHD is just when you think you're on top of them they then do something utterly bloody stupid. It's not predictable at every time. Their frontal lobe is working, it just keeps letting things slip through. So it is one of their great problems that they

walk into difficulty because they do not use their frontal lobe to say “Is this wise? What happened last time I did it?” - so it’s a big problem” (Dr Christopher Green).

“At a cognitive level they would have long term memory which gives them prompts, but in terms of the application of that into choices of the now, they are people of the now” (Dr Trevor Parry).

“I think they have great difficulty... if we think of what is required to do that, you’re typically on-line moment by moment bringing up from your long term memory information that you have learned from consequences or whatever, or your previous experience doing something - to work out how to integrate it with the current moment or how to work it with the planned future action. And I think again, if you cannot either rapidly retrieve this knowledge that you actually have and can’t access it quickly, or that you can’t integrate it rapidly enough to make an appropriate decision, it will appear that you can’t utilise and learn from past mistakes or past behaviour” (Associate Professor Rosemary Tannock).

M: Recent research has suggested that ADHD children may have an impaired sense (or perception) of time. What do you understand this to mean?

When asked to discuss the predicted impairments in the sense of time of ADHD children, participants tended to cite problems such as learning to tell the time and reduced awareness of the passage of time. While there was some limited support for the notion of an impaired sense (or perception) of time amongst ADHD children, all participants seemed to agree that ADHD children have difficulty with the self-regulation of their behaviour with respect to time (i.e., the sequencing and organisation of behaviour). For example:

“Many [ADHD] youngsters do appear to be unaware of how to tell the time - which is an important start - they don’t seem to have a concept of time... the children seem to have difficulty in terms of working out how much time will be required to complete a task, to allow themselves to prepare for a project - each component. And I think maybe what’s happening is that the children don’t seem to have the appropriate language to use to represent those concepts of time... Another area we’ve found where they have difficulty is when we actually measure the perception of time. So if we use a cognitive method to measure perception of time, they do seem to have - and this is with short intervals - they seem to have remarkable difficulty distinguishing between intervals that are very brief - like less than half a second... what happens there is that they produce a much longer interval. However when we ask them to produce a longer interval, say two seconds or six seconds, they actually reproduce it as though it was much shorter” (Associate Professor Rosemary Tannock).

“The sense of time derives from the ability to analyse the environment in a sequence, so that as the environment is changing there is a sequence of changes that is taking place. In order to sense time, the person has to have the ability to hold slices of the environment in mind in a sequence... that’s working memory... Because working memory is being disrupted by the inhibitory problems, people with ADHD are unable to retain sufficient sequences of information in mind that allow for a normal sense of time” (Professor Russell Barkley).

“Children with ADHD have very poor time management and organisational skills. They have difficulty sequencing activities - for example they will not know in the morning to do the necessary activities in time to get to school. They

have little concept of distance in time, and have difficulties pacing their work so they finish it in the time given" (Dr Annemaree Carroll).

"ADHD people are - one of their greatest problems is a problem with organisation. And ADHD adults will tell you that if they get on top of their organisation - that is when their life comes together. Now central to organisation is time. So I wouldn't see it as a specific thing - it is a problem of organisation" (Dr Christopher Green).

"They're people of the immediacy - is the number one factor and it's very difficult to extrapolate beyond the immediate. But there's also that which is compounded in the now by the multiple... whereas if they have been helped to break it into manageable aliquots... and they need to learn that because it just doesn't come. It's more organisation. That's why I personally think this is much more a struggle that relates to difficulty with organisation rather than time per se (Dr Trevor Parry).

"That's not something I've studied very much... I certainly have seen the problem that many of these folks have in estimating correctly how much time it's going to take them to do things - for example, they'll plan an errand and need to get from - they're here at 3:00 and they want to be someplace else at 3:30 - and they have no problem in thinking about themselves as being there at 3:30 but allow no time for travel" (Dr Thomas Brown).

M: What do you see as the role of language in children with ADHD?

Barkley has previously described the importance of language in the self-regulation of behaviour (Barkley, 1997a, c). In response to this question the other participants discussed the importance of language in relation to reading, and its role in the sequencing of information and behaviour. Participants also

described the frequent comorbidity between ADHD and language impairments:

"I think this is a crucial element. Don't forget that obviously as soon as we get to school-age children, how we are determining whether a child has the symptoms of ADHD is often heavily based on the children's everyday language. And I think one of the notions of the language is that it allows you to map and sequence and store in your mind these representations... And certainly this ability to sequence seems to be very crucial both in terms of utilising language to explain ideas and utilising language to represent sequencing, and therefore also to guide one's behaviour in an orderly, sequenced manner" (Associate Professor Rosemary Tannock).

"That's a complex one. I mean first of all, language disorder is a much more common comorbidity than we would realise. Secondly, language is often, as spoken, circuitous - slips off target. If you listen to some of these adult ADHD experts talking - there will be one talking this afternoon - you will go mad because he's all over the place - it is like an interrogation, so there's a big problem there. And of course language is the basis of dyslexia and dyslexia is another comorbidity so certainly it's tied up with it all" (Dr Christopher Green).

"I think the link between ADHD and language impairments is short term working memory. A lot of the people we see who have ADHD also have a Disorder of Written Expression where working memory is crucial but I think it's also important in the development of language skills... there's some peculiar problems that many people with ADHD have in their reading where they have difficulty retaining what they've read and being able to remember what happened in the first half of the sentence when they read the second half of the sentence" (Dr Thomas Brown).

M: Have you noticed any patterns in the verbalisations of children with ADHD?

“Well I know they tend to have a little more trouble with narrative - the work that Rosemary Tannock herself - and has been summarised in the book that Brooks published on language and behaviour and attentional impairments - I think addresses this pretty well. Often they sort of jump around in the details that they give you and have a little difficulty in sequencing their accounts so that you end up with fragments as they talk with you about things and you have to sort of weave the pieces together yourself” (Dr Thomas Brown).

“There is no doubt that a lot of kids with ADHD also have a specific difficulty with language processing... But is this bit that we’re seeing here intrinsic to call it ADHD or is it in fact one of the comorbid issues, as I would label it, where whatever it is, 35-55% of the kids have specific learning disability and that’s mostly in language based areas” (Dr Trevor Parry).

“They have problems sequencing the language. If given a set of instructions or giving a set of instructions, they will often have problems getting them in the correct and sequenced order... Actual verbalisation of sequences may actually assist children with ADHD to complete tasks in the correct order” (Dr Annemaree Carroll).

M: In your experience, do ADHD children have trouble with the internalisation of speech?

“They have difficulties thinking silently rather than actually rehearsing things out loud. Therefore, they often need to talk to themselves out loud if they are faced with a task” (Dr Annemaree Carroll).

“That’s what Vygotsky said, the more difficult the problem, the more you have to fall back on earlier stages of private speech, because they’re more influential than quiet speech happens to be. So even normal children can be induced to speak publicly – even adults – if you give them a difficult problem” (Professor Russell Barkley).

“I’m not sure. Some people say that the reason that all of us don’t get into trouble is that we internalise our language like a pilot before he takes off saying “Have I got the fuel, are the flaps working?” - this way - and that is what stops pilots crashing and it’s what stops you and I crashing. But ADHD it is said maybe they don’t internalise, maybe they don’t do a dry run in their head - they just crash” (Dr Christopher Green).

(5) Further comments and unresolved issues

In line with the exploratory nature of the semi-structured interviews, when topics of interest were raised during the interviews, participants were encouraged to provide as much relevant information as possible. Each of the participants was also given the opportunity to make additional comments at the conclusion of their interview. Whilst not all of the data obtained in this manner were pertinent to the present study, a number of significant comments were made and are reported in the present section.

M: Do you see “Attention-Deficit/Hyperactivity Disorder” as an appropriate name for the disorder?

The results revealed considerable agreement between participants who regarded the current terminology as restrictive and increasingly inappropriate. A range of alternatives were also suggested.

"No. I don't know what to call it. And I think it's because at the moment it's very hard not only for us as professionals and scientists but I think also for parents, it's hard when you have a very dreamy, inattentive child to know that this child also has the same label as a child who's bouncing off the walls - just that alone doesn't make sense... I've seen in the literature terms like executive dysfunction disorder emerging in the adult literature, and I wouldn't be surprised if this doesn't sort of filter down to the child level. What we call it I don't know because we simply don't know what the fundamental problems are with ADHD" (Associate Professor Rosemary Tannock).

"The first thing that I want to say is that I think the terminology is becoming to me increasingly inappropriate and unhelpful, in terms of the complexities of problems that I see children struggling with" (Dr Trevor Parry).

"No, I don't think Attention Deficit Disorder is a very good term for it because we're beginning to realise that attention is multi dimensional and that maybe only one aspect of attention is involved... Behavioural inhibition disorder might be a better term for this. Executive Function deficit disorder might also be close to the mark. Developmental disorder of executive function. But I think those would be much closer to the core of the disorder than Attention Deficit Disorder has been. Also realising that we may have another attention disorder on our hands here, that really is an attention deficit and that's the inattentive type of ADHD. So I don't like the name, but we're going to keep it for a while" (Professor Russell Barkley).

"No. I think that we ought to separate out the term 'hyperactivity' from the name of the disorder. Some people want it to come to things like 'Executive function impairment' or 'Mild neurological impairment' or something like that. And I think that because of the history of research that it makes sense... to think

of it as an attentional disorder rather than as a disruptive behaviour disorder because it's not always accompanied by disruptive behaviour... But I think that the term 'Hyperactivity-Impulsivity' or even just 'hyperactivity' in the name of the Predominantly Inattentive Type is an oxymoron" (Dr Thomas Brown).

"The name will change and I predict it will change next time to BID - behavioural inhibition disorder - for the short fused, and ADD for the learning problems" (Dr Christopher Green).

"ADHD has been fraught with so much controversy over the past decade or more. If it could be established that there are two distinct disorders... then I think a change in name could be useful to distinguish the two disorders from each other. My only concern in this however, is that there have been so many name changes over the past four decades, that people may just think here we go again without truly understanding the major breakthroughs that have been made in the field" (Dr Annemaree Carroll).

M: Do you agree with its placement in the Disruptive Behaviour Disorders category of the DSM-IV?

Some participants firmly agreed with the placement of ADHD under this category, while others did not. The responses received included:

"Well it's a major problem of disruptive behaviour. My interest with ADHD is I think its number one problem is that it's a wrecker of relationships. It wrecks relationships between mothers and children and children and mothers, children and peers. It breaks up adult relationships - a massive break up in relationships of ADHD adults - so it's a disruptive one most certainly" (Dr Christopher Green).

"I think that the Combined Type that involves the hyperactive-impulsive behaviour clearly does because of its high comorbidity with Oppositional and Conduct Disorder. Statistics ranging anywhere from 35-60% have Oppositional Disorder and 15-20% have Conduct Disorder - that's a good placement for them. I think that the Inattentive group on the other hand, as has been repeatedly shown, shares very little comorbidity with the other disruptive behaviour disorders and consequently I don't think it belongs under that hierarchy" (Professor Russell Barkley).

"Where else do you put it? Some researchers would suggest that ADHD would be better placed under the Pervasive Developmental Disorders because of the links that have been found to Autistic Spectrum Disorder. More research needs to be done" (Dr Annemaree Carroll).

"Absolutely not. I think this is probably the greatest disservice we're doing to these youngsters. And it also leads to a different type of treatment, which is the biggest concern. And if indeed this condition or at least a huge chunk of it - a group of individuals with this condition - are truly showing these neurodevelopmental/cognitive impairments, this really is simply doing them a major disservice, because we're misunderstanding why this child may be being inattentive or impulsive or disorganised. And therefore by just using these treatment approaches - behavioural modification techniques - sure we can using various response costs you can train even animals to respond appropriately, but that's not getting at the core problem. And I think it's truly blaming a child for misbehaving when it's truly a processing problem" (Associate Professor Rosemary Tannock).

Chapter summary

The purpose of this exploratory study was to examine the current conceptualisation(s) of ADHD held by leading professionals in the area of ADHD research. The data obtained from the semi-structured interviews, which was presented here, will be critically examined in the following chapter, where it will serve to provide key directions for the subsequent phase of the research. In particular, the predicted executive impairments of children with ADHD will be identified and discussed, with a view to their further investigation in Study Two. Furthermore, Chapter Four will serve to discuss the selection, and nature, of the instrumentation to be used in Study Two, with a view to ensuring that the measures chosen are designed to be sensitive to the constructs under examination.

CHAPTER FOUR

Study One: An exploratory study in the conceptualisation of the executive functions in ADHD

Discussion

The results of Study One provide valuable insight into the current conceptualisation(s) of ADHD. In this chapter, the data obtained from the review of literature (Chapter Two) and the semi-structured interviews (Chapter Three) are used to develop the theoretical framework within which the subsequent investigative phase of the research will proceed. In particular, the predicted executive impairments of children with ADHD are identified and discussed, with a view to their further investigation. In addition, this chapter also provides information pertaining to the selection and nature of the instrumentation to be employed in Study Two, which concerns itself with the empirical investigation of the predicted executive impairments of ADHD children.

The results of the semi-structured interviews, like the review of literature, were divided into a number of sections. Initially, the current conceptualisation(s) of ADHD were examined, with an emphasis on Barkley's (1997a) Unifying Theory of ADHD, which arguably represents the most comprehensive and testable theory of the disorder available to date. Indeed, many of the predictions arising from the Barkley model are examined in further detail in the semi-structured interviews (Study One) and the subsequent empirical study (Study Two). The results of Study One revealed that participants identified four broad areas of executive impairment as central to the current conceptualisation(s) of ADHD, namely: deficiencies in response inhibition, verbal and non-verbal working

memory, selective and/or sustained attention, and the sense (or perception) of time. The nature of each of these predicted impairments is examined in further detail in this chapter, which also describes the formulation of hypotheses, and the selection of instrumentation, to be used in Study Two.

The predicted executive impairments of ADHD children

When asked to describe their conceptualisation of ADHD, the participants in the semi-structured interviews commonly cited difficulties with organisation, self-monitoring, the executive functions, and response inhibition as characteristic of ADHD children. Thus, all participants described problems with self-regulation, or those mechanisms through which it is attained, as central to their understanding of ADHD. Four specific executive impairments were identified from the interviews. These were response inhibition, verbal and non-verbal working memory, selective and sustained attention, and the sense (or perception) of time.

Response inhibition

Barkley (1997a) argued that response inhibition is the central impairment of children with ADHD, and that this in turn compromises the effective deployment of the executive functions, which he defined as those self-directed behaviours that are responsible for self-control (Barkley, 1997c). Barkley also proposed that response inhibition was the mechanism by which these behaviours (which start out as public) are privatised over the course of development, as the public aspects of these behaviours are inhibited, and control by the external environment is replaced by self-regulation. Whilst Brown also provided support for Barkley's theory of ADHD, he disagreed on the primacy of response inhibition in the model. In addition, it is important to

remember that Barkley's inhibitory deficit model of ADHD was designed to apply only to the Hyperactive-Impulsive and Combined Types, and not the Predominantly Inattentive Type, for whom impairments in response inhibition are not considered characteristic. Thus the predicted impairment in response inhibition in children with ADHD might be mediated by ADHD subtype, with those children who display symptoms of hyperactivity-impulsivity (i.e., the ADHD Combined Type) expected to perform more poorly than those who do not (i.e., the ADHD Predominantly Inattentive Type). In addition, Tannock suggested that the frequency of errors and the reaction times of ADHD and Control children on the response inhibition task are also worthy of study. In particular, Tannock indicated that whilst children with ADHD may appear impulsive, measurement of their reaction times suggests that they may in fact be slower to respond than non-ADHD children. Thus the instrumentation to be applied in the present study was chosen to provide measures of response inhibition, error rates, and reaction times in ADHD and Control children. The Sustained Attention to Response Task (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) was selected for this purpose, and is discussed in further detail later in this chapter.

Verbal and non-verbal working memory

A second impairment that was cited by all participants as characteristic of ADHD children was problems with working memory. During the semi-structured interviews, both Brown and Green related the difficulties that children with ADHD appear to have with reading to an underlying impairment in working memory. In particular, Brown alluded to the problems ADHD children appear to have with the sequencing and organisation of narratives, citing the work done by Tannock in this area. Both Brown and Tannock

suggested that the problems with working memory might play a central role in ADHD.

More specifically, Tannock argued that the problem with ADHD may pertain more to the manipulation of information in working memory rather than to any deficiency in memory capacity itself. Barkley concurred, arguing that the memory impairments which appear to manifest in ADHD children are the result of the inhibitory problems which occur at the point of performance, and are therefore not the result of an underlying deficit in memory per se. Thus Barkley predicted that whilst ADHD children might be less proficient at the storage and retrieval of information from memory, their performance on cued recall tasks should be relatively unimpaired. Parry agreed, stating that long term memory appears to be unaffected "at a cognitive level." In contrast, other participants (such as Brown and Green) accepted the notion of a memory deficit, with Green being quick to qualify his statement that "not all ADHD children necessarily have problems with working memory - most probably do."

Therefore it is desirable that the instrumentation to be employed in Study Two is sensitive to both the verbal and non-verbal aspects working memory, in addition to providing measures of cued and uncued recall. This will allow the examination of Barkley's (1997a) model of ADHD which conceptualises verbal and non-verbal working memory as separate executive processes, and Barkley's prediction that cued recall is unimpaired in ADHD children. The Children's Memory Scale (Cohen, 1997), which was advanced by Brown as a measure of verbal memory registration, was considered ideal for this purpose, since it incorporates subtests which are sensitive to both verbal and non-verbal memory, and the immediate, delayed, and cued recall of information.

Selective and sustained attention

The third characteristic that was identified by all participants as typical of ADHD children was attentional impairment. However, each of the participants appeared to conceptualise “attention” in a slightly different manner. Whilst only Brown considered attention to be the central impairment of children with ADHD, he clarified that the construct to which he was referring was “attentional impairment broadly defined.” Similarly, Barkley referred to attention as multi-dimensional and suggested that only one aspect of attention may be involved in ADHD. In a similar vein, Green asserted: “I think that attention is a bad word... it is the moving of attention - it isn’t inattention.” Furthermore, Tannock, Parry and Carroll all referred to the attentional problems associated with ADHD as part of a broader cognitive construct.

More specifically, participants were asked to describe the attentional impairments that they associated with the Predominantly Inattentive and Combined Types, respectively. Whilst the results revealed no discernible patterns according to subtype, all participants cited attentional impairment as characteristic of both ADHD subtypes. Brown, for instance, posits that “PI type symptoms are present in those that we would diagnose as Predominantly Inattentive Type but they also are present in virtually all of the people who have the Combined Type.” Parry’s view appears somewhat similar, and has “inattentive disorganisation” common to both subtypes, with the primary difference between them being the presence (or absence) of hyperactive/impulsive symptoms. Green proposed that very few ADHD children display symptoms of inattention only (i.e., the Predominantly Inattentive Type), and that nearly all of them manifest at least some symptoms of hyperactivity/impulsivity.

In contrast, Barkley described the attentional impairment seen in the Combined Type as “an output disorder,” and the problem seen in the Predominantly Inattentive type as “an input problem.” For the Combined Type, Barkley proposed that “there is no problem with how information is being perceived and processed but that the problems come in when behaviour must be organised and executed.” However, Barkley predicted that the Predominantly Inattentive Type “does have to do with the initial perceptual, selective, and processing aspects... they are focused or selective attention problems.” Alternatively, Carroll attributed the problem seen in the Combined Type of rapidly flitting from one task to another to “selective attention difficulties,” and those encountered by the Predominantly Inattentive Type to “poor sustained attention.”

Barkley however went further, suggesting that in the Combined Type, “their sustained attention and distractibility problems are due to the working memory deficits and the inhibitory deficits.” Tannock concurred, suggesting that although her research group has been unable to separate the attentional characteristics of the subtypes based on their symptom counts, “As soon as we go to the cognitive processing, then I think we might be seeing some differences for example in working memory.”

These predictions will be examined in further detail in Study Two, where instrumentation sensitive to the attentional impairments of children with ADHD will be selected to complement the measures of response inhibition and working memory that have already been chosen. The Test of Everyday Attention for Children (TEA-Ch; Manly, Robertson, Anderson, & Nimmo-Smith, 1999), was chosen for this purpose. The TEA-Ch consists of a number of subtests that between them assess selective attention, sustained attention,

attentional switching, and dual task performance, and thus permitted more thorough examination of the predicted attentional impairments.

Concept of time

Participants were also asked about Barkley's (1997a) suggestion that children with ADHD may have an impaired sense (or perception) of time. This was because the limited literature available to date which pertains to the sense of time in ADHD children (e.g., Barkley et al., 1997; Dooling-Litfin, 1997), has implied that this is an issue which may warrant further investigation. Thus, in the semi-structured interviews, participants were asked to comment on the proposal that sense of time is impaired in ADHD children. In response, the majority of participants described the problems encountered by ADHD children as relating to the organisation of behaviour with respect to time, rather than as an impaired sense of time itself. For example, Green stated: "central to organisation is time... I wouldn't see it as a specific thing - it is a problem with organisation." Parry concurred, adding that: "this is much more a struggle that relates to difficulty with organisation rather than time per se." Brown and Carroll shared this view as well, with both also citing the difficulties many ADHD children have in correctly estimating the amount of time it will require to complete a given task.

However, Barkley was far more explicit in his predictions about the impaired sense of time in ADHD children. It is Barkley's contention that "the sense of time derives from the ability to analyse the environment in a sequence... In order to sense time, the person has to have the ability to hold slices of the environment in mind in a sequence." Therefore Barkley argues that: "because working memory is being disrupted by the inhibitory problems, people with ADHD are unable to retain sufficient sequences of information in mind that

allow for a normal sense of time.” Barkley went on to describe instrumentation that has been specifically designed for, and applied to, the investigation of his sense of time construct in ADHD children: “Now as you know, we’ve been looking at it through time - temporal reproduction tasks.” Barkley went further, making this instrumentation available to be used in Study Two, in which the effects of stimulus duration, mode of presentation (visual or auditory), and distractors on the time reproduction of ADHD and Control children were examined.

Instrumentation

This section provides detailed information about the selection and nature of the instrumentation to be used in Study Two. Four tests were employed in the present study and these were selected because between them, they assess all of these domains of functioning, with each test being specifically designed to assess one of these constructs. Due to the recent development and availability of the tests employed in Study Two, and hence their limited exposure in the literature available to date, it was thought necessary to provide further information pertaining to the nature of each test, its development, and psychometric properties. Therefore, each of the four tests is outlined in some detail below, and the dependent measures of which they are comprised are discussed. Whilst this information might arguably have been incorporated into the relevant methodology chapter, the selection of instrumentation for Study Two represented a distinct phase of the research, being inextricably linked to the findings of Study One, and is therefore presented separately.

Response inhibition: The Sustained Attention to Response Task

Whilst numerous studies have suggested that children with ADHD make more commission errors than Control children on various Continuous Performance Test (CPT) paradigms (Losier, McGrath, & Klein, 1996), this has often been taken as evidence of impaired sustained attention in ADHD children. However, the Sustained Attention to Response Task (SART; Robertson et al., 1997) is unlike the typical CPT paradigm, in which participants are required to monitor long sequences of stimuli and respond to infrequent targets. Instead, Robertson et al. (1997) argued, sustained attention to a task would be more heavily taxed by a paradigm in which the automatic response set was transferred to the non-targets. In this case, when rare targets occur, active, controlled processing is required to overcome the prepotent automatic response. Thus the construct which Robertson et al. (1997) refer to as sustained attention, appears to be synonymous with Barkley's (1997a) concept of response inhibition, which he describes as "inhibition of the initial prepotent response to an event." In the present study, therefore, the SART was utilised to gather data on the construct which Barkley (1997a) refers to as response inhibition, and Robertson et al. (1997) refer to as sustained attention.

The computer-administered SART consists of two phases: an inhibition phase, which is administered first, and a vigilance phase. These two phases resemble the reverse CPT and standard CPT paradigms respectively. In each phase, 225 single digits (i.e., 25 of each of the digits from 1 to 9) are presented visually over a 4.3 minute period. Each digit is presented for 250 ms followed by a 900 ms mask. The digits and mask appear in white on a black background on a Toshiba Satellite 4000CDT notebook computer screen (250 x 190 mm), approximately 40

cm from the participant's eyes. Figure 2 shows a sample SART digit (left) and mask (right) respectively.



Figure 2. Sample digit (left) and mask (right) for the SART.

At the commencement of each phase, participants are given a number of practice trials, and may elect to receive additional practice trials should they wish. During the SART inhibition phase, participants are instructed to respond with a button press to each digit (using their preferred hand), except on the 25 occasions when the digit “3” appears, when a response is expected to be withheld. The target digit is distributed throughout the sequence quasi-randomly and appears in one of five randomly allocated font sizes (48, 72, 94, 100 and 120 point) to enhance processing of the numerical value rather than the peripheral visual features of the non-response target. Figure 3 shows a sample non-target digit (i.e., “7” - button press required) and target digit (i.e., “3” - no button press required).

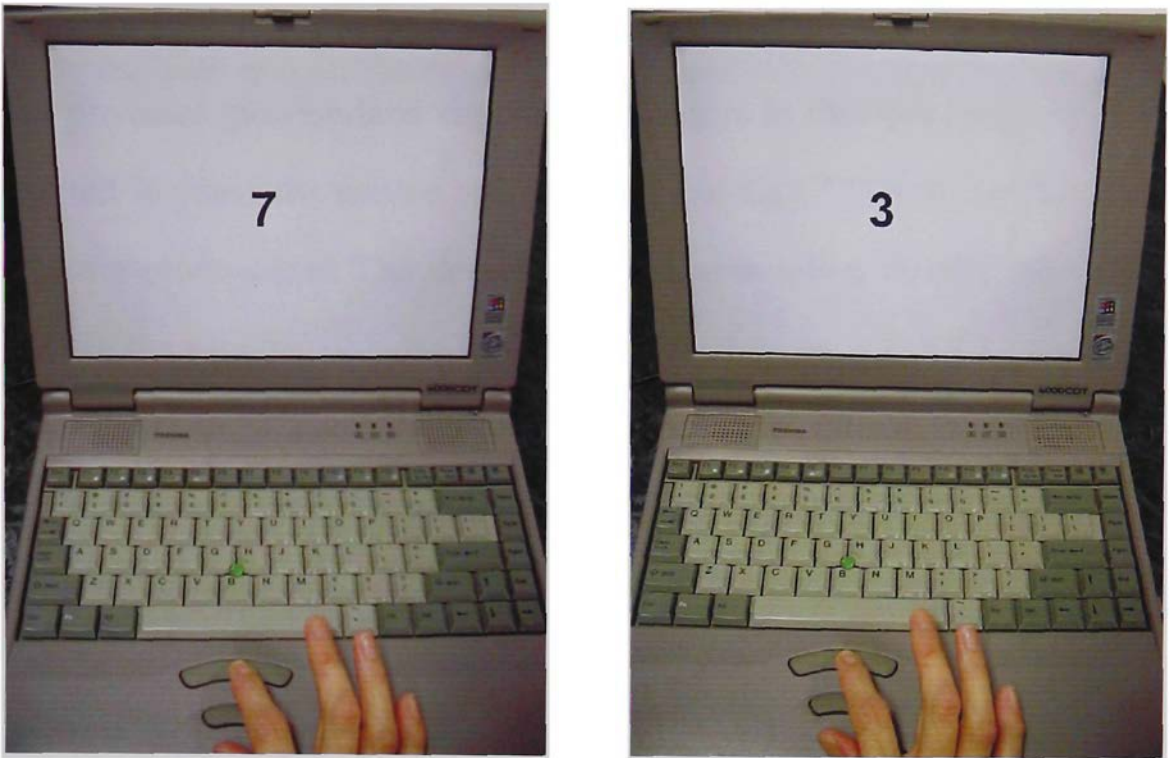


Figure 3. Sample non-target (left) and target (right) digits for the SART inhibition phase.

The dependent measures taken during the SART inhibition phase are the number of False Positives (i.e., failures to inhibit responding to the target digit “3”) and the number of Misses (i.e., failures to respond to non-target digits) made by participants. In those instances in which a response (i.e., button press) was provided, the SART also records the participant’s reaction time. While the number of False Positives and Misses are equivalent, respectively, to the number of Omission Errors and Commission Errors described in the literature review, the terminology used here is considered preferable since it is less confusing and more accurately describes the nature of the errors made by participants. Thus False Positives are generally attributed to failures of response inhibition and are considered to reflect impulsivity (Swaab-Barneveld et al., 2000), whereas Misses are generally attributed to failures of sustained attention (Robertson et al., 1997).

The second phase of the SART consists of a control task of the same duration, which provides the standard vigilance paradigm. In this task, participants are instructed to press the mouse button when the digit "3" appears, but not for any of the other digits. The dependent measures taken during the vigilance phase are the number of False Positives (i.e., failure to withhold a response to digits other than "3") and the number of Misses (i.e., failure to press when the digit "3" appears) made by participants. Reaction time data are again recorded when responses are received.

While the available psychometric data are limited, there is growing evidence to suggest that the SART is sensitive to those slips of attention that occur in individuals with frontal lobe and white matter damage as a result of traumatic brain injury (Robertson et al., 1997; Manly, Robertson, Galloway, & Hawkins, 1999). According to Robertson et al. (1997), the SART provides a measure of the active, controlled processing required to overcome the prepotent automatic response, which is akin to Barkley's (1997a) notion of response inhibition. The SART has also been found to distinguish teenagers with dyslexia from non-dyslexic controls (Moore & Andrade, 2000), and appears to have satisfactory test-retest reliability ($r = .76$; Robertson et al., 1997). The SART was used to gather data on response inhibition in children with ADHD, and the present study may prove to be a valuable source of additional psychometric data.

Expected outcomes

In line with Barkley's (1997a) inhibitory deficit model of ADHD, it is anticipated that the ADHD boys will make more False Positives than Control boys on the SART inhibition phase. However, it is important to note that Barkley's (1997a) model of ADHD was designed to apply only to the Hyperactive-Impulsive and Combined Types of ADHD, and not the

Predominantly Inattentive Type. This is because ADHD-PI children do not exhibit the same characteristic hyperactive-impulsiveness seen in the other two subtypes. Thus, we would expect that the ADHD-CT boys would record more False Positives (i.e., failures to inhibit) on the inhibition phase of the SART than either the ADHD-PI or the Control boys.

Furthermore, evidence from research (e.g., Houghton et al., 1999; Pennington & Ozonoff, 1996) has suggested that ADHD children have difficulty inhibiting or modifying their responding once a pattern has been established. Given the repetitive nature of the SART task, it is expected that the ADHD boys will record less Misses than Control boys. In contrast, it is expected that the ADHD boys will register less False Positives and more Misses than the Control boys on the vigilance phase of the SART, due to their supposed difficulties with sustained attention.

An additional outcome that will be examined using the SART is whether the mean error reaction times of the ADHD and Control boys are significantly different. Whilst anecdotal accounts might suggest that ADHD children (and in particular, the Combined Type) are highly impulsive, there is little empirical evidence to support this. Indeed, the results of recent research (e.g., Houghton et al., 1999), and the account of Tannock provide evidence to suggest that ADHD children may actually be slower to respond (and more variable in their responses) than non-ADHD children.

Working memory: The Children's Memory Scale

The Children's Memory Scale (CMS) comprises a number of subtests that have been designed to assess three domains of functioning: non-verbal learning and memory (Dot Locations and Faces); verbal learning and memory (Stories and

Word Pairs); and attention/concentration (Numbers and Sequences). In addition to measures of immediate recall, each of the verbal and non-verbal subtests also includes a delayed recall component that is performed after an interval of approximately 30 minutes. The administration of the CMS battery requires approximately 40 minutes and proceeds as follows:

In Dot Locations, participants are asked to memorise the placement of six (or eight, depending on Age) plastic markers after briefly observing a diagram of the arrangement. Participants are then asked to reproduce the positions of the markers using a 3 x 4 (or 4 x 4) grid and six (or eight) plastic markers. Figure 4 shows the stimulus and response phase of the Dot Locations task respectively. The Dot Locations Learning score is calculated as the number of markers placed correctly across three trials using the same diagram. Participants are then shown a new arrangement of the markers to memorise, and immediate (Dot Locations Total Score) and delayed recall (Dot Locations Delayed) scores are recorded.

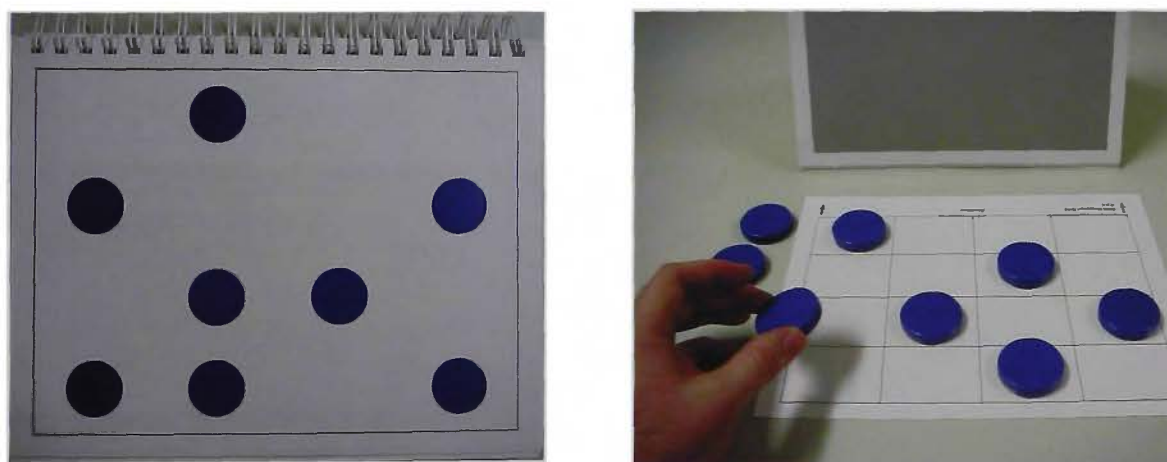


Figure 4. Stimulus (left) and response (right) phases for the CMS Dot Locations subtest.

In the Stories subtest, participants are asked to listen carefully to the reading of two simple short stories. Immediately after hearing each story, the participant is asked to recite the story from memory. The dependent measure taken is the number of story elements recalled verbatim (Stories Immediate). Participants are told to remember both stories because they will be asked to recite them again after a 30 minute delay, at which time their score is again recorded (Stories Delayed), and participants are asked a series of “yes/no” questions which relate to the themes of the stories. The number of correct answers given to these questions provides the Delayed Recognition score.

In the Faces task, participants are shown a series of 12 (or 16, depending on Age) human faces, one at a time for five seconds each, and asked to remember each one. The participant is then shown another series of 36 (or 48, depending on Age) faces, one at a time, and asked to identify each one as either a face he or she was asked to remember or a new one. Figure 5 shows two sample items from the Faces subtest. The dependent measures are the number of correct responses given immediately (Faces Immediate), and after a 30 minute delay (Faces Delayed).



Figure 5. Sample items from the CMS Faces subtest.

In Word Pairs, participants are read a set list of word pairs and asked to remember them. Participants are then read the first word of each pair and asked to provide the second word from memory. Over three trials, a learning score is produced (Word Pairs Learning). Participants are then asked to recall both words of each pair from memory (Word Pairs Immediate). Similarly, a measure of delayed recall (Word Pairs Delayed) is taken after a suitable interval (approximately 30 minutes). Participants are then read a series of word pairs and asked to identify which of those pairs he or she was asked to remember earlier, providing a measure of Delayed Recognition.

In the Numbers subtest, participants are asked to recite digit spans of increasing length both forwards and backwards. The dependent measure is the total number of items completed successfully. The Sequences subtest involves completing a series of increasingly difficult sequences, beginning with the numbers from one to ten and the letters (A to Z) of the alphabet, leading up to the months of the year in reverse order. Bonus points are awarded for completing the sequences quickly (within predetermined time periods) and points are deducted for each error made (up to three errors, after which the item score is reduced to zero). The dependent measure is the total point score across all items.

The CMS has been standardised against a sample of 1000 U.S. children aged between five and 16 years of age. Reliability estimates calculated using split-half correlations and corrected using the Spearman-Brown formula range between .71 (Faces Immediate) and .91 (Word Pairs Learning). Test-retest reliability was assessed using 125 children and a mean testing interval of 59.6 days, and yielded values of between .83 and .86. The CMS has also been found to correlate strongly with measures of cognitive ability and executive

functioning, including the WISC-III ($r = .58, p < .01$) and the Wisconsin Card Sorting Test (Heaton, Chelune, Talley, Kay, & Curtiss, 1993; $r = .40, p < .01$).

Expected outcomes

The use of the CMS, which provides distinct measures of verbal and non-verbal memory in addition to immediate and delayed recall, allows several hypotheses to be investigated in the present study. In particular, the verbal and non-verbal memory performance of ADHD and Control boys will be examined. In addition, the attention/concentration subtests of the CMS, which require the manipulation of stored information, will be used to investigate Tannock's assertion that the memory impairment is in working memory rather than in memory itself. In a similar manner, Barkley's prediction that children with ADHD will do just as well as Control children on cued recall tasks will be investigated using the delayed recall (or delayed recognition) tasks provided by the CMS. It is also possible to analyse whether there is a significant difference in the ability of the ADHD and Control children to retain information in memory across a short temporal delay (i.e., approximately 30 minutes).

Attention: The Test of Everyday Attention for Children

The Test of Everyday Attention for Children (TEA-Ch) is a normed and standardised battery of "game-like" tests that are designed to assess three different types of attention in children between 6 and 16 years of age. In the present study, four of the nine subtests of the TEA-Ch (Sky Search, Score!, Creature Counting, and Sky Search: Dual Task) were used to measure selective attention, sustained attention, attentional switching, and dual task performance in ADHD and Control boys. The administration of these four subtests required approximately 20 minutes.

In Sky Search (which is reproduced in Figure 6), participants are given a large printed sheet which is filled with pairs of spaceships, and asked to circle those pairs in which both spaceships are identical. The dependent measures taken are the number of spaceship pairs (or “targets”) correctly identified (Targets) as well as the average Time Per Target. To correct for the potentially confounding effect of variations in motor speed, performance is calculated relative to a control task in which there are no distractors, resulting in a Focused Attention score. The Sky Search task has been found to correlate significantly with other measures of attention, specifically, the Stroop task (Trenberry, Crosson, DeBoe, & Leber, 1989; $r = .40$, $p < .001$), the Trails Test Parts A and B (Spreen & Strauss, 1991; $r = .69$ and $.45$, $p < .001$), and the Matching Familiar Figures Test (Arizmendi, Paulsen, & Domino, 1981; $r = .22$, $p < .05$).

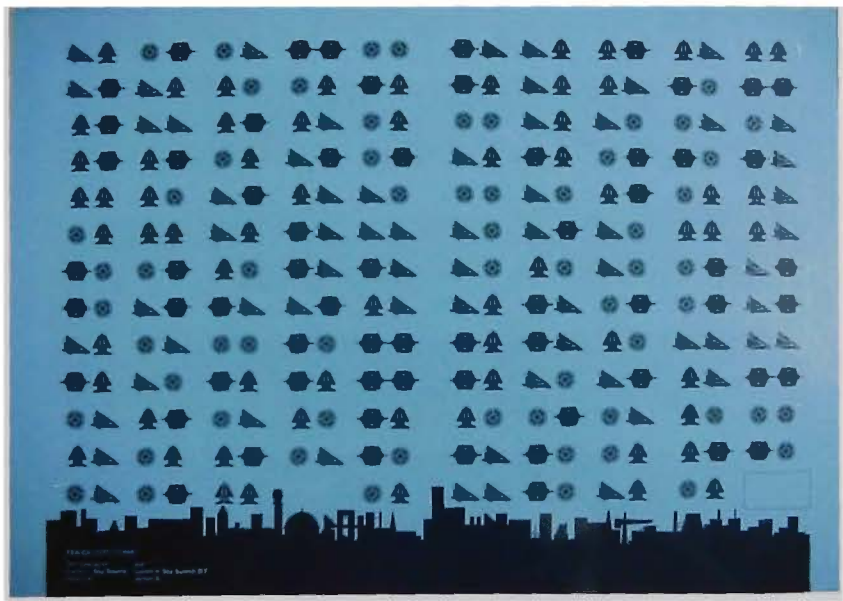


Figure 6. Illustration of the TEA-Ch Sky Search subtest.

The Score! subtest requires children to count the number of scoring sounds (i.e., beeps) they hear being played on a cassette tape. The repetitive nature of the task provides an ideal measure of the child’s sustained attention; the dependent

measure (Sustained Attention) being the number of items completed correctly over several trials. The Score! task also correlates significantly ($r = .28, p < .01$) with the Matching Familiar Figures Test (Arizmendi et al., 1981).

In the Creature Counting subtest, participants are required to count the number of alien creatures in a burrow (see Figure 7), and also to repeatedly switch between counting upwards and counting downwards according to directional arrows. For example, in Figure 7, the participant would count as follows: “one, two, three, four, five, six, **down**, five, four, three, two, **up**, three, four, five.” Several trials are administered and the dependent measures recorded are Accuracy (i.e., the number of trials which participants completed successfully) and Time (i.e., the time taken per successful switch).



Figure 7. Illustration of the TEA-Ch Creature Counting subtest.

With regards to other neuropsychological measures, the Creature Counting Accuracy score has been found to correlate significantly with the Stroop task (Trenberry et al., 1989; $r = .31, p < .01$) and Matching Familiar Figures Test

errors (Arizmendi et al., 1981; $r = .35$, $p < .001$), whilst the Time score has been found to correlate with Part B of the Trails Test (Spreeen & Strauss, 1991; $r = .21$, $p < .05$).

The Sky Search: Dual Task subtest requires participants to identify pairs of “target” spaceships (as in Sky Search, but using a new configuration), whilst keeping count of the scoring sounds (as in the Score! subtest). The dual task decrement is calculated according to the following formula, and gives a measure of the impairment which results as a consequence of the dual task being added:

$$\frac{DT_{T/T}}{p} - SS_{T/T}$$

where $DT_{T/T}$ is the Dual Task Time Per Target, p is the proportion of counting games completed correctly, and $SS_{T/T}$ is the Sky Search Time Per Target.

Expected outcomes

The findings of research to date which has examined the attentional characteristics of children with ADHD have been largely inconsistent. Whilst various CPT paradigms have been used to measure sustained attention (Lin et al., 1999), the results of such studies have been somewhat equivocal, with some investigations concluding significant deficits in sustained attention amongst ADHD children (e.g., Barkley et al., 1992), while others have not (e.g., Van der Meere & Sergeant, 1988a, b). However, the results of Study One might also prove informative in directing the investigation of attention in ADHD children. In particular, Barkley’s suggestion that the attentional problems seen in the Predominantly Inattentive and Combined Types might be qualitatively different, is worthy of further study. Specifically, Barkley predicted that the attentional problem associated with the Predominantly Inattentive Type is

selective or focused attention, whereas that in the Hyperactive-Impulsive and Combined Types is sustained attention. This conjecture will be examined using the TEA-Ch, which incorporates subtests designed to measure both selective and sustained attention.

In addition, the relationship between the measures of sustained attention provided by the TEA-Ch and the SART respectively will be examined. The data obtained from the TEA-Ch measure of attentional switching will be interpreted in the context of earlier findings which have suggested that children with ADHD might be impaired on tasks that require set-shifting (or switching) such as the Wisconsin Card Sorting Test (e.g., Houghton et al., 1999). Furthermore, the TEA-Ch measure of dual task performance will be used to examine Barkley's (1997a) prediction that children with ADHD have an impaired capacity for interference control.

Concept of time: The Time Perception Application (Version 1.0)

The computer-administered Time Perception Application (Timetest) was administered in the present study using a Toshiba Satellite 4000CDT notebook computer. The Timetest software (Barkley et al. 1998) was used to gather data on time reproduction in ADHD and Control boys whilst controlling for several factors: stimulus duration (from 0.5 to 6.0 seconds), the presence (or absence) of distractors, and presentation format (Visual or Auditory). In the Timetest, the Visual and Auditory time reproduction tasks are presented separately, with each task incorporating separate Distractor and non-Distractor conditions.

In each of the Visual trials, participants are presented with a visual stimulus on the computer screen (a light bulb), which lights up for the duration that is to be reproduced. For those trials which involve Distractors, a visual distractor, such

as an image of a bug, balloon, or other visual character, moves across the computer screen while the duration to be reproduced is being presented (see Figure 8). No distractors are presented during the time reproduction phase.

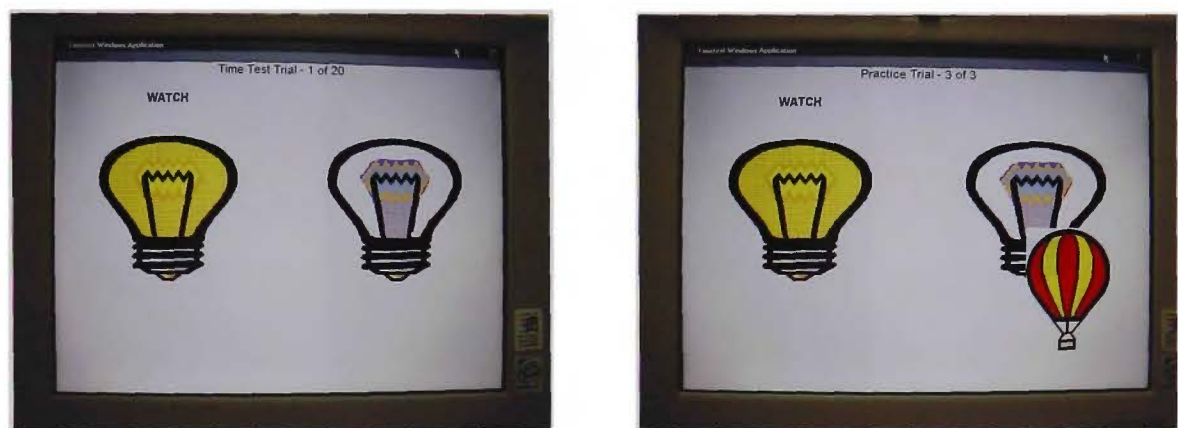


Figure 8. Sample non-Distractor (left) and Distractor (right) conditions for the Timetest Visual time reproduction phase.

The instructions to participants are identical in both the with-Distractor and non-Distractor conditions. Participants are asked to reproduce the duration for which the light bulb was illuminated, regardless of the Distractor, by holding down the computer space bar for a length of time that is, in their estimation, equivalent to the stimulus duration. Figure 9 illustrates the way in which participants are required to respond in the time reproduction phase of the Visual task.

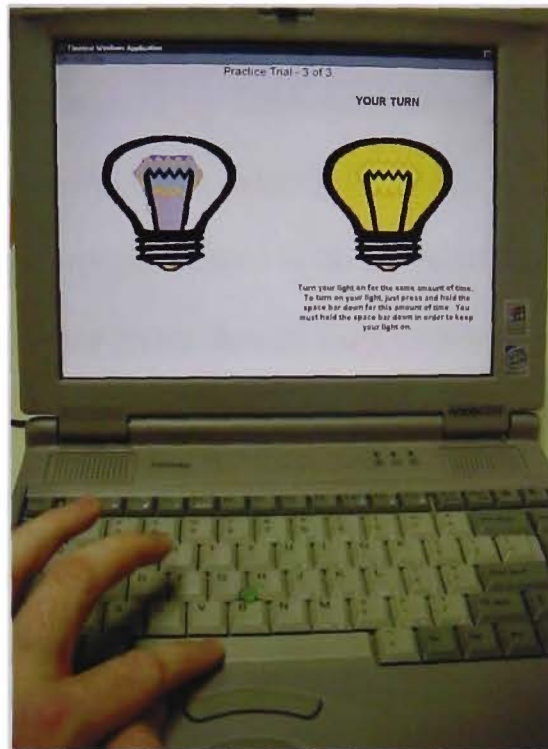


Figure 9. Illustration of the Timetest Visual time reproduction phase.

In each of the Auditory trials, the computer produces a single audible tone, the duration of which is equal to the time interval to be reproduced. For the Auditory trials, Distractors take the form of sounds (such as a train whistle, a lion roaring, a swinging golf club or a car braking) which are presented during the stimulus tone (but not during the reproduction phase). Participants are required to respond to the Auditory trials in the same way as they did for the Visual trials, by holding down the space bar for the duration to be reproduced.

Each subtest incorporates four trials at each of five stimulus durations (which may be chosen in advance by the researcher), resulting in a total of 20 trials, which are presented in random order. The Timetest program is designed to accept stimulus durations of between 500 and 60000 milliseconds (i.e., 0.5 to 60 seconds). For the present study, durations of 0.5, 2.0, 3.0, 4.0 and 6.0 seconds were chosen, since they place lower demands on motor control and persistence than the longer time intervals (i.e., 12, 24, 36, 48, and 60 seconds) used by

Barkley et al. (1997). In addition, the time intervals used in the present study were consistent with those used by Schachar, Tannock and Logan (1993) and Tannock (personal communication, March 2, 2001). At the commencement of each subtest, participants are presented with three practice trials, and may elect to receive additional practice trials should they prove necessary.

Dependent measures

For the purposes of analysis, Timetest converts the raw data obtained from participants into absolute discrepancy scores and coefficient of accuracy scores, which are identical to the constructs used by Barkley et al. (1997). The absolute discrepancy scores represent the absolute magnitude of the errors made by participants in each of their time reproduction tasks, and thus provide a measure of the magnitude of the errors made by the children regardless of the direction of the errors (Barkley et al., 1997). The coefficient of accuracy scores indicate whether participants were more likely to underestimate or overestimate their time reproductions. These scores were calculated by dividing the participant's estimate of the stimulus duration by the actual stimulus duration, resulting in a coefficient of 1.00 for perfect reproductions, less than 1.00 for underestimations and above 1.00 for overestimations.

The Timetest program calculates the absolute discrepancy and coefficient of accuracy scores for each of the participant's 20 trials (comprising four repetitions at each of the five time intervals) on each of the four subtests. The mean absolute discrepancy and coefficient of accuracy scores for each of the time intervals are then calculated, based on the four repetitions.

Expected outcomes

The present study sought to extend the findings of previous research on time reproduction in ADHD children. In particular, the present study sought to examine the effect of Distractors and the mode of presentation (Visual or Auditory) on time reproduction. The results of previous studies would suggest that children with ADHD may make significantly larger absolute time reproduction errors than Control children (Cappella, Gentile & Juliano, 1977; Walker, 1982; Barkley et al., 1997), whilst the direction of these errors (i.e., over- versus underestimations) has been variable (Dooling-Litfin, 1997).

Therefore it is expected that the boys with ADHD will be significantly less accurate than Control boys on the time reproduction task. In addition, it is anticipated that the Visual and Auditory Distractors will decrease the accuracy of time reproduction in the ADHD boys significantly more than it will for the Control boys. However, the relative accuracy of ADHD and Control children on the Visual and Auditory time reproduction tasks does not appear to have been examined in the literature available to date, and as yet, the expected outcomes are unknown. The results discussed by Tannock in Study One might also clarify whether boys with ADHD will over- or underestimate the intervals presented to them. In a study employing a similar measure of time reproduction, Tannock reported that the children with ADHD overestimated shorter time intervals (i.e., less than a second) and underestimated longer time intervals (i.e., between one second and six seconds).

Chapter summary

This chapter has discussed the predicted executive impairments of ADHD children that were identified from the review of literature and the semi-structured interviews conducted as part of Study One. These impairments were

examined with a view to further investigation in Study Two, using instrumentation specifically designed for this purpose. This chapter provided detailed information about the instrumentation to be used in Study Two and the way in which each of these constructs were operationalised. The following chapter describes the methodology that was undertaken in Study Two, and the results obtained are presented in Chapter Six.

CHAPTER FIVE

Study Two: Response inhibition, working memory, attention, and concept of time as executive functions in boys with ADHD

Method

The purpose of Study Two was to compare the performance of boys with ADHD and Control boys on measures sensitive to the predicted executive impairments of ADHD children, which were identified in the literature and in Study One. In particular, four such impairments were advanced as characteristic of ADHD children, namely: deficiencies in response inhibition, working memory, sustained attention, and the concept of time. The nature of these predicted impairments was examined in further detail in the previous chapter, where instrumentation designed to be sensitive to each of these areas was identified and discussed. This chapter therefore describes the sample of participants that was recruited, the manner in which data were gathered and analysed, and the hypotheses that were tested in Study Two.

Participants

The ADHD participants in the present study were recruited through a Consultant Paediatrician (Dr Whiting) who had agreed to collaborate on the research. All of the ADHD participants had been diagnosed by the Consultant Paediatrician as meeting the DSM-IV (American Psychiatric Association, 1994) criteria for ADHD and had subsequently been referred to a clinical psychologist (by the paediatrician) for the assessment of undiagnosed comorbid disorders. All participants with ADHD were administered, among other measures, the Child Behavior Checklist (Achenbach & Edelbrock, 1986), which is a broad-band rating scale providing coverage of the major dimensions of child

psychopathology. Only ADHD children with no diagnosed comorbid conditions were included in the present study. Data were obtained from 67 ADHD boys (22 of whom had been diagnosed as ADHD Predominantly Inattentive Type, and 45 as ADHD Combined Type) and 68 non-ADHD Control boys.

The Control Group was comprised of boys from Grades Two through Seven who were recruited from one local public primary school which is situated in an area of moderate socio-economic status. None of the participants with ADHD attended this school. All children at the participating school are screened each year to identify those students who are “at risk of educational failure” (according to the criteria stipulated by the Education Department of Western Australia, EDWA, 1998), and for reading disabilities (using the Neale Analysis of Reading Ability, Neale, 1989). Children who are identified through this process are referred to the resident school psychologist for further evaluation. None of the participants included in the present study had been identified in the screening procedure at any time in their school life, nor had they received unsatisfactory academic grades indicating work 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 and/or other conditions. The vision of all participants was normal or corrected and none had major sensori-motor difficulties.

Descriptive statistics, including the mean Age, Verbal IQ, and Performance IQ, are presented for the ADHD-PI, ADHD-CT and Control group in Table 2. Estimates of Verbal and Performance IQ were obtained for all participants using the Vocabulary, Similarities, Block Design and Object Assembly subscales of the Wechsler Intelligence Scale for Children, 3rd Edition (WISC-III, Wechsler,

1991). This subset of the WISC-III has been found to correlate .93 to .95 with the full administration of the WISC-R (Sattler, 1988). An estimated Verbal or Performance IQ of 80 or more was a minimum requirement for inclusion in the study (Malone & Swanson, 1993).

Participants in the ADHD-PI group were aged between 8 years 6 months and 16 years 1 month, with estimated Verbal IQ scores between 78 and 141 and Performance IQ scores between 58 and 146. In the ADHD-CT group, participants were aged between 6 years 6 months and 16 years 0 months, with Verbal IQ scores between 83 and 133 and Performance IQ scores between 87 and 146. Participants in the non-ADHD Control group were aged between 6 years 7 months and 12 years 6 months, with Verbal IQ scores between 72 and 133 and Performance IQ scores between 70 and 155.

Table 2
Pre-matching means and standard deviations (in parentheses) of participants' Age, Verbal IQ (VIQ), and Performance IQ (PIQ) according to Group

Group	n	Age Mean (SD)	VIQ Mean (SD)	PIQ Mean (SD)
ADHD-PI	22	12.0 (2.07)	111.1 (17.41)	113.9 (22.82)
ADHD-CT	45	10.6 (2.30)	106.2 (13.36)	112.6 (14.82)
Controls	68	9.9 (1.77)	102.2 (15.63)	113.7 (18.01)

Matching measures

Preliminary statistical analyses revealed significant differences between the mean Ages of the three Groups [$F(2,132) = 9.40, p < .001$]. In particular, Scheffé post hoc comparisons revealed that the ADHD-PI boys were significantly older than both the ADHD-CT boys ($p = .034$) and the Control boys ($p < .001$). Given these significant Age differences, and in view of the anticipated Age-related performance on the dependent measures, it was considered inappropriate to compare the performance of the ADHD-PI, ADHD-CT and Control boys directly. Instead, where possible the ADHD and Control boys were individually matched on Age to reduce the potentially confounding effects of developmental differences. The nature of the matching procedure and its implications for the analysis of data, along with a statement of rationale, are discussed in further detail later in this chapter.

The subsequent analyses also revealed slight significant Group differences for Verbal IQ [$F(2,132) = 3.12, p = .047$], although no differences were found on Performance IQ [$F(2,132) = .06, n.s.$]. Given the significant differences in the mean Age and Verbal IQ across the three Groups, an attempt was made to extend the individual matching of the ADHD and Control children on Age to include both of these variables. However, it was not possible to obtain a closely matched sample in this manner, since satisfactory matching on one variable (Age) could only be achieved at the expense of less satisfactory matching on the other (Verbal IQ).

Settings

Testing sessions were conducted with each participant individually. All of the ADHD children were tested in a room in The Centre for Attention and Related

Disorders, which is located within The Graduate School of Education, The University of Western Australia. The non-ADHD Control group were tested at their primary school, in a room specifically set aside for this purpose. In all instances, the rooms were quiet, free of extraneous distractors, and the layout of furniture and equipment was identical.

The results of earlier neuropsychological research (Houghton et al., 1999; Barkley, 1997b) has suggested that in order to control for potential confounding variables, test batteries should be administered in an environment which approximates that of the classroom, and at a common time of day. Thus all testing sessions conducted in the present phase of the research were arranged for mornings.

Procedure

Permission to conduct this research study was initially obtained from the Human Rights and Ethics Committee of The University of Western Australia. An information letter which explained the purpose of the research, was then sent to the parents of ADHD children who had been involved in an earlier study (Houghton et al., 1999), inviting them to allow their child(ren) to participate. The parents also received an informed consent to participate form (which was prepared in accordance with UWA Human Rights and Ethics Committee guidelines), advising them of what participation would entail. (A copy of the information letter and consent form sent to parents has been included in Appendix H.) Notices inviting participation were also placed in the newsletter of the Learning and Attentional Disorders Society of Western Australia (LADS) and in the rooms of one local Consultant Paediatrician who had agreed to collaborate on the current research. Parents who responded to

these notices, and whose child(ren) met the criteria for participation, were also provided with copies of the information letter and consent form.

By the commencement of the testing phase, the parents of 67 ADHD boys had returned completed consent forms that had been signed by themselves and the participant(s). Appointment times for the testing sessions were subsequently arranged by telephone. As in previous research (Houghton et al., 1999), and with the approval of the child's paediatrician, parents' attention was drawn to the section of the information letter which requested that no stimulant medication be administered to their children on the afternoon and/or evening prior to testing. This was to allow sufficient time for the effects of the stimulant medication to dissipate, ensuring that medication status will not appear as a confounding factor in the results of the present research. A further verbal check was made on this immediately prior to testing, where it was found that all parents had complied with this request.

The non-ADHD Control Group was comprised of boys recruited from one local public primary school. Parents of all boys in Grades Two through Seven at the participating school received a copy of the information letter and consent form, requesting their assistance in the research. A 70% response rate was obtained. Of the children whose parents chose to allow them to participate in the research, approximately 20% were excluded because their school psychological assessments and/or academic records indicated diagnosed conditions (including learning difficulties).

Test administration

Children participating in Study Two were required to perform a number of tasks which previous research has shown they find non-threatening and enjoyable (Houghton et al., 1999). Tests were administered in a randomised order by two postgraduate (PhD) research students who were experienced in their administration. Each testing session began with a short general conversation before moving into the battery of four tests, which were administered in a randomised order. Each testing session lasted approximately 70 minutes and the test administrators reported that the test battery was not taxing and maintained the engagement of participants. Complete data were obtained for all of the tests administered, which along with the short duration of testing suggests that results were not unduly affected by fatigue (Siedman, Biederman, Faraone, Weber, Menin, & Jones, 1997). However, CMS data were not available for one of the Control participants due to an absence from school, and Timetest data were not collected for a number of ADHD participants due to timetabling difficulties. This reduced the final matched sample size for these measures to 49 and 44 respectively, but the individual matching on Age was unaffected.

In addition, during the testing period, the parent/guardian of each of the boys with ADHD was asked to complete the long form of the Conners' Parent Rating Scale - Revised (Conners, 1997). These data were used as an objective measure of hyperactivity-impulsivity and inattention amongst the Age-matched ADHD-PI and ADHD-CT samples, and are reported in Chapter Six (see p. 133). Although data were unavailable for one of the boys with ADHD, this was not considered sufficient grounds to exclude this participant from the study.

Matching procedure

The following procedure was undertaken because it was considered inappropriate to compare the performance of the ADHD-PI, ADHD-CT and Control Groups directly in view of the significant differences in the mean Age and Verbal IQ of the three Groups. In order to address these Age and Verbal IQ differences, it was decided to individually match the ADHD and Control children as closely as possible on both of these variables. Whilst a number of minor problems were encountered in using this approach, none were insurmountable, and all appeared to be less problematic than the potentially confounding effect of the significant Age and IQ differences themselves. It is, however, arguable that the matching of the two ADHD subgroups to the homogenous Control Group would itself result in an inappropriate statistical design, and this will be addressed in the following section. Each of the problems that were encountered in the matching process is outlined in detail below and the way in which it was addressed is discussed.

The initial attempt at matching revealed that a trade-off exists between the stringency of the applied matching criteria and the potential size of the matched sample. This is because the iterative process that results in successively closer matching also necessarily reduces the sample size, as participants who cannot be satisfactorily matched are removed. Hence, the closer the sample was individually matched (i.e., the more stringent the matching criteria), the smaller the size of the sample that would result. Alternatively, unless additional participants are introduced into the matching pool, the larger the desired sample size, the less accurate the individual matching becomes. In the present study, therefore, a decision had to be made that accommodated both the

desired stringency of the matching criteria (i.e., as close as possible), and the sample size (i.e., as large as possible).

In a related problem, the individual matching of the ADHD and Control children on both Age and Verbal IQ simultaneously proved to be problematic. Although it was possible to individually 'match' a subset of the ADHD and Control boys to within 12 months of Age and 15 points on Verbal IQ, subsequent analysis revealed that it was not possible to obtain a satisfactory match on both Age and Verbal IQ simultaneously. A one-way repeated measures (or matched groups) multivariate analysis of variance (MANOVA) was used to evaluate the individual matching of the ADHD and Control boys, and revealed that these differences were nonetheless significant. Thus in order to maintain sufficient stringency in the matching criteria whilst retaining an adequate sample size, the attempt to match on both Age and Verbal IQ simultaneously had to be abandoned. Instead, a decision had to be made whether to match on either Age or Verbal IQ.

It was decided to match the ADHD and Control Groups as closely as possible on Age. This was due to a number of reasons, including the lower level of dispersion observed on Age than on estimated Verbal IQ, and previous research which has indicated that children with ADHD may experience a depressed Verbal IQ (e.g., Barkley et al., 1997c; Houghton et al., 1999). Furthermore, given the developmental nature of ADHD, and hence the anticipated Age-related nature of performance on the dependent measures, it was considered likely that developmental differences between the ADHD and Control Groups being compared would result in a potentially confounding effect.

The ADHD and Control children were therefore matched to within three months on Age, and this resulted in a final matched sample of 100 participants, consisting of 14 ADHD-PI boys, 36 ADHD-CT boys, and their 50 individually Age-matched Controls. Descriptive statistics for the post-matching sample are provided in the following chapter. A repeated measures MANOVA design was again used to evaluate the matching of the Groups on Age, Verbal IQ, and Performance IQ, and revealed no significant differences between the ADHD and Control Groups, indicating that the means for the two Groups did not differ on any of the three variables.

Data analyses

The matching procedures employed in the previous section were each evaluated using a repeated measures (or correlated groups) design. This is because under certain circumstances, such as when matched data or correlated samples are used, the repeated measures design is more appropriate and provides greater statistical power than the factorial design. This was the case in the present study since the individual matching of the ADHD and Control boys on Age induces a correlation between the measures taken on the ADHD and Control Groups. Hence matching has the effect of decreasing the error variance and of precluding the matching variables from becoming competing causal factors of any effects (Kirk, 1995). Naturally the matching variable must have reasonable correlation with the dependent variables, which was the case in the present study, where the correlations between Age and the dependent variables were as high as .74, with the majority above .40 (the 95% significance level). The correlations between the matching variable (Age) and the dependent variables for the SART, CMS, and TEA-Ch respectively are presented in Table 4 (p. 137), Table 7 (p. 141), and Table 10 (p. 148) in Chapter Six. Similar correlations were not calculated for the Timetest due to the large number of dependent variables.

Nevertheless the matching of two discrete ADHD subgroups to a homogeneous Control group remains a cause for concern. In particular, the inclusion of a between-subjects factor for ADHD Subtype in conjunction with the repeated measures Group factor (ADHD vs. Control) would arguably result in an inappropriate statistical design, since such a distinction is meaningless in the Control Group. Although this posed a potentially significant problem, preliminary analysis revealed that there were no significant differences between the performance of the ADHD-PI and ADHD-CT boys on any of the dependent measures, so this variable was excluded from the main analysis. It must be acknowledged however, that this result is based on the relatively small sample size of the ADHD-PI Group ($n = 14$), and thus has limited statistical power, suggesting that the result be interpreted with caution.

Each of the tests administered in the present study was analysed using a one factor (Group: ADHD vs. Control) repeated measures MANOVA, except for the Timetest, in which two separate four factor (Group \times Mode \times Distraction \times Time) repeated measures univariate analyses of variance (ANOVAs) were used. In the case of significant interaction effects, lower order interaction effects and simple main effects were considered. In order to claim substantive as well as statistical significance, where significant results are reported, they are accompanied by an associated Effect Size (ES). Effect Size is a standardised contrast calculated by dividing the difference in means by the estimated population standard deviation. This provides an estimate of the number of standard deviations between the means being compared. An Effect Size of 0.50 to 0.75 or greater is considered appreciable (Cohen, 1970).

Hypotheses

From the research questions presented at the end of Chapter Two, and the expected outcomes discussed in the previous chapter, a series of hypotheses have been formulated that will be examined in Study Two. The hypotheses generated relate to the predicted executive impairments of ADHD children that were identified in Study One, that is: impairments in response inhibition, working memory, attention, and concept of time. The hypotheses have been arranged according to these four domains of functioning and relate directly to the instrumentation that was chosen to assess each of these areas.

All hypotheses were tested at the 95% significance level using the statistical design described in the previous section. Any differences found therefore, are representative of significant differences between the ADHD and Control boys, and can not be attributed to variations in Age between the Groups.

Response inhibition (SART)

Hypothesis one (H1) parts (a) to (c) pertain to the Inhibition phase of the SART in which participants have to inhibit their response to infrequent targets (i.e., the digit "3"). Hypothesis two (H2) part (a) pertains to the Vigilance phase of the SART where participants are required to respond with a button press to the infrequent target digit (i.e., "3").

H1(a). There will be a significant difference between the number of False Positives made by the ADHD-CT, ADHD-PI and Control boys on the Inhibition Phase of the SART. Specifically, the ADHD boys will record significantly more False Positives than the Control boys.

H1(b). Boys diagnosed with ADHD-CT will be significantly more impulsive in their responding than the Control boys, resulting in smaller reaction times. However, boys diagnosed with ADHD-PI will be significantly slower in their reaction times than either the ADHD-CT and Control boys.

H1(c). There will be a significant difference between the number of Misses made by the ADHD-CT, ADHD-PI and Control boys on the Inhibition Phase of the SART. Specifically, the ADHD boys will record significantly more Misses than the Control boys.

H2(a). There will be a significant difference between the number of Misses made by the ADHD-CT, ADHD-PI and Control boys on the Vigilance phase of the SART. Specifically, the ADHD-CT will make significantly less, and the ADHD-PI boys will make significantly more, Misses than Control boys.

Working memory (CMS)

H3(a). There will be a significant difference between the performance of the ADHD and Control boys on the measures of verbal memory provided by the CMS. Specifically, the ADHD boys will be significantly impaired relative to the Control boys.

H3(b). There will be a significant difference between the performance of the ADHD and Control boys on the measures of non-verbal memory provided by the CMS. Specifically, the ADHD boys will be significantly impaired on measures of non-verbal memory relative to the Control boys.

H3(c). There will be a significant difference between the performance of the ADHD and Control boys on the measures of attention/concentration provided

by the CMS. Specifically, the ADHD boys will be significantly impaired relative to the Control boys.

H4. There will be a significant difference in the memory retention of the ADHD and Control boys as measured by the immediate and the commensurate delayed recall tasks of the CMS. Specifically, the performance of the ADHD boys will be significantly impaired relative to that of Controls.

Attention (TEA-Ch)

H5(a). There will be a significant difference between the performance of the ADHD and Control boys on the measures of selective attention provided by the TEA-Ch. Specifically, the ADHD-PI boys will be impaired relative to the ADHD-CT and Control children.

H5(b). There will be a significant difference between the performance of the ADHD and Control boys on the measures of sustained attention provided by the TEA-Ch. Specifically, the ADHD-CT boys will be impaired relative to the ADHD-PI and Control children.

H5(c). There will be a significant difference between the performance of the ADHD and Control boys on the measures of attentional switching provided by the TEA-Ch. Specifically, the ADHD-CT boys will be impaired relative to the ADHD-PI and Control children.

H5(d). There will be a significant difference between the performance of the ADHD and Control boys on the measures of dual task performance provided by the TEA-Ch. Specifically, the ADHD boys will be impaired relative to the Control children.

Concept of time (Timetest)

H6(a). The ADHD boys will be significantly less accurate than Control boys in their reproduction of 0.5 to 6.0 second time intervals.

H6(b). The performance of the ADHD boys will be significantly further impaired by the presence of distractors, relative to that of Control boys.

H6(c). Boys with ADHD will tend to overestimate shorter time durations and underestimate longer time durations on the Timetest relative to the Control boys, consistent with the results reported by Tannock.

CHAPTER SIX

Study Two: Response inhibition, working memory, attention, and concept of time as executive functions in boys with ADHD

Results and Discussion

This chapter describes the results obtained using the tests of response inhibition, memory, attention, and concept of time, with a large sample of ADHD and non-ADHD Control boys. In order to address the potentially confounding effect of significant Age differences between the ADHD and Control Groups, participants were individually matched to within three months of Age. Whilst significant Age differences also emerged between the ADHD-PI and ADHD-CT participants, preliminary analysis revealed that there were no significant differences on the dependent measures according to ADHD Subtype. Furthermore, the nature of the statistical design employed (which was described in detail in Chapter Five) is such that no direct comparisons are drawn between the ADHD Subtypes, and so the ADHD-PI and ADHD-CT samples were merged to form a composite ADHD Group.

Descriptive statistics

The close individual matching on Age, whilst successful, resulted in a corresponding reduction in the size of the matched sample. The composition of the final sample therefore represents only a subset of those participants from whom data was gathered, and comprised 50 ADHD boys (14 of whom were ADHD-PI and 36 ADHD-CT) and 50 Age-matched Control boys. Examination of the data obtained from the Conners' Parent Rating Scale - Revised (Conners, 1997) revealed that the mean rating for inattention amongst the ADHD-PI boys was 29.60 (SD = 1.94) compared to 24.42 (SD = 1.21) for the ADHD-CT boys,

which was not significant [$F(1,46) = 1.90, p = .175$]. However, the mean Conners' rating for hyperactivity-impulsivity was 11.86 (SD = 1.79) for the ADHD-PI boys compared to 16.48 (SD = 1.12) for the ADHD-CT boys, which was significant [$F(1,46) = 4.70, p = .035, ES = .70$], indicating that the ADHD-CT boys were rated as significantly more hyperactive-impulsive than the ADHD-PI boys. A series of revised descriptive statistics are presented in Table 3.

Table 3
Post-matching means and standard deviations (in parentheses) of participants' Age, Verbal IQ (VIQ), and Performance IQ (PIQ) according to Group

Group	n	Age Mean (SD)	VIQ Mean (SD)	PIQ Mean (SD)
ADHD	50	10.1 (1.64)	106.4 (14.74)	113.3 (19.36)
Controls	50	10.1 (1.59)	103.1 (15.86)	114.9 (18.34)

However despite the significant Age differences between the ADHD-PI and the ADHD-CT groups, there were no significant differences on any of the tests of executive functioning that were employed in the present study. Thus the reporting of data for either of these subgroups separately is misleading, since the ADHD boys were individually matched with Control boys on Age regardless of their Subtype. Hence the participants in the composite ADHD Group were aged between 6 years 6 months and 12 years 7 months, whilst participants in the Control Group were aged between 6 years 7 months and 12 years 7 months. Verbal IQ estimates ranged between 58 and 141 for the ADHD

Group and between 72 and 133 for the Control Group. Performance IQ scores were between 58 and 146 for the ADHD Group, and between 70 and 155 for the Control Group.

A one-factor (Group: ADHD vs. Control) repeated measures multivariate analysis of variance (MANOVA) was used to evaluate the individual matching of the ADHD and Control participants on Age (in months), and the Group matching on Verbal and Performance IQ. The analysis revealed no significant Group main effect [$F(3,47) = 1.27$, n.s.], indicating that the means of the ADHD and Control Groups did not differ significantly on any of these three variables.

Analysis of the dependent measures

The data obtained from the tests of response inhibition, memory, attention and concept of time were each analysed separately using repeated measures analysis of variance (ANOVA) designs. The close individual matching on Age facilitates the inclusion of the Group (ADHD vs. Control) repeated measures factor, since it induces a correlation between the measures taken on the ADHD and Control Groups (Kirk, 1995). However, the matching variable must have reasonable correlation with the dependent variables. As anticipated, this was the case in the present study, with the majority of the dependent variables being significantly correlated with Age. In particular, the dependent measures comprising the CMS and TEA-Ch were strongly correlated with Age. The correlations between Age and the dependent variables are reported separately for the SART, CMS, and TEA-Ch as part of the relevant analysis.

The data obtained from the tests of response inhibition, memory and attention were each analysed using a one-way repeated measures (Group: ADHD vs. Control) multivariate analysis of variance (MANOVA) design. This was

followed by an examination of the univariate main effects for each of the dependent variables. For the Timetest, the absolute discrepancy and coefficient of accuracy measures were analysed using two separate four factor (Group x Mode x Distraction x Time) analyses of variance (ANOVAs), with repeated measures on all factors. In the event of significant interaction effects, lower order interactions and main effects were analysed and simple main effects were calculated.

Response inhibition

Whilst only one of the four measures comprising the SART was found to correlate significantly with Age, it was the number of False Positives made on the inhibition phase of the task. As can be seen in Table 4, the correlations indicate that while the number of False Positives recorded by the Control boys does not appear to correlate with Age, the boys from the ADHD group made less False Positives as Age increased. Hence the variable most likely to reflect the ability (or rather inability) to inhibit a response was found to correlate significantly with Age for the boys with ADHD. This finding appears to suggest that the ability of the boys with ADHD to inhibit a response might continue to improve with increasing Age, while the performance of the Age-matched Control boys would not. Thus it may be that the ability to inhibit a response continues to develop in boys with ADHD until a later Age than for non-ADHD Control boys.

Table 4

Correlations between the matching variable (Age) and the Sustained Attention to Response Task (SART) dependent variables

Dependent Variable	ADHD (n = 49)	Controls (n = 49)	Total (n = 98)
Inhibition Phase			
False Positives	-.32*	-.08	-.22*
Misses	-.06	.06	-.01
Vigilance Phase			
False Positives	-.06	-.24	-.13
Misses	-.09	-.20	-.14

* p < .05
 ** p < .01

An examination of the SART data revealed a significant multivariate main effect for Group [$F(4,45) = 14.94, p < .001$], indicating that this test of response inhibition clearly discriminates between the ADHD and Control boys. Whilst this result was supported by significant (and substantive) univariate main effects on the Inhibition phase of the task (as shown in Table 5), no such differences were observed for the Vigilance phase of the SART. This appears to be in line with Hypothesis One, which suggested that there would be a significant difference between the ADHD and Control boys on the Inhibition phase of the SART.

Table 5

Group main effects and effect sizes for the SART

Measure	F(1,48)	p	ES
Inhibition Phase			
False Positives	15.96	< .001	.81
Misses	51.49	< .001	1.45
Vigilance Phase			
False Positives	.41	.524	
Misses	.00	.983	

An inspection of the means (see Table 6) for the SART Inhibition phase reveals that the ADHD boys in fact made significantly less False Positives than the Control boys on this task. This finding suggests that the boys with ADHD actually performed better on this measure of response inhibition than the Age-matched Control boys. Thus while there were significant differences between the performance of the ADHD and Control boys, providing partial support for Hypothesis One (part a), the direction of these observed differences was contrary to expectations.

In line with this result (but again contrary to expectations), the present study also found that the boys with ADHD were less impulsive in their responding than the Control boys, which was contrary to Hypothesis One (part b). Indeed, the response times obtained suggested that the ADHD boys were in fact slower to respond (mean RT = 401.39ms, *SD* = 16.01) than Control boys (mean RT = 339.59ms, *SD* = 10.40) on those occasions when responses were received [$F(1,48) = 11.97, p = .001, ES = .70$]. Nevertheless the results obtained in the present study seem to be consistent with a growing number of studies that have

study seem to be consistent with a growing number of studies that have reported slower stop signal reaction times amongst ADHD children (Aman, Roberts, & Pennington, 1998; Nigg, 1999; Oosterlaan, Logan, & Sergeant, 1998; Purvis & Tannock, 1997; Schachar et al., 1995).

Table 6

Group means and standard deviations (in parentheses) for the SART

Measure	ADHD		Controls	
	Mean	SD	Mean	SD
Inhibition Phase				
False Positives	17.78	(.57)	20.92	(.40)
Misses	14.82	(1.51)	4.08	(.40)
Vigilance Phase				
False Positives	4.22	(.70)	4.24	(.61)
Misses	11.78	(2.27)	9.98	(1.55)

However, an even stronger result ($ES = 1.45$) revealed that the boys with ADHD recorded significantly more Misses on the Inhibition task than the Control boys, providing support for Hypothesis One (part c). Thus it is not immediately apparent whether it was the ADHD or Control boys who performed more poorly on the SART. This finding suggests that while the ADHD boys were more proficient at inhibiting their responses to the target digit (i.e., “3”) than the Control boys, they were also less likely to respond to the non-target digits for which a response was required.

The finding that the boys with ADHD made a reduced number of False Positives than the Control boys appears to challenge the notion of impaired response inhibition in boys with ADHD, which Barkley (1997b) predicted was the central impairment in the disorder. However the results of the present study would appear to contrast with several studies to date that have found impairments in response inhibition in ADHD children, using a variety of paradigms (e.g., Aman, Roberts, & Pennington, 1998; Iaboni, Douglas, & Baker, 1995; Nigg, 1999; Schachar, Mota, Logan, Tannock, & Klim, 2000).

Alternatively, it may be that the reduced number of False Positives and increased number of Misses amongst the ADHD group reflect the use of a more conservative approach to the SART task, or an inability to inhibit an established pattern of responses. A number of studies would seem to provide evidence to support this, with Nigg (1999) and Sergeant and Van der Meere (1998) both reporting that ADHD children were less proficient at modifying an established pattern of responses than Control children. Similar results were also found by Houghton et al. (1999) who reported that ADHD children were less likely to modify their subsequent responding on the Wisconsin Card Sorting Test (WCST; Heaton et al., 1993), even in the presence of corrective feedback.

Memory

Correlations were also calculated between Age and the dependent measures comprising the CMS, and these are presented in Table 7. All but four of the variables produced strong positive correlations with Age ($p < .01$), with the notable exceptions of Stories delayed recognition and three of the Word Pairs measures. The pattern of correlations was also very similar for both the ADHD and Control Groups, except for the Dot Locations delayed and the Stories delayed recognition measures.

Table 7

Correlations between the matching variable (Age) and the Children’s Memory Scale (CMS) dependent variables

Dependent Variable	ADHD (n = 50)	Controls (n = 50)	Total (n = 100)
Dot Locations			
Learning	.58**	.47**	.53**
Total Score	.60**	.43**	.52**
Delayed	.43**	.03	.26**
Stories			
Immediate	.40**	.64**	.49**
Delayed	.33*	.63**	.45**
Delayed Recognition	-.13	.30*	.08
Faces			
Immediate	.60**	.62**	.61**
Delayed	.56**	.56**	.55**
Word Pairs			
Learning	-.01	.03	.03
Total Score	.00	.04	.01
Delayed	.11	.07	.09
Delayed Recognition	.74**	.67**	.70**
Numbers	.40**	.40**	.40**
Sequences	.52**	.68**	.57**

* p < .05
** p < .01

The repeated measures (Group: ADHD vs. Control) MANOVA revealed a significant multivariate main effect for Group [$F(14,36) = 2.58, p = .011$] across the 14 dependent variables that comprise the CMS. As can be seen in Table 8, this was supported by univariate main effects for Group on seven variables, six of which involve verbal memory subtests (Stories and Word Pairs) and the other a measure of attention/concentration (Sequences). In contrast, no significant differences were observed on any of the measures of non-verbal memory.

An examination of the means (see Table 9) reveals that it was the ADHD boys who performed more poorly than the Control boys on all of the measures for which significant differences were reported. In each case, the Effect Sizes are sufficient to claim that the observed differences are substantive. However, the evidence for significant impairment amongst the ADHD Group was strongest on the measures of verbal memory, with the largest effects being observed on the Stories and Word Pairs measures. This appears to be consistent with the results of other studies that have suggested that Verbal IQ may be depressed in children with ADHD (Barkley, 1997b). This finding also supports Hypothesis Three (part a) which predicted that the ADHD boys would be significantly impaired on measures of verbal memory.

Table 8

Group main effects and effect sizes for the CMS

Measure	F(1,49)	p	ES
Dot Locations			
Learning	2.68	.108	
Total Score	2.45	.124	
Delayed	.36	.551	
Stories			
Immediate	13.93	< .001	.75
Delayed	15.14	< .001	.78
Delayed Recognition	5.81	.020	.48
Faces			
Immediate	1.48	.230	
Delayed	3.67	.061	
Word Pairs			
Learning	7.42	.009	.54
Total Score	12.56	.001	.71
Delayed	9.14	.004	.60
Delayed Recognition	2.44	.125	
Numbers	.39	.536	
Sequences	5.28	.026	.46

Table 9

Group means and standard deviations (in parentheses) for the CMS

Measure	ADHD		Controls	
	Mean	SD	Mean	SD
Dot Locations				
Learning	18.18	(.57)	19.22	(.44)
Total Score	24.40	(.76)	25.74	(.57)
Delayed	5.96	(.30)	6.18	(.23)
Stories				
Immediate	43.78	(2.02)	53.68	(2.27)
Delayed	40.40	(2.03)	51.18	(2.17)
Delayed Recognition	24.66	(.30)	25.78	(.33)
Faces				
Immediate	33.74	(.77)	34.70	(.69)
Delayed	31.34	(.92)	33.14	(.69)
Word Pairs				
Learning	19.94	(.95)	23.00	(.70)
Total Score	24.76	(1.15)	29.54	(.92)
Delayed	4.52	(.30)	5.78	(.28)
Delayed Recognition	36.52	(.78)	37.68	(.78)
Numbers	14.62	(.51)	15.10	(.53)
Sequences	46.38	(1.98)	51.50	(1.62)

In contrast, no significant differences were observed on the measures of non-verbal memory provided by the CMS. This result seems to contradict Hypothesis Three (part b), suggesting that non-verbal memory may be unimpaired in boys with ADHD. This result is consistent with the CMS normative data (Cohen, 1997) which indicates that relative to matched Controls, ADHD children were impaired on the verbal immediate and attention/concentration indices of the CMS. However, while the Cohen (1997) study also excluded ADHD children with comorbid diagnoses, all of the ADHD children involved in the Cohen (1997) study were receiving stimulant medication prior to test administration. That similar results were obtained in the present study, where all participants were unmedicated for at least 20 hours prior to testing, is a significant finding.

Furthermore, partial support was provided for Hypothesis Three (part c), which predicted that the ADHD boys would be significantly impaired on the measures of attention/concentration provided by the CMS. While no significant differences were observed on the numbers subtest, which resembles the WISC-III digit span subtest, significant differences were apparent on the sequences subtest, which involved holding a series of numbers, letters, or words in mind, and manipulating them (i.e., working memory).

In order to examine Hypothesis Four, which predicted that the memory retention of ADHD boys would be significantly impaired relative to that of Control boys, a second analysis was conducted to investigate the effect of a temporal delay on the memory performance of ADHD and Control children. The data obtained from the CMS subtests which incorporate measures of both immediate and delayed recall (i.e., Dot Locations, Stories, Faces and Word Pairs) were subjected to a two-factor (Group x Delay) repeated measures

MANOVA, with the immediate and delayed recall scores as the dependent variables. However, while the results revealed significant main effects for Group [$F(4,46) = 6.61, p < .001$] and Delay [$F(4,46) = 21.76, p < .001$] respectively, the interaction of these two variables was not significant.

As expected, the memory performance of both the ADHD and Control participants was significantly diminished by the 30 minute delay between the immediate and delayed recall tasks. The significant multivariate main effect for Delay was supported by significant univariate main effects on all four of the CMS subtests used in the present analysis: Dot Locations [$F(1,49) = 6.58, p = .013$], Stories [$F(1,49) = 35.36, p < .001$], Faces [$F(1,49) = 33.18, p < .001$], and Word Pairs [$F(1,49) = 8.08, p = .007$]. However, contrary to Hypothesis Four, the temporal delay did not affect the memory retention of the ADHD boys significantly more than it did that of the Control boys. Whilst the finding of a significant main effect for Group appears to be consistent with the results of the earlier analysis, it must be interpreted with caution. This is because the present result is based on data from only four of the CMS subtests and, in the absence of a significant Group x Delay interaction, effectively merges the immediate and delayed recall measures for each subtest into a single composite score. Hence the significant Group differences are of little interest in comparing memory retention across a temporal delay.

Attention

Table 10 shows the correlations between Age and the TEA-Ch dependent variables for the ADHD Group, the Control Group and the overall sample (Total). As can be seen, all but one of the TEA-Ch variables correlates significantly with Age for both the ADHD Group and the overall sample, indicating that performance on these measures was significantly Age-related.

However, what is not so readily apparent from the table is the fact that the performance of the ADHD Group (and the overall sample) on each of these measures shows a strong positive relationship with Age. This is because all of those measures on which negative correlations were obtained (i.e., Sky Search Time Per Target, Creature Counting Time, and Dual Task) are found to increase as performance diminishes. For example, the Time Per Target measure relates to the time taken to complete a given task, and the negative correlation with Age indicates that older participants (in general) required less time to complete the task than younger ones and are correspondingly more proficient.

Table 10
Correlations between the matching variable (Age) and the Test of Everyday Attention for Children (TEA-Ch) dependent variables

Dependent Variable	ADHD (n = 50)	Controls (n = 50)	Total (n = 100)
Sky Search			
Targets	.35*	.18	.27**
Time Per Target	-.46**	-.46**	-.43**
Focused Attention	-.15	-.24	-.17
Score!			
Sustained Attention	.41**	.23	.33**
Creature Counting			
Accuracy	.46**	.20	.33**
Time	-.50**	-.52**	-.49**
Dual Task	-.38**	-.29*	-.32**

* p < .05
** p < .01

In contrast, only three of the TEA-Ch measures that were taken on the Control Group were found to correlate significantly with Age. Once again, despite the negative correlations obtained, the nature of the measures themselves is such that these correlations are indicative of a strong positive relationship between performance and Age on these three measures. Thus the performance of the ADHD Group appears to be strongly Age-related on the TEA-Ch as a whole, whilst the performance of the Control Group appears to be related to Age on only a subset of these measures.

That these differences between the ADHD and Control Groups were apparent, despite the close individual matching in Age, may provide support for the notion that ADHD represents a delay, in this case, in the development of attentional skills. This is because the overall performance of the ADHD boys appears to improve with Age, whilst the performance of the Control boys improves on only some measures but not on others, which may be indicative of potential ceiling effects. An examination of the mean scores obtained by the Control boys may help to clarify this situation, and is conducted after the reporting of the respective main effects. However, this interpretation of the results obtained is advanced with some caution due to its inferential nature, and the failure to observe significant differences between the means of the ADHD and Control Groups on all but the Creature Counting measure.

A one-way repeated measures MANOVA (Group: ADHD vs Control) was conducted on the data obtained using the TEA-Ch, and a significant multivariate main effect for Group [$F(7,43) = 2.42, p = .035$] was observed. This indicates that there was a significant difference between the overall performance of the ADHD boys and their individually Age-matched Controls on the measures comprising the TEA-Ch. This multivariate main effect was

supported by significant univariate main effects on the measure of attentional control and switching provided by the Creature Counting subtest. That no significant differences were obtained on the TEA-Ch measures of selective attention, sustained attention, or dual task performance, provides no support for Hypotheses Five (parts a, b, and d).

Table 11 shows the significant univariate main effects for Group that were observed on the Creature Counting measures of Accuracy (i.e., the number of trials which participants completed successfully) and Time (i.e., the amount of time required per successful switch). Examination of the magnitude of the associated Effect Sizes reveals that the main effect for Accuracy ($ES = .81$), is indicative of substantive Group differences on this measure, while the main effect for Time ($ES = .49$) would be considered a moderate effect. This result therefore is in line with Hypothesis Five (part c) which suggested that the ADHD boys would be differentiated from Control boys on the measure of attentional switching, and is consistent with the results of earlier research by Cepeda et al. (2000). In addition, since there were no significant differences on this measure according to ADHD subtype, the observed difficulties with attentional switching appear to be characteristic of boys of both ADHD subtypes.

Table 11

Group main effects and effect sizes for the TEA-Ch

Measure	F(1,49)	p	ES
Sky Search			
Targets	2.83	.099	
Time Per Target	2.42	.126	
Focused Attention	.18	.672	
Score!			
Sustained Attention	1.99	.165	
Creature Counting			
Accuracy	16.33	< .001	.81
Time	6.00	.018	.49
Dual Task	1.65	.205	

An examination of the means (see Table 12) reveals that, in those cases where significant effects were reported, it is the ADHD boys who under-perform relative to the Control boys. That is, the overall mean Accuracy scores revealed that the Control children completed significantly more Creature Counting trials successfully (i.e., 5.68) than the ADHD children (4.32). Similarly, the Time scores revealed that on average, the ADHD boys required more time per successful switch (5.08 seconds) than the Control boys (4.37 seconds).

Table 12

Group means and standard deviations (in parentheses) for the TEA-Ch

Measure	ADHD		Controls	
	Mean	SD	Mean	SD
Sky Search				
Targets	18.00	(.37)	18.68	(.25)
Time Per Target	6.20	(.44)	5.51	(.22)
Focused Attention	4.36	(.43)	4.15	(.19)
Score!				
Sustained Attention	8.16	(.29)	8.60	(.18)
Creature Counting				
Accuracy	4.32	(.30)	5.68	(.18)
Time	5.08	(.22)	4.37	(.20)
Dual Task	3.86	(1.46)	1.92	(.57)

The result that no significant Group differences were apparent on measures of selective and sustained attention provided by the TEA-Ch does to some extent conflict with the findings of previous research. It is important to note however, that unlike many previous studies, the present study employed instrumentation (i.e., the TEA-Ch) that was specifically designed to measure the construct of attention (Manly et al., 1997). Therefore the finding of no significant differences on the TEA-Ch measures of selective and sustained attention should not be dismissed out of hand.

For example, numerous studies have used a variety of CPT paradigms (Losier, McGrath, & Klein, 1996) to demonstrate that sustained attention is impaired in

ADHD. However, while there is considerable evidence to suggest that ADHD children make more CPT commission errors than Controls, Robertson et al. (1997) argued that sustained attention would be more heavily taxed by tasks of shorter duration where the automatic response is transferred to the non targets (such as the SART). Thus it may be that the very nature of the “sustained attention” constructs measured by the TEA-Ch, the SART, and the traditional CPT respectively, are in fact qualitatively different.

One possible interpretation of these results is that Robertson et al. (1997) are correct and that deficits in sustained attention might be more readily observed on tasks such as the SART, which employs a reverse-CPT paradigm, than on the traditional CPT (or the TEA-Ch). Were this the case, the results obtained in the present study using the SART might be indicative of a deficit in sustained attention amongst the ADHD Group (relative to the Control Group). Such a result would appear to be consistent with the findings of earlier research and the present study, although the failure to replicate the significant Group differences using the TEA-Ch would necessitate further examination of the actual construct under scrutiny.

Alternatively, it may be that the failure to observe significant Group differences on the TEA-Ch measures of selective or sustained attention was the result of a potential ceiling effect affecting the Control boys. While the performance of the ADHD Group on these three measures was found to improve significantly with Age, that of the Control Group did not. Furthermore, the TEA-Ch examines selective attention using a simple visual search task in which participants must identify 20 target pairs of spaceships (Manly et al., 1999). An examination of Table 12 reveals that the ADHD and Control boys correctly identified an average of 18.00 and 18.68 targets respectively, which are close to the maximum

possible score of 20. Similarly, the sustained attention measure requires participants to count the scoring sounds on a cassette tape over 10 trials, and the mean scores of 8.16 and 8.60 for the ADHD and Control group respectively, may suggest that this task failed to place sufficient demands on attention and processing. However, despite the greater demands placed on performance by the dual task measure, for which participants were asked to complete both these tasks simultaneously, no significant differences were found.

Concept of time

The previous chapter described the procedure through which the raw data collected using the Timetest were converted into the two dependent variables that were used in the present analysis. The absolute discrepancy and coefficient of accuracy scores were each analysed separately using a 2 (Group) \times 2 (Mode) \times 2 (Distraction) \times 5 (Time) univariate ANOVA design, with repeated measures on all factors. A repeated measures design was appropriate since participants from the ADHD and Control Groups were individually matched, and data were gathered for all participants at each level of Mode (Visual and Auditory), Distraction (Off and On), and Time (0.5, 2.0, 3.0, 4.0, and 6.0 seconds). The four factor design employed effectively tests 15 hypotheses which are, in order of decreasing complexity: the four-way interaction of Group, Mode, Distraction and Time; the four three-way interactions; the six two-way interactions; and the four main effects for Group, Mode, Distraction and Time, respectively.

The highest order (i.e., four-way) interaction effect is examined first, since it relates to the most complex hypothesis that can be tested using the design. The analysis then naturally proceeds by interpreting the interaction effects of successively lower orders (i.e., three-way and two-way interaction effects) until only the main effects for the individual variables remain. In the event of

significant interaction effects, lower order interactions and main effects were analysed and simple main effects were calculated. Of particular interest in the present study are those significant main effects or interactions that involve the Group factor, as it is expected that the ADHD Group will under-perform relative to Controls. However, the interpretation of a main effect for Group (i.e., ADHD vs. Control) would be qualified by the presence of a significant Group x Distraction interaction, indicating for example that the effect of a distractor was more pronounced amongst the ADHD Group than the Control Group.

Absolute discrepancy scores

The absolute discrepancy scores represent the absolute magnitude of the mean time reproduction errors made by participants on the Timetest. Using the absolute discrepancy scores as the dependent variable revealed a significant Group x Mode interaction and a significant main effect for Time. Significant main effects were also observed for both of the factors present in the interaction (i.e., Group and Mode). However, the interpretation of these main effects is qualified by the presence of the significant interaction effect, which indicates that the mean absolute discrepancy scores are moderated by two factors: Group (i.e., ADHD vs. Control) and the Mode of task presentation (Auditory vs. Visual). The ANOVA summary table for the Group x Mode interaction effect is presented in Table 13. All other main effects and interactions, except the main effect for Time, were found to be non-significant.

Table 13

Partial ANOVA summary table for the Timetest Absolute Discrepancy Scores:
Group x Mode interaction effect

Source	df	MS	F	p
Group	1	15.13	7.48	.009
Error (Group)	43	2.02		
Mode	1	2.57	9.57	.003
Error (Mode)	43	.27		
Group x Mode	1	2.25	10.28	.003
Error (Group x Mode)	43	.22		

The nature of the Group x Mode interaction effect can be seen in Figure 10. Simple main effects for Group were calculated for the Visual and Auditory tasks respectively, and revealed that the ADHD group made significantly more absolute error than their respective Controls on both the Visual [0.99 vs. 0.72 seconds respectively, $F(1,43) = 66.35$, $p < .01$, $ES = .55$] and Auditory time reproduction tasks [0.84 vs. 0.72 seconds respectively, $F(1,43) = 13.05$, $p < .01$, $ES = .24$]. The magnitude of the observed Effect Sizes was sufficient to suggest that the Group differences observed on the Visual task are substantive in nature, whilst those seen on the Auditory task are not.

Furthermore, simple main effects for Mode were calculated for the ADHD Group and the Control Group separately, to identify whether the observed differences between the absolute discrepancy scores for the Visual and Auditory tasks were significant. The results revealed that the mean absolute discrepancy of the ADHD group was significantly larger on the Visual task

than on the Auditory task [0.94 vs. 0.89 seconds respectively, $F(1,43) = 21.98$, $p < .01$, $ES = .32$], although no such differences were observed for the Control Group. However, the Effect Size obtained is not sufficiently large enough to conclude that these differences are substantive.

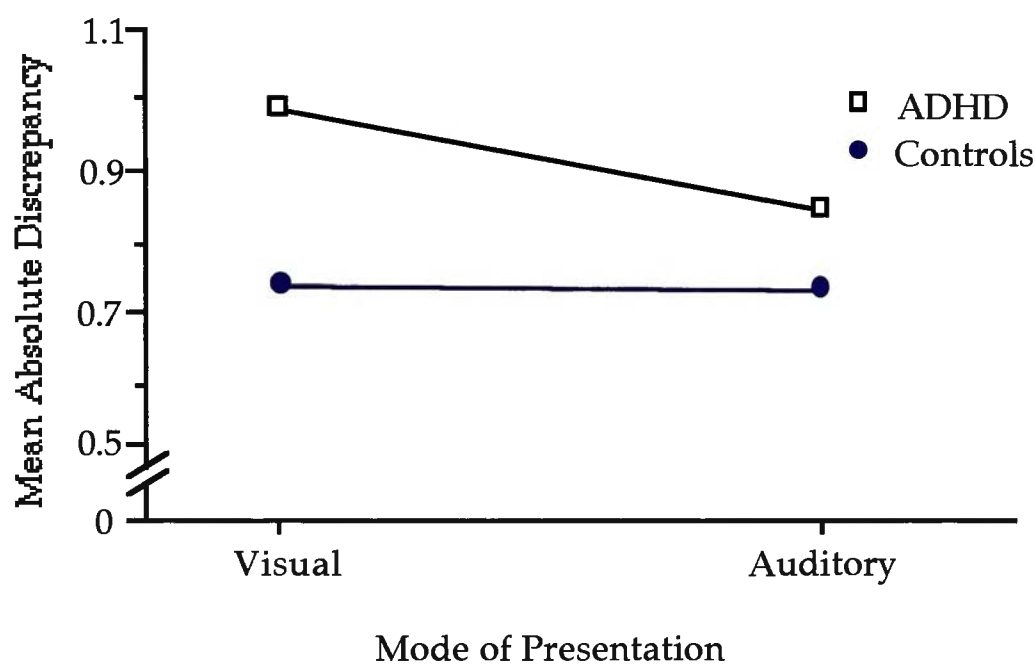


Figure 10. Plot of the Group x Mode interaction effect for the Timetest Absolute Discrepancy scores.

The significant main effect for Time [$F(4,172) = 283.94$, $p < .001$] which is illustrated in Figure 11 consisted largely of a strong linear effect. Specifically, this result reveals that the absolute time reproduction errors of both ADHD and Control groups increased in direct proportion with the length of the duration to be reproduced. This result appears to have been consistently reported in the time reproduction literature to date (e.g., Barkley et al., 1997; Cappella, Gentile & Juliano, 1977; Dooling-Litfin, 1997; Walker, 1982).

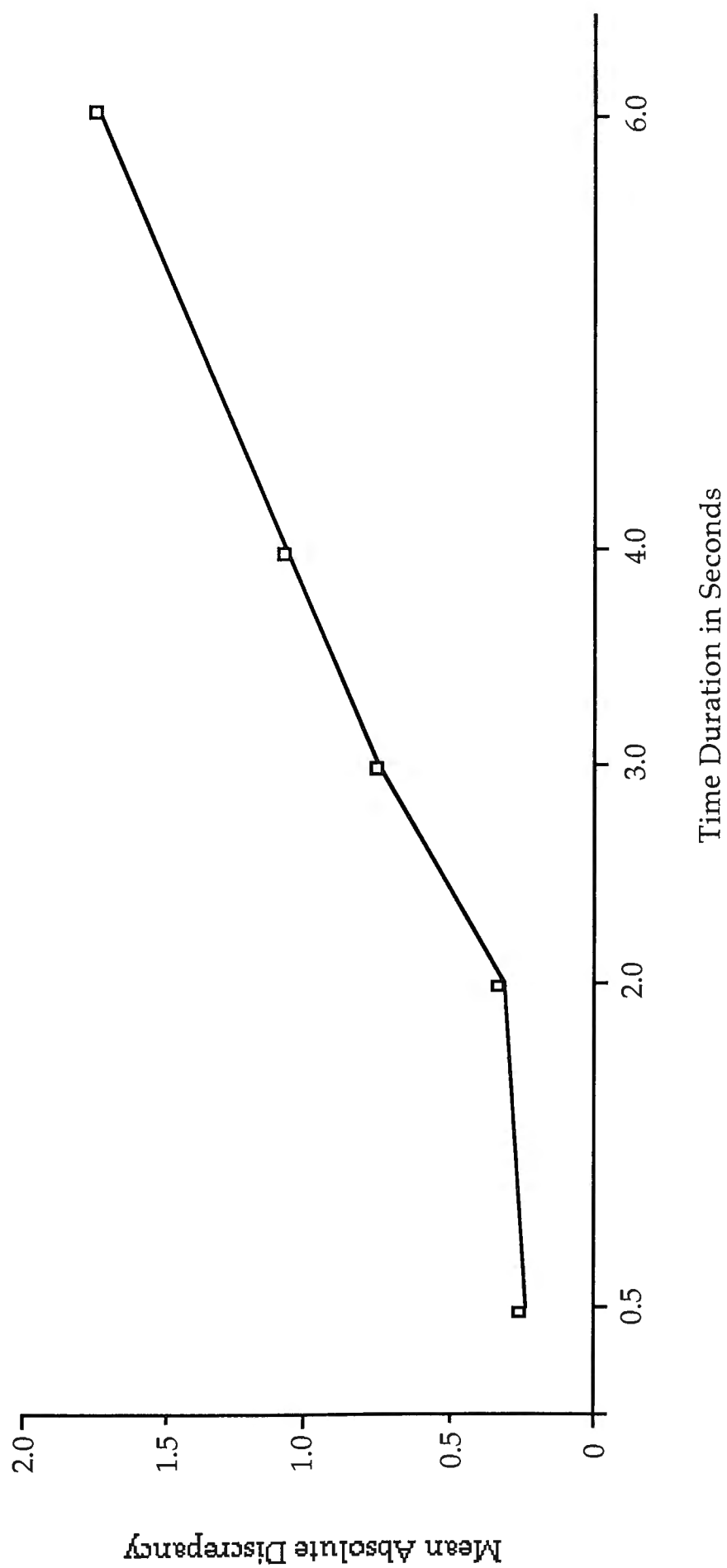


Figure 11. Plot of the linear main effect for Time for the Timetest Absolute Discrepancy scores.

In line with Hypothesis Six (part a), the performance of the ADHD boys was impaired on the measure of time reproduction relative to that of non-ADHD Controls. However, it is worth noting that there was no significant interaction or main effect involving Distraction, which is contrary to Hypothesis Six (part b). The results obtained appear to indicate that time reproduction in both ADHD and Control children was unaffected by the visual or auditory distractors used in the present study. This result appears to conflict with the findings of earlier research, with Barkley et al. (1997) and Zakay (1992) both reporting that time reproduction errors increased in the presence of distractors. However, this discrepancy may be due, at least in part, to differences in the types of distractors that were used in the two studies. For example, a Jack in the Box operated by the researcher was used in the Barkley et al. (1997) study. In comparison, the computer-generated distractors used in the present study did not require participants to look away from the computer, since the visual and auditory distractors were presented on the same screen or speaker as the stimulus, thereby raising questions about their actual level of distractibility. However, it is also possible that this discrepancy arose due to a difference in ADHD populations studied. Although the boys in the present study had been clinically diagnosed as ADHD, those used in the Barkley et al. (1997) study were clinic-referred.

Coefficients of accuracy

A similar analysis was conducted using the coefficient of accuracy scores, which express the degree of under- or over-reproduction as a percentage of the stimulus duration, scaled so that 1.00 represents a perfect reproduction. Thus under-reproductions are represented by numbers less than 1.00 (such as 0.80), and over-reproductions by numbers greater than 1.00 (such as 1.20). The analysis revealed the presence of two significant three-way interactions: Group

x Mode x Time [$F(4,172) = 6.20, p < .001$] and Mode x Distraction x Time [$F(4,172) = 6.78, p < .001$]. Four of the two-way interaction effects subsumed by these higher order interactions were also significant: Distraction x Time [$F(4,172) = 3.42, p = .010$], Mode x Time [$F(4,172) = 46.62, p < .001$], Group x Time [$F(4,172) = 3.58, p = .008$], and Mode x Distraction [$F(1,43) = 7.82, p = .008$]. Significant main effects were also observed for Time [$F(4,172) = 61.03, p < .001$] and Mode [$F(1,43) = 38.83, p < .001$].

An examination of the Group x Mode x Time interaction (see Figure 12) revealed that both the ADHD and Control participants tended to overestimate the shortest time interval (0.5 seconds) and underestimate the longer time intervals (3.0, 4.0, and 6.0 seconds) on the Visual task. However, the nature of the interaction effect is such that the ADHD boys appeared to be more pronounced in the under- and over- estimations than Control children. In contrast, the performance of the ADHD and Control Groups is virtually indistinguishable on the Auditory task, with both Groups consistently underestimating the time intervals to be reproduced. Although the discrepancy between the visual and auditory modes of presentation was unexpected, this result appears to provide partial support for Hypothesis Six (part c), and the findings of Tannock (2001).

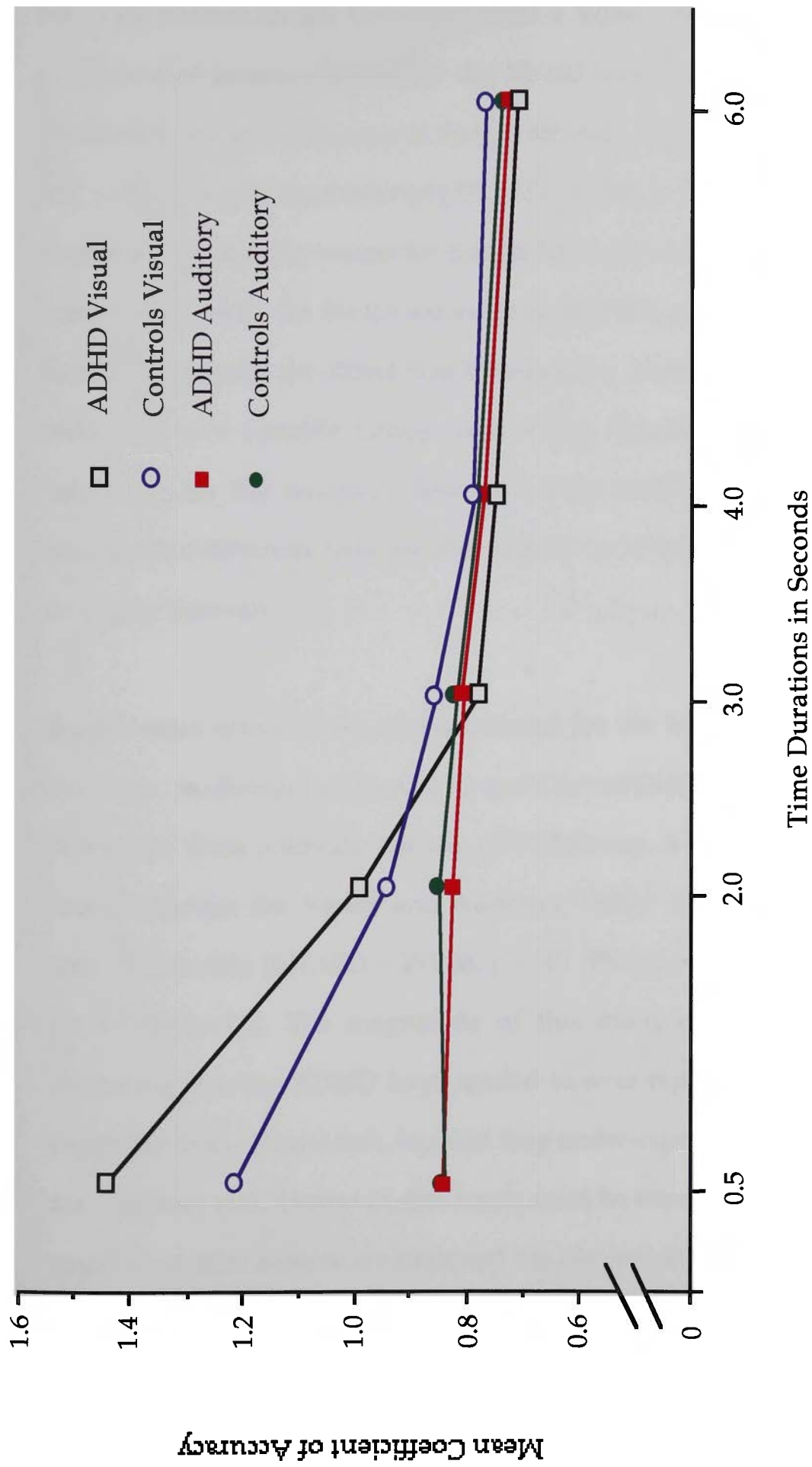


Figure 12. Plot of the Group x Mode x Time interaction effect for the Timetest Absolute Discrepancy scores.

By way of confirmation, simple main effects for Group were calculated separately for both the Visual and Auditory tasks and at each of the five Time intervals present in the Group \times Mode \times Time interaction. Comparing the coefficient of accuracy scores for the Visual time reproduction task revealed significant Group differences at the 0.5 second [$F(1,172) = 42.87, p < .01, ES = .99$] and 3.0 second time intervals [$F(1,172) = 4.87, p < .05, ES = .33$]. The mean coefficient of accuracy scores for the ADHD and Control Groups respectively, were 1.44 and 1.21 for the 0.5 second task, and 0.78 and 0.86 for the 3.0 second task. Furthermore, the Effect Size obtained for the 0.5 second time interval is indicative of a sizeable Group main effect. Simple main effects were also calculated for the Auditory task, and these confirmed that there were no significant differences between the ADHD and Control Groups at any of the five Time intervals.

Simple main effects were also calculated for the Mode of presentation (i.e., Visual vs. Auditory) for the ADHD and Control Groups separately and at each of the five Time intervals. For the ADHD Group, a significant difference was found between the Visual and Auditory Modes of presentation on the 0.5 second task only [$F(1,172) = 291.98, p < .01, ES = 2.58$, with means of 1.44 and .84 respectively]. The magnitude of this main effect is extremely large, indicating that the ADHD boys tended to over-reproduce the time intervals presented in the Visual task, but that they under-reproduced those presented in the Auditory task. However, this result must be interpreted with some caution, since no similar results are obtained for the lengthier time intervals. For the Control children, significant differences were found at the 0.5 second [$F(1,172) = 112.21, p < .01, ES = 1.60$, with means of 1.21 and 0.84 for the Visual and Auditory tasks respectively], and 2.0 second [$F(1,172) = 7.16, p < .01, ES = .40$, with means of 0.94 and 0.85] Time intervals.

An examination of the Mode x Distraction x Time interaction (presented in Figure 13) reveals that whilst responses to the Visual task varied from over- to under-reproductions as the Time durations increased, the Auditory tasks were consistently under-reproduced at all Time durations. Furthermore, whilst the Auditory distractors appeared to have little effect, the Visual distractors appeared to be effective, particularly at the shorter time intervals. This was confirmed by the simple main effects for Distraction (i.e., Off vs. On) at the 0.5 second [$F(1,172) = 60.27, p < .01, ES = 1.17$, with means of 1.19 and 1.47 respectively] and the 2.0 second [$F(1,172) = 8.58, p < .01, ES = .44$, with means of 0.92 and 1.02] intervals of the Visual task. Thus the effect of the Visual distractors appears to be quite pronounced at the 0.5 second interval, and moderate at the 2.0 second interval. In contrast, no significant differences were found on any of the intervals comprising the Auditory task.

For the non-distractor condition, a significant main effect was observed for Mode of presentation (i.e., Visual vs. Auditory) at the 0.5 second duration [$F(1,172) = 84.62, p < .01, ES = 1.39$], with means of 1.19 and .85 respectively, and a correspondingly large Effect Size. However, no further significant differences were obtained, indicating that the Mode of presentation did not significantly affect the coefficient of accuracy of either the ADHD or Control participants at the longer time intervals. In addition, significant main effects for Mode were observed on the 0.5 second [$F(1,172) = 309.70, p < .01, ES = 2.65$, with means of 1.47 and .83 respectively] and 2.0 second tasks [$F(1,172) = 26.37, p < .01, ES = .77$, with means of 1.02 and .84] of the with-distractor condition. Both of these main effects are appreciable in their Effect Sizes, indicating substantive differences between the Auditory and Visual phases of the task on the with-distractor conditions. Thus, the Visual distractors proved to be more effective than the Auditory distractors, especially for shorter Time intervals.

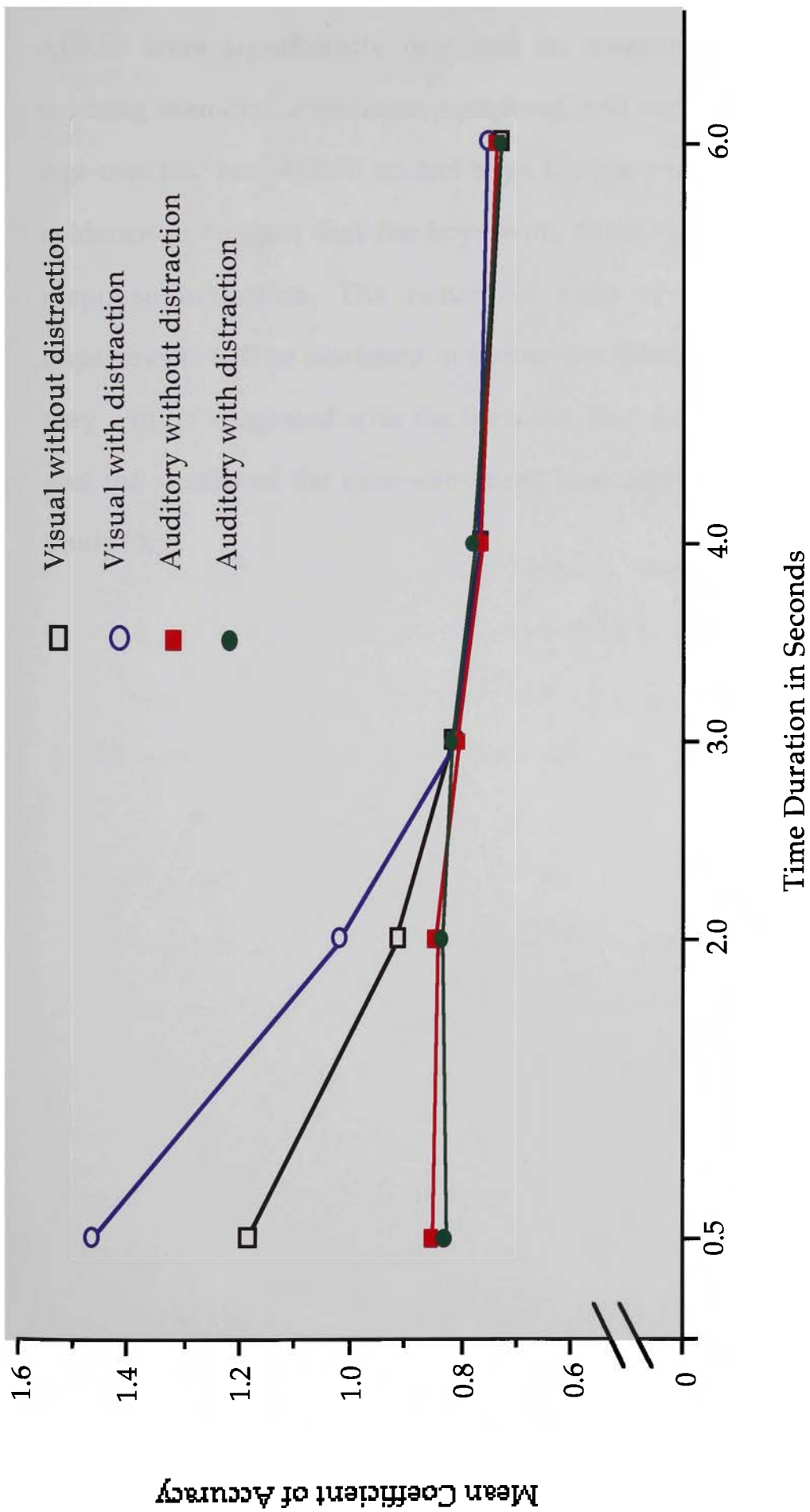


Figure 13. Plot of the Mode x Distraction x Time interaction effect for the Timetest Absolute Discrepancy scores.

Chapter summary

The findings from the battery of tests administered revealed that the boys with ADHD were significantly impaired on measures of verbal memory and working memory, attentional switching, and time reproduction, relative to Age-matched non-ADHD control boys. Contrary to expectations, there was no evidence to suggest that the boys with ADHD exhibited an impairment in response inhibition. The nature of each of these observed executive impairments will be discussed in further detail in the following chapter, where they will be integrated with the literature that was reviewed in Chapter Two and the results of the semi-structured interviews which were conducted in Study One.

CHAPTER SEVEN

Summary and Conclusions

This chapter is presented in four sections. In the first section, the results of the present research are discussed within the context of the relevant literature, which was identified in Chapter Two. The second section explores how these findings might be integrated with the existing research and theory in this area to verify or challenge various aspects of the current conceptualisation of ADHD, which was examined in Study One. Where appropriate, those modifications to the prevailing understanding of ADHD which are suggested by the data obtained in the present study will be identified and discussed. Section Three considers the methodological implications which have arisen from the present research, and discusses ways in which these factors might be addressed in subsequent studies. Finally, Section Four outlines the suggested directions for future research and provides concluding comments.

Research summary

The present study sought to contribute to the ongoing development of theory and understanding about ADHD. Two separate, yet inter-related, studies were employed for this purpose. The initial exploratory study (Study One) employed individual interviews with a number of leading international scholars in the field of ADHD to examine the current conceptualisation of ADHD. This was then followed by a large-scale empirical investigation which sought to investigate the conceptualisation of ADHD as purported by the leading international scholars and the research literature. These two studies were sequential in that Study One provided the theoretical framework within which the subsequent empirical investigation could proceed, and Study Two served to validate aspects of the conceptual model established in Study One.

The interviews employed in Study One allowed a fuller understanding of recent advances in the field of ADHD to be obtained and this assisted in the development of an overall conceptualisation of ADHD. The main findings of this exploratory study revealed that the current emphasis in the conceptualisation of this condition is very much underpinned by Barkley's (1997a) Unifying Theory of ADHD, which according to the participants represents the most scientifically comprehensive theory to date. In line with this, participants emphasised the role played by executive functions and the concomitant difficulties in organisation, self-monitoring, inhibition, and storing and recalling information that children with ADHD experience (e.g., Barkley, 1997a; Denckla, 1996; Houghton et al., 1999; Pennington & Ozonoff, 1996). These suggestions are very much in line with recent research on ADHD which appears to have focused on response inhibition (e.g., Nigg, 2000; Oosterlaan & Sergeant, 1998; Schachar et al., 2000), working memory (e.g., Kaplan et al., 1998; Kuntsi et al., 2001; Oie et al., 1999), attention (e.g., Cepeda et al., 2000), and the concept of time (e.g., Barkley et al., 1997; Sonuga-Barke et al., 1998).

Previous research (e.g., Dane, Schachar, & Tannock, 2000; Houghton et al., 1999) has clearly identified two distinct ADHD subtypes, and in the present study there was overwhelming support for the existence of these subtypes. Participants made clear distinction between those children with inattention problems only (i.e., the Predominantly Inattentive Type), and those who also present with hyperactivity, impulsivity, and inattention (i.e., the Combined Type). It should be noted however, that while participants' responses were indicative of two ADHD subtypes, the majority acknowledged the existence of a third subtype, comprised of children with hyperactivity/impulsivity only. Thus the demarcation between two or three distinct subtypes was not clear.

A major finding in Study One pertaining to the conceptualisation of ADHD was the identification of four broad areas of executive impairment in children with ADHD. In line with previous research, participants consistently cited deficiencies in response inhibition (Nigg, 1999; Schachar et al., 2000), verbal and non-verbal working memory (Kaplan et al., 1998; Kuntsi et al., 2001; Oie et al., 1999), and perception (or concept) of time (Barkley et al., 1997; Dooling-Litfin, 1997) in their discussions. Specifically, the inability to stop an ongoing response, the inability to hold information in mind, and problems with reproducing intervals of time were thought to be particularly pertinent for further investigation. With reference to attention, there was a degree of uncertainty in participants' responses that indicated that they were less sure about what particular aspects of attention that might be impaired in children with ADHD.

In summary, Study One was exploratory in nature and confirmed much of the previous research pertaining to executive deficits in children with ADHD. The recent development of theoretical models of ADHD, such as Barkley's (1997a), which emphasise the underlying component processes of the disorder, has represented a significant advance in the field (Tannock, 1998). Study One therefore accessed the views of six leading international scholars who provided new information which could be incorporated into our current theoretical conceptualisation(s) of ADHD and tested in the subsequent empirical study.

Study Two involved 50 children diagnosed as ADHD (14 of whom were Predominantly Inattentive and 36 Combined Type) and 50 non-ADHD Controls. A battery of tests commensurate with the suggestions made in Study One were administered to the sample. Findings revealed that the performance of the ADHD and non-ADHD Control boys was differentiated on measures of response inhibition, verbal memory, attentional switching, and time

reproduction. In all cases, the ADHD boys were found to underperform relative to their Age-matched Controls, except on the SART measure of False Positives, on which they made less errors than their non-ADHD counterparts. While this result appears to conflict with previous research that has suggested that ADHD children make more omission errors than Controls (e.g., DeWolfe, Byrne, & Bawden, 1999; Losier, McGrath, & Klein, 1996; Oades, 2000; Swaab-Barneveld et al., 2000), it must be acknowledged that the results of such studies have been somewhat equivocal.

Nevertheless, the finding that the boys with ADHD recorded less False Positives than Controls on the measures derived from the SART would appear to challenge the suggestion that ADHD boys have an impairment in response inhibition. In addition, the present study also found that the ADHD boys were in fact slower to respond than Control boys on those occasions when a response was provided, which is contrary to the expected pattern of impulsive responding. While these results seem to contrast with recent theories (e.g., Barkley, 1997a), they do appear to conform with a growing body of literature which suggests that ADHD children have slower stop signal reaction times than Controls (e.g., Leth-Steensen et al., 2000; Nigg, 1999; Purvis & Tannock, 1997; Schachar & Logan, 1990).

It was also found that the ADHD boys recorded significantly more Misses than the Control boys on the measure provided by the SART. This appears to be in line with the results of research using Continuous Performance Tests (CPT) (e.g., DeWolfe, Byrne, & Bawden, 1999; Losier, McGrath, & Klein, 1996; Oades, 2000; Swaab-Barneveld et al., 2000), and the stop signal task (e.g., Oosterlaan & Sergeant, 1995; Pliszka et al., 1997; Schachar et al., 2000). Although the number of Misses (or Commission Errors) recorded on these tasks are considered to

represent failures of sustained attention, it must be acknowledged that there were no significant differences observed on the measure of sustained attention provided by the TEA-Ch. However, it is also possible that the failure to detect differences in sustained attention using the TEA-Ch might have been the result of a potential ceiling effect.

With regards to memory, the ADHD boys appeared to underperform on the measures of verbal memory provided by the CMS. In particular, the ADHD boys were significantly impaired on both the immediate and delayed recall measures of the stories and word pairs subtests of the CMS. Boys with ADHD also answered less story comprehension questions correctly than the Control boys, resulting in poorer performance on the delayed recognition measure. Furthermore, the ADHD boys were found to be less proficient than Controls on the CMS sequences subtest, which has been advanced as a measure of attention/concentration (Cohen, 1997). In contrast, there was no apparent impairment amongst the ADHD group on the measures of non-verbal memory, or the delayed recognition component of word pairs, which required participants to distinguish those pairs which they had been asked to remember previously from those that were new to them.

While systematic investigations of working memory have been rare (Tannock, 1998), the results of the present study appear to be consistent with the existing research. Relative to Controls, ADHD children have been found to underperform on a range of tasks which load working memory, including repetition of digits forwards and backwards (Barkley, Murphy, & Kwasnik, 1996; Kuntsi et al., 2001), mental arithmetic (Zentall & Smith, 1993), and the Tower of Hanoi (Pennington, Grossier, & Welsh, 1993). Recent research has also suggested that children with ADHD perform more poorly on verbal working memory (Kaplan

et al., 1998; Oie, Sundet, & Rund, 1999) and sentence span tasks (Kuntsi et al., 2001) than non-ADHD Controls. However, the results of these studies have also intimated these deficits are not specific to ADHD. For example, Oie et al. (1999) found that adolescents with schizophrenia exhibited impairments in both visual and verbal working memory, and Kaplan et al. (1998) reported that impairments in verbal working memory were even greater in the RD and ADHD + RD comparison groups.

Contrary to expectations, the TEA-Ch measures of selective attention, sustained attention, or dual task performance did not discriminate between the ADHD and Control boys. However, the present study did find evidence to suggest that boys with ADHD are impaired on the measure of attentional switching, which is consistent with the results of Cepeda et al. (2000). While Manly et al. (1999) also found no significant differences in selective attention between 24 ADHD boys and similarly aged Controls using the TEA-Ch, significant differences were reported on measures of sustained attention, attentional switching and dual task performance. The failure to detect differences in sustained attention also appears contrary to the results of research using the CPT (Losier, McGrath, & Klein, 1996), although the results of such studies have been somewhat equivocal (Swaab-Barneveld et al., 2000). Alternatively, it may be that the CPT and the measure provided by the TEA-Ch, which was specifically designed to be sensitive to sustained attention, are in fact examining different attentional constructs. It is also possible that the failure to detect significant differences on the measures of selective and sustained attention was the result of potential ceiling effects (see Chapter Six).

The ADHD boys were also found to be less accurate than Controls on the visual time reproduction task. In an interesting discrepancy, no significant differences

were apparent for the auditory form of the task. As has been consistently reported in the literature (e.g., Barkley et al., 1997; Dooling-Litfin, 1997), the absolute time reproduction error (i.e., absolute discrepancy) increased for both groups in direct proportion to the duration to be reproduced. Examination of the coefficient of accuracy scores revealed a significant Group x Mode x Time interaction, indicating that the ADHD boys tended to overestimate shorter time intervals and underestimate longer intervals relative to Controls on the visual task, while their performance could not be distinguished on the auditory task. To date, few studies appear to have examined time reproduction in ADHD children, although the results of such studies do suggest that ADHD children do have impairments in this area. In particular, Tannock (personal communication, March 2, 2001) confirmed that a similar pattern of results has recently been obtained amongst her research group. The present study therefore sought to extend previous research by examining the effect of distractors and the mode of presentation (i.e., visual or auditory) on time reproduction in boys with ADHD.

Of particular interest to the present study was the finding that the distractors used in the present study had no effect on the performance of either the ADHD or Control children. However, a number of explanations might account for this surprising finding, which despite a wealth of anecdotal evidence to the contrary, seems to suggest that the ADHD boys are no more distractible than Controls. It may be that the computer-generated distractors used in the present study were ineffective because they were presented on the same screen or speaker as the stimulus, and therefore did not require participants to divert their attention from the computer. Alternatively, it might be as Barkley (personal communication, March 29, 2000) suggested, that the time intervals used in the present study were too short for the distractors to be effective, since

Zakay (1990) found that non-ADHD children can master five to six second intervals by five years of age.

Advancing the conceptualisation of ADHD

While the development of theoretical models of ADHD has represented a significant advance in the field (Tannock, 1998), and such models have had a perceptible influence on the current conceptualisation(s) of the disorder, the results of Study One revealed that the present understanding of the disorder remains largely heterogeneous. However, the results of Study Two have provided a clearer understanding of the deficits associated with ADHD by confirming the predicted impairments in the areas of memory, attention, and concept of time. This section will examine how these findings verify or challenge aspects of the current conceptualisation of ADHD, and how they serve to further contribute to the understanding of ADHD that was developed in Study One.

Although current theories of ADHD (such as Barkley, 1997a) tend to focus on the hyperactive-impulsive and combined types to the exclusion of the predominantly inattentive type, the present investigation also included those ADHD children who present with symptoms of inattention only (i.e., ADHD-PI). Since the ADHD-HI subtype is clinically rare, the performance of 45 ADHD-CT boys was compared to that of 22 ADHD-PI boys and 67 non-ADHD Controls. However, no significant differences were observed between the ADHD subtypes on any of the measures used in the present study. Although it is suggested that this result be interpreted with caution due to the limited size of the ADHD-PI sample, recent research by Dane, Schachar, and Tannock (2000) also found no significant differences in the mean activity level of ADHD children according to subtype. While other studies have reported evidence of

subtype differences between the ADHD-PI and ADHD-CT groups (e.g., Houghton et al., 1999), there remains little research to date that has systematically examined the subtypes as delineated by DSM-IV.

Recent theories of ADHD (such as Barkley, 1997a; Quay, 1997) have also proposed that response inhibition, and not attention, is the central impairment in ADHD. While there is considerable evidence to support this notion (see Barkley, 1999, for a review), it has also been suggested that ADHD is characterised more by significant variability in responding than any specific situational deficit (Leth-Steensen et al., 2000). This might also account for the failure to consistently observe impairments in attention amongst children with ADHD. However, there are also data which suggest that an impairment in response inhibition is also characteristic of children with Conduct Disorder (Oosterlaan & Sergeant, 1996; Schachar et al., 2000), or externalising behaviour disorders in general (Oosterlaan, Logan, & Sergeant, 1998), and is therefore not specific to ADHD. That the present investigation has demonstrated that boys with ADHD (and no diagnosed comorbid conditions) are unimpaired on the SART measure of response inhibition (and in fact perform better than Age-matched Control boys), is therefore a clearly significant finding.

This study also appears to be consistent with the growing body of literature that has reported that ADHD children have slower stop-signal reaction times (or are generally slower in their responding) than non-ADHD Controls (e.g., Houghton et al., 1999; Leth-Steensen et al., 2000; Nigg, 1999). There was also some evidence to suggest that the ADHD group were more variable in their responding than their non-ADHD counterparts, which Leth-Steensen et al. (2000) described as “the most consistent finding in the ADHD cognitive literature” (p. 168). Recently Leth-Steensen et al. (2000) examined the response

times of ADHD boys using a distributional approach, and found that they could be distinguished from those of age-matched Control boys by an increased number of abnormally slow responses, resulting in an abnormally large tail of the distribution. While such an analysis is beyond the scope of the present study, the data obtained using the SART could be examined further using a similar approach to verify or challenge the findings of Leth-Steensen et al. (2000), albeit with a suitably larger sample size.

The present study also used a new test to systematically examine memory in children with ADHD. That the results obtained revealed that boys with ADHD were impaired on measures of verbal memory and learning, but not on measures of non-verbal memory, appears to confirm the decision to examine verbal and non-verbal memory separately, and is consistent with the limited literature in this area. However, that recent research has reported significant impairments among ADHD boys using similar instrumentation might serve to qualify the finding that non-verbal memory is unimpaired in boys with ADHD. For example, while the results of the faces subtest revealed no significant differences between the ability of the ADHD and Control boys to recognise and remember faces, there is evidence from research which suggests that ADHD children have difficulty interpreting facial expressions. Furthermore, while no impairment was observed on dot locations, which involved reproducing a pattern of markers from memory, ADHD children appear to be impaired on the finger windows test, in which a finger must be pointed through a series of “windows” in sequential order (Kaplan et al., 1998; Tannock, 2001).

The CMS also served to highlight the distinct nature of memory and working memory. In the present study, the ADHD boys were found to be impaired on the measure of working memory (i.e., sequences), which involved holding in

mind a series of letters, words, or numbers, and manipulating them. However, there was no evidence to suggest that the ability to hold information in mind (i.e., memory retention) was impaired in boys with ADHD. Thus it may be as Barkley and Tannock suggested (see Chapter Three) that the memory problems associated with ADHD are not the result of an underlying deficit in memory per se. Rather, the difficulties for ADHD children seem to be located within working memory, and appear to manifest when information must be manipulated (e.g., the sequences subtest) or recalled in a sequence (e.g., the stories subtest, finger windows subtest). The delayed recall measures would appear to provide further support for this notion, revealing that while the ADHD and Control group did not differ on the quantity of word pairs recalled, significant differences were apparent on the measure of story comprehension. There is evidence from research, however, that suggests that working memory impairments are not specific to ADHD, and may also be characteristic of children with Reading Disability (Tannock, 2001), autism, Tourette's syndrome, and conduct disorder (Pennington & Ozonoff, 1996).

Perhaps the most surprising result obtained in the present study was the failure to detect significant differences on the measures of selective and sustained attention provided by the TEA-Ch. Contrary to Barkley's hypothesis (see Chapter Three), there were no significant differences between the ADHD-PI and ADHD-CT groups on the measures of attention provided by the TEA-Ch, suggesting that the qualitative nature of the attentional impairment may not differ according to ADHD subtype. While this finding does seem to conflict with the results of earlier research (and the data obtained using the SART) which have suggested that children with ADHD have an impairment in attention (and in particular, sustained attention), these studies have used a diverse range of measures and produced equivocal results. In contrast, the

present study employed the TEA-Ch, which was specifically designed to be sensitive to attention in ADHD children.

That no significant differences were observed between the ADHD group and the non-ADHD Controls on the TEA-Ch measures of attention appears to provide partial support for recent conceptualisations of ADHD that have suggested that an impairment in response inhibition, and not attention, is characteristic of ADHD. The performance of the ADHD and non-ADHD Control boys was discriminated only by the measure of switching attention provided by the TEA-Ch, which required participants to hold information in mind (i.e., the creature count), so as to manipulate it (i.e., to change the direction of counting). Taken together, the results obtained using the CMS and TEA-Ch appear to suggest that working memory is impaired in ADHD. This also seems to be consistent with the results of Cepeda et al. (2000), who found that the switching costs (i.e., the time required to switch between two tasks being performed concurrently) were significantly larger for ADHD children. However, Cepeda et al. also found that stimulant medication alleviated these switching costs to a degree that no significant differences were apparent relative to non-ADHD Controls.

According to Barkley (see Chapter Three), the psychological concept of time arises from the ability to hold a series of events in mind in a sequence. The present study has provided evidence that the capacity for verbal memory and working memory might be impaired in children with ADHD, which could account for their observed difficulty in organising behaviour with respect to time. While the data obtained from participants in the semi-structured interviews suggested that the problem was more likely with the organisation of behaviour with respect to time than with time perception per se, the results

obtained using the Timetest appear consistent with the limited work to date in this area. An interesting discrepancy was also revealed between the visual and auditory forms of the time reproduction task. While this significant finding does not appear to have been reported in the literature to date, it should be interpreted with a degree of caution until it can be replicated.

Methodological implications

The purpose of Study Two was to examine the predicted executive impairments of children with ADHD, whilst systematically addressing the range of methodological limitations that were identified in the review of existing research. These included: limited sample sizes, inconsistent diagnostic procedures, poor age-matching between groups, and failure to control for comorbid disorders or medication status at the time of testing. While the present research addressed these issues, a number of other methodological considerations need to be acknowledged. First, it is possible that the informed consent procedures used in the present study might have resulted in a systematic sampling bias. While sampling bias has the potential to undermine the ecological validity of research, appropriate ethical standards were strictly maintained at all times and participation was entirely voluntary.

Second, many previous studies have failed to adequately operationalise the constructs that they have sought to examine. In these instances, the instrumentation used to assess a poorly defined construct (such as the executive functions) effectively defines the construct under examination. The present study sought to address this by using instrumentation that was specifically designed to be sensitive to the predicted impairments of ADHD children that were identified in Study One. However, it must be acknowledged that since the

instrumentation used in the present study is newly developed, to date there is only limited psychometric data pertaining to its reliability and validity.

Third, given the high rates of comorbidity amongst ADHD children, it appears unlikely that the large sample of ADHD boys used in the present study could be entirely free of comorbid disorders, despite the confirmed absence of any diagnosed comorbidity by the Consultant Paediatrician. However, the ADHD boys in the present study were drawn from a larger sample of 3500 ADHD children, of whom only 122 had no diagnosed comorbidity, which appears to be in line with recent evidence from Barkley (2001a), suggesting that 3% of ADHD children have no diagnosed comorbidity.

Finally, the use of individually Age-matched samples in the present study does not appear to be common in current research. However, while it has been argued that matching on IQ might be inappropriate since ADHD children may have depressed IQ scores (Barkley, 1997b), there is no similar argument against matching on Age. Furthermore, the repeated measures design used in the present study was considered preferable to the use of Age-based norms, since ADHD appears to affect the course of normal development and only limited normative data were available for the instrumentation used. However, it must be acknowledged that the repeated measures design used in the present study would not have been possible if significant differences were observed according to ADHD subtype. This is because the combination of a single, homogeneous Control group with an ADHD-PI sample and an ADHD-CT sample would result in an inappropriate statistical design.

Directions for further research

While the present study has confirmed and contributed to the understanding of the executive impairments of boys with ADHD and no diagnosed comorbidity, there is also evidence which suggests these impairments are not specific to ADHD alone. Research has also found impairments in response inhibition to be characteristic of children with conduct disorder (Schachar et al., 2000) and possibly even externalising behaviour problems in general (Oosterlaan et al., 1998). Furthermore, impairments in working memory and attention are also apparent in children with Reading Disability (Kaplan et al., 1998; Tannock, 2001), schizophrenia (Oie et al., 1999), and autism (Pennington & Ozonoff, 1996). In order to address the issue of specificity, it is suggested that future research includes a disordered comparison group, such as children with Reading Disability or conduct disorder (Tannock, 2001).

The present study found that boys with ADHD were significantly impaired on measures of working memory and attentional switching, which appears to be consistent with Barkley's (1997a) Unifying Theory of ADHD. However, it might be that the impairments in emotional self-regulation also predicted by this model may be even more problematic for the child with ADHD, since they will impact on their relationship with their family, peers, and educators. These predicted impairments were not examined in the present study since they are yet to be adequately operationalised. The use of poorly defined constructs may account for some of the inconsistent results that have been obtained in many previous studies of ADHD. To address this issue might require the development and testing of new measures, such as those used in the present study, that are specifically designed to be sensitive to the predicted impairments of ADHD children. Furthermore, while little normative data are as

yet available for the measures used in the present study, this can only be addressed through further research.

The finding of modality-specific impairments on the measures of memory and time reproduction is an interesting finding that may be further explored in future research. That boys with ADHD were clearly impaired on measures of verbal memory, but showed no impairment on measures of non-verbal memory, might also have implications for the design of teaching and intervention strategies for children with ADHD. The measures of working memory also provided clear evidence of impairment in situations in which attentional switching is required, such as reversing the direction of counting or reciting sequences. This may also warrant further investigation in future research, particularly in classroom settings. Further to this future research should seek to examine the generalisability of the executive impairments found in the present study to ecologically valid domains of childhood functioning.

In conclusion, the present research has raised a number of important issues pertaining to ADHD. Whilst the continual evolution of the conceptualisation of ADHD has paralleled the progress of research, it has also contributed to its status as perhaps the most controversial disorder of childhood. In the present study, the current conceptualisation of ADHD was examined and systematically tested against a scientific model of the disorder, to be verified or challenged, and modifications suggested where appropriate. Clear evidence of significant impairments in working memory, attentional switching, and the concept of time, in boys with ADHD (and no diagnosed comorbidity), compared to Age-matched non-ADHD Control boys was demonstrated. This process has significantly contributed to the development of theoretical understanding about ADHD.

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APPENDICES

APPENDIX A

Semi-structured interview questions

1. Briefly, how would you describe your conceptualisation of ADHD?
 - What are the key features of ADHD?
 - What sort of disorder is ADHD?
2. Please describe your current personal view of the ADHD subtypes.
 - Two subtypes of ADHD, that is, the Combined Type (which subsumes the Predominantly Hyperactive-Impulsive Type) and the Predominantly Inattentive Type, have been suggested. What are your views?
 - Please comment on the proposal that the Predominantly Inattentive Type and the Combined Type represent separate disorders?
3. Please differentiate the characteristics of these subtypes.
 - In particular, would you distinguish the nature of any attentional problems between these subtypes?
 - Is attentional impairment central to ADHD? If not, what is?
4. A recent theory has response inhibition as the core deficit in ADHD, which in turn leads to impairment in specific executive functions (EF).
 - What is your view on this?
 - How do you conceptualise the EF? (What is their range and role?)
 - Are these EF manifested differently or impaired in ADHD? If so, how?
 - How would you expect EF impairments to be manifested in children with ADHD?
5. Children with ADHD (and in particular, the Combined Type) appear to have difficulty inhibiting their immediate responses even when deferral of this response would lead to future gratification. Can you give some examples where this may happen?
 - These children may also persistently give incorrect responses (perseverate) even when corrected. Can you think of any examples where this may occur?
 - Can you describe any circumstances under which these children might have difficulty maintaining their interference control?
6. It appears that working memory may also play a significant role in ADHD.
 - What are your thoughts on this?
 - How do you think working memory might manifest differently in children with ADHD?
7. Some researchers have suggested that children with ADHD may experience an impaired sense (or perception) of time. What do you understand this to mean?
 - In what ways might this be demonstrated?
 - How does it affect their organisation of behaviour with respect to time?
 - How does it impinge on the integration of time and space?
 - How does it affect their performance of dual tasks and attention?

8. How would you describe the ADHD child's ability to make use of their past experiences and knowledge (i.e., hindsight)?
 - Are these children able to apply this experiential knowledge to new situations?
 - Can you provide any examples of this?
9. What do you see as the role of language in children with ADHD? (e.g., with respect to sequencing, rule-governed behaviour)
 - Have you noticed any patterns in the verbalisations of children with ADHD? (e.g., internalisation of speech?)
10. In the light of this discussion, do you see "Attention-Deficit/Hyperactivity Disorder" as an appropriate name for the disorder? Do you agree with its placement in the Disruptive Behaviour Disorders category of the DSM-IV?

Interview transcript: Professor Russell Barkley

Moderator (M): How would you describe your conceptualisation of ADHD?

I think the problem is largely one of the development of self-regulation. I think we have to ask what self-regulation entails in its development. And as I said I suggested I think there were four major forms of behaviour that start out as public, are then turned on ourselves as a means of controlling us, and then gradually are made private - so that others cannot see us do these things to ourselves. Specifically, the four things are: the ability to sense privately to ourselves, primarily including visual imagery - being the most important of those - but other senses also being capable of private use without others seeing us. This allows us to simulate information mentally without actually having to test it out in the real world first. The second one is language which we've talked about - that's a very Vygotskian view of language - turned on the self, made private. The third is emotional behaviour that is then made private - the individual uses emotions to themselves. And then lastly is this concept of reconstitution, which I think is probably most akin to play - and I don't mean so much social play but more intellectual and manipulative play - a child who takes apart and rebuilds blocks and designs and manipulates the environment - and then gradually is able to do this not only with symbols and language but then can do it internally as well.

So I think that over development those four behaviours slowly become private and as they do they take over the guidance of public behaviour, so that public behaviour is being guided by private information, mentally represented information, and that information pertains to time and the future and anticipated change in the environment - which is what time is - it's change in the environment. So this means that over the course of child development there is a shift between external control to internal control, of control by the temporal moment to control by the conjectured future, because we don't know what the real future is - it's a conjectured future - plans, anticipations - and from public observed self-control to private self-control that's no longer observable.

Now this may sound speculative or conjectural - but there are some very precise predictions about this, not just about ADHD but that would test some of these postulates. First of all, if I'm correct in this, it means that the regions of the brain that are being used for the public behaviour are also the ones used for the private behaviour, which means you can't do both at the same time. Specifically, you can not talk to me and talk to yourself simultaneously - you can alternate, and you can alternate rapidly as we often do, but you can't do them both because they are using the same pathways in the brain. The only difference between them is that the private behaviour involves turning off the release of that motor system, probably at the level of the striatum, but there is a barrier that's being imposed that allows the private behaviour to take place without releasing it into the skeletal-muscular system - into the spinal cord for instance. The striatum seems to be a very good switching station for differences between automatic and reflected behaviour - perhaps that's the mechanism for this shift between the two. But in any case, that's testable, and given the availability of neuroimaging methods, especially functional neuroimaging, it can be tested. In a few instances as I said in the book it has. If you look at the regions of the brain that light up for public speech, they are almost identical -

Broca's area, Wernicker's area, for private speech, the only difference being that in the private speech there is a decrease in activity in the motor strip itself associated with speech, as you would predict, you have to suppress the motor.

The second prediction out of this, which is testable, is that if the behaviours I'm talking about were made private over evolutionary time in order to keep other people from seeing them happen, in other words we were doing it to keep our competitors from knowing what we're doing with ourselves, then there is no need to eliminate the display of the behaviour completely; it only has to be suppressed sufficiently that it is not detectable by another person. If that's true it means that there ought to be micromovements that very fine instruments could detect, when you were engaged in a private behaviour, but that somebody else would not be – would not be visible to. For instance, if I were to ask you to recite the Pledge of Allegiance mentally, or some other – a Shakespearean sonnet - in your head, we should be able to notice that there are micromovements of the tongue, the lips, the larynx, and so forth – they're not visible to the naked eye from a distance of three feet, but they would be measureable by microelectrodes inserted into those muscle groups. Well as you know, that's the leading point because somebody's already done the study and that's exactly what they found. That when adults think they're talking to themselves in their mind, there are noticeable, measureable changes in the musculature.

Most recently, a study has shown that if you ask an adult to visualize picking up a block and rotating a block 90 degrees, and you have electrodes in the arm, there is a significant increase in micromuscle movements. The arm does not move, but tension in the arm goes up – it is as if you actually were moving the arm. Now the individual does not report these feelings; if you ask them "Did you move your lips?" – "No, I didn't" – "Did you move your arm?" - "No, I didn't - my arm didn't move" but the fact is that there are movements that are subthreshold, outside of awareness, that are actually taking place. That would fit with this evolutionary idea, which by the way is not mine, it's Humphreys, the English psychologist who originally proposed the fact that – and Carl Popper even before him - that private behaviour would allow you to simulate action and let your ideas die in your place because if you did that publicly and it was lethal, you've only got one shot at it. If you did it privately and then went "Oops" – nothing lost but the idea is dead. And Humphreys actually said that one reason that we may develop visual imagery and other forms of private behaviour, as he said, is out of competition with our peer group. There's no reason to do it in nature, but there's a social reason why you'd want to do it, which is that you would not want other people to see the mechanism you used to control yourself because they could use it to control you.

So - and that's a long-winded answer - it's better than 450 pages which is what the length of the book was, but it's a synopsis of that theory. Now that's a rather profound shift in the disorder. First of all it links the disorder to normal development, it argues for what the normal developmental stages and processes are, it says that ADHD is a delay in those stages that is directly traceable to a delay in the first construct, which is inhibition. And why is inhibition so important? Well how can you privatise behaviour if you can't inhibit - that's what inhibition is doing.

M: As I understand it, the inhibition actually provides the time for these processes to occur?

It gives you the time for it, but the other thing which I don't think came across quite so clearly in the book is it is the mechanism that privatises the behaviour. You can't privatise a public behaviour if you don't inhibit the public manifestation of it. So not only does it give you the time to do these things because it's delaying the prepotent response, it's also precluding the public aspects of these private activities while you're thinking about it. And because ADHD is disrupting this inhibitory mechanism, not only are more prepotent responses being released, but more behaviour is being engaged in publicly that others would have been doing in private.

A specific for instance: we know that children and adults with ADHD talk more than others. My theory says that they may not talk more, they may talk publicly more. You and I may be engaging in just as much speech, but it's private.

M: You notice that when some of the kids are doing the Wisconsin Card Sort you can hear what they are thinking basically.

That's what Vygotsky said, the more difficult the problem, the more you have to fall back on earlier stages of private speech, because they're more influential than quiet speech happens to be. So even normal children can be induced to speak publicly – even adults – if you give them a difficult problem.

M: Actually that comes back to some of the other questions I've got here. What do you see as the role of language in children with ADHD? Have you noticed any patterns in the verbalisation of children with ADHD? I know your theory owes something to Bronowski -

Well Bronowski owes something to Vygotsky and he even says that in his article. So the ideas about language are Vygotsky's ideas more than Bronowski's. So the role of language in ADHD is that ADHD does not so much create a language disorder but a disorder in the control of behaviour by language. And let's not be specific to language, let's include symbolisation because although largely that is language, there are other symbolic methods that we use besides language. In any case, there is nothing wrong with the language system, the problem lies in the exertion of control over behaviour that language would afford, and doesn't in these individuals.

M: One of the things that comes out of your theory obviously and I guess a lot of people don't read this on the first reading is that it is designed to apply to the Combined Type and not so much the Predominantly Inattentives.

Well I was just being safe about that and I was being safe for a couple of reasons. First of all, if the Combined Type [sic] is being conceptualised as not having problems with inhibition, which is how we conceptualise it, and my model places inhibition at a key point in the development of these other functions, then there's no way that my model could speak to the Inattentive type. But that's also an empirical question. We should go out and test the Inattentive type on executive function batteries and see whether or not they develop this. Now fortunately one of your countrymen has just done this and he has an article in press – Houghton?

M: Houghton? He's my supervisor.

Did he share this paper with you?

M: Well this was one of our studies, yes. I worked on the study.

I know I've talked to him about it. You guys have shown that the executive deficits, particularly the inhibitory deficits, but especially their other executive deficits, rather than specifically inhibitory deficits.

M: They only seem to come out in the Stroop and the Wisconsin. That could be a factor of the fact that we took 3500 kids, narrowed them down to just the ones who had pure ADHD, off medication.

And took out all the other overlapping confounds.

But on the other hand, Jose Bauermeister, who did a study with Puerto Rican children, he reported some preliminary results on this morning, and I'm his collaborator, we're not finding those differences. We're finding that both groups have executive function deficits relative to learning disabled and normal children. Now, when we look at our data, there are a couple of problems with it so it doesn't automatically defeat the theory. First of it all it does support the theory: ADHD children do have executive function deficits. What it doesn't support is my separating out the inattentive subtype and saying "I don't know if this applies to them or not".

M: We're not quite sure where they fit in the scheme of things. We get the impression that they fit somewhere between the Controls and the Combined's but we're not sure exactly where and how -

Yes, and that's what he's finding - that they're not as bad as the Combined's but they're clearly different from the two other control groups. But the Puerto Rican study has a couple of problems. We're using teacher identification rather than parent identification. There was also a paper that reported that Hispanic parents under-report the severity of hyperactivity and aggression, not attention, but hyperactivity and aggression. Which means that we may have children who actually are much more hyperactive and aggressive but who wound up in our inattentive only group. So there's some contamination between the groups. Even though we tried to get at least a half a standard deviation or more of separation on the hyperactive scales, the fact is that there may be some cultural reporting problems here so that's why I excluded them at this point: I don't know where to put them. My speculation is that if we could refine the selection of that group better, and I have some suggestions on how we might do that, eliminating these children who are really Combined Type children but are subthreshold by a single symptom or two and they wind up being classified as inattentive but they're really Combined Type - that what you would find is that the inattentive only children resemble children with deficits in Posner's attention model that deal with posterior hemisphere mechanisms of focus, selection and speed of processing of the information, whereas ADHD children are more in Posner's frontal inhibit/sustain/shift aspects of his attentional model. But I can't prove that.

M: How would you distinguish the nature of the attention problems between the Predominantly Inattentive and the Combined.

Very quickly I think that the Combined Type is an output disorder, meaning that there is no problem with how information is being perceived and processed but that the problems come in when behaviour must be organised and executed, or when strategies must be applied to the information coming in

to organise it better. In other words, an executive technique must be added on to the information processing system in order to organise the information in a more convenient and efficient way, such as a memorisation strategy – but that's a self-directed action so it still fits within this idea that it's an output problem.

I think that the - specifically the attentional problems there are: one, resistance to distraction, which is the interference control/inhibition problem; and an inability to guide behaviour by internal information, which is the sustained attention/sustained effort problem that they have - they can't persist under the control of plans, rules, thoughts about the future – their behaviour deteriorates markedly as a result of that and they can't persist in motivation either. So I think that their sustained attention and distractibility problems are due to the working memory deficits and the inhibitory deficits.

In the inattentive children, I think it is an input problem. I think it does have to do with the initial perceptual, selective, and processing aspects – the front end of an information processing model. And so I think it's a different attentional mechanism - I would say that they are focused or selective attention problems and the other is an executive/behaviour control problem. That's how I would conjecture that they differ.

M: The children with ADHD appear to have difficulty inhibiting their immediate responses even when deferral would lead to future gratification. Can you give some examples where this may happen? And the next question is also on their perseveration whether there are some examples that you could give?

In the case of the deferred gratification the most immediate examples that come to mind are the ones I cite in the book which is Campbell's cookie delay task and Joel Newman's delay of gratification software program where you have a choice and you only have a few seconds to make it between this reward now and a larger reward that's being deferred in the software program. But any task that sets up a competition between two schedules of reward, one involving an immediate and the other involving a delayed but larger one. Now what examples in life might that pertain to? Well anything that involves a reinforcer being available, but socially you have to wait for it. You put down a plate of cookies in front of four children; they can all grab for the cookies or they can each pass them around and take their turn. You sit down at a meal with another individual and dinner is served. You immediately start serving yourself and eating without regard for whether the other people have been served and is there enough and how much do I take and still leave enough for them.

Etiquette. Social etiquette would involve situations like this. Money would involve situations like this. If you put an ADHD child in a room and there's money on the counter and you then leave the room, how likely is that child to steal that money? Steve Hinshaw showed in one of his papers - doing just that - that ADHD children of course are very quick to steal your money - when you're out of the room. Especially if they have aggressive behaviour and they're ADHD - those are the worst of the worst cases. So anytime that there is a reinforcer that is now available to them but the consequences for accessing that – socially, the consequences would be devastating - you're better off foregoing the immediate pleasure.

Now perseveration. Well first of all, the Wisconsin Card Sort is a classic example of that where a reinforced pattern of behaviour is occurring, a shift

occurs in the strategy, the rule, the concept that must now be applied and the individual must use their errors to detect that a change has occurred and then analyse those errors for a possible strategy. So the card sort actually picks up several parts of my model. One is the inhibitory part that when error messages are occurring that you have to be able to be sensitive to errors and stop your behaviour. The second is you have to be able to hold your errors in mind, to analyse their sequence for - is there a recognisable pattern? You must then play with several options, which is the reconstitution part of it. Is it this? Is it that? And test out those options and then institute them. So I think that there are aspects of Card Sort that gets at each of these. Most closely the factor analytic studies would put it under the reconstitution part, but clearly several studies show that there is an inhibitory aspects to Card Sort, not just a flexibility aspect to Card Sort. Do you see my point - that would be perseveration on a psychological task. Now in the real world, what would it be? You're engaged in an academic task in school and the sign or the symbol of your math problems change and you start to get errors.

M: How would you describe the ADHD child's ability to make use of their past experiences and knowledge (i.e., hindsight)? Can they apply that to new situations?

I would say that while they have the capacity for recalling the past - that is to say that there is not a memory deficit - the past has been processed and stored, maybe not as well or as efficiently or as organised, but they have a past and it's there. And on cued recall they can tell you about the past. What happens however, is at the point where a response must be initiated, that response is not inhibited to allow time for this recall of the past back into working memory in order for the results of that analysis of the past to then decide the response. Because remember what is happening here, as Bronowski made very clear in his paper. It is not just the response that's being delayed, it's the decision about the response that is being delayed. It's one thing to delay a response and then do it anyway five minutes later. It's another thing to delay the decision about the response so that it can be changed and improved upon. And it's the decision that's being delayed, not just withholding the response. I think this is where Edmund Sonuga-Barke misses the point when he talks about ADHD as just delay aversion and not an inhibitory problem. There's more here than just delay aversion I think. So that's how I would answer that.

M: Some researchers have suggested (and this was probably you) that children with ADHD may experience an impaired sense (or perception) of time. What do you understand that to mean?

What I take it to mean is this. The sense of time derives from the ability to analyse the environment in a sequence, so that as the environment is changing there is a sequence of changes that is taking place. In order to sense time, the person has to have the ability to hold slices of the environment in mind in a sequence. In order to not only perceive that a change has occurred, but to perceive a potential pattern to the change - that's working memory - what the Europeans might call sequential memory, very similar to what we call working memory. It's this ability to hold multiple points of information in mind in order to see a pattern or a sequence that might be used. So that's where the time comes from. So given the model, I would suggest that because working memory is being disrupted by the inhibitory problems, people with ADHD are unable to retain sufficient sequences of information in mind that allow for a normal sense of time, and the ability to detect patterns in that change, to detect

where time is going. And therefore you would expect them to be very inaccurate in judging intervals of time, in reproducing those intervals of time, and in real world adaptive functioning to have significant problems with deadlines, with periods of work where there are temporal elements to the task that have to be considered, where things must be organised in a sequence. Because you don't want to forget that – remember if time is really a sequence of change then what we are really saying here is that there is a deficit in sequential ordering of events and we should see them get the ordering of events out of sequence as well. So that's where the sense of time problem comes in. Now as you know, we've been looking at it through time - temporal reproduction tasks - but there's also that questionnaire that we developed which Bauermeister used with Puerto Rican children and found the same results we have, so there are now three studies that have used that questionnaire and shown marked differences between ADHD and normal children.

M: Actually Steve was interested in that – actually what sort of questions you asked to get at that particular construct.

Well we sat around and just brainstormed some issues and I have children and we also began to look at what do I ask my kids to do and other people ask their kids to do like how far in advance do you begin to prepare a book report when you have two weeks to do it? If you're called to come in for dinner within ten minutes, how likely is the child to be on time? Does your child talk about the past, does your child talk about the future? So we were looking at referencing time in language as I talk about in the book. By the way, that is a study that is just dying to be done: tape record the conversations of ADHD child with their peers and with others and then count the number of references to temporal durations and see whether or not there are differences. I would predict that there would be drastic differences in how much ADHD children reference time and temporal durations in their conversations with others, but it's never been tested, so I don't know.

So there's one more study. I mean there are hundreds of studies that you could do out of these arrangements but the beauty of this is that first of all, they're precise enough to make predictions, they're precise enough to be testable in experiments, which makes the theory eminently falsifiable, on countless fronts.

M: I think that's one of the bravest elements about your theory and the most admirable.

I've gone out on a limb.

M: I think that's the thing that's been lacking up until now – yours is the only comprehensive -

So far it is. But I think there was enough literature to compel us to move in that direction. I mean notice that Quay began to move in that direction with his use of Jeffrey Gray's model although it's nowhere near as big a conceptual leap as mine would be. It's the idea of putting your money where your mouth is and testing it. And that, by the way, is actually how science advances. Science is very much of a Darwinian process. As even Carl Popper said, it's not through paradigm shifts.

So where was I? Well, we were talking about the testability of the model. And I'm old enough now, and I've done enough in my career now where I'm not so

personally attached to my ideas that it's painful for them to be falsified, that I have a certain intellectual distance from them where I actually would relish them being tested to begin with, and should they be falsified either whole or partially, I celebrate that because it feeds back to refine the model.

Let's put it this way. You and I know that any model of ADHD whether it's the way I've organised it, or some other arrangement of those boxes, has to explain inhibition, working memory, time problems, delayed internalisation of language, and problems with fluency and flexibility. Those are givens, they're in the data, they're consistently shown in whatever research you find. It doesn't matter. So it may be that I have not got the boxes in the right conditional order: that inhibition comes first and that the executive deficits are secondary. It may be that there are actually primary executive deficits. It may be that the inhibitory system that I'm trying to distinguish from working memory is an inherent part of working memory, which Bruce Pennington has already said. If he can prove that, I would yield to that in a minute, because that's how we advance. But I know we can't go back. We'll never return to a point where we don't talk about representational working memory and time and inhibition - they have to be part of any theory. So my hope is this: as Durham said about his theory of cultural evolution, "My goal was not to build a ship that would float for a long time, but to build a ship that would lead others to build a better ship".

So let's put it on the water, let's see if it floats, and let's go back to the drawing board and improve upon it. I'm a Darwinian at heart, I'm a scientist to the core and I'm not so arrogant or aggrandising to think that this is the definitive theory of this disorder.

M: Just finally, in the light of this discussion, do you see "Attention-Deficit/Hyperactivity Disorder" as an appropriate name for the disorder? And do you agree with its placement under the Disruptive Behaviour Disorder category?

No and maybe. No, I don't think Attention Deficit Disorder is a very good term for it because we're beginning to realise that attention is multi dimensional and that maybe only one aspect of attention is involved and that that really isn't so much attention as we've thought of it as an input problem but really having more to do with inhibition and the mental - and the guidance of behaviour by mental information - by internal information. So that behavioural inhibition disorder might be a better term for this. Executive Function deficit disorder might also be close to the mark. Developmental disorder of executive function. But I think those would be much closer to the core of the disorder than Attention Deficit Disorder has been.

Also realising that we may have another attention disorder on our hands here, that really is an attention deficit and that's the inattentive type of ADHD. So I don't like the name, but we're going to keep it for a while.

Now as far as the second part of that, do I think it belongs under the Disruptive Behaviour Disorders, the maybe comes from the fact that I think that the Combined Type that involves the hyperactive-impulsive behaviour clearly does because of its high comorbidity with Oppositional and Conduct Disorder. Statistics ranging anywhere from 35-60% have Oppositional Disorder and 15-20% have Conduct Disorder - that's a good placement for them. I think that the Inattentive group on the other hand, as has been repeatedly shown, shares very

little comorbidity with the other disruptive behaviour disorders and consequently I don't think it belongs under that hierarchy.

I'm now working on a paper that takes an evolutionary perspective, not a pop evolutionary perspective like Hartman's on ADHD's as hunters in a farmers' world - I find that tripe - but a real evolutionary psychology perspective on what are the executive functions for, why might they have evolved, and what would that tell us then about studying them, ADHD.

Let's get back even further. Evolutionary Psychology - I'm talking about serious evolutionary psychology - the world that Leda Cosmides, and John Tooby, and David Buss and others have done and Harold Clockton in England. I mean there is a subspecialty in psychology that it is evolutionary psychology and it is a real science. Just look at the American Psychologist two months ago for David Buss' paper on evolutionary psychology - it's a good demonstration of testable ideas, hypotheses about this.

We have to ask why the executive functions, what do they do? As I've said, the ultimate function I believe is the maximisation of future over immediate consequences. Well if that's such a wonderful idea, why haven't other creatures evolved it? If it's like the eye, everybody ought to have one. Then as you know, the eye has evolved 40 times independently in the history of life - at least 40 times, probably more. But I'm talking about 40 separate times. So eyes are a good idea. Executive functions don't seem to be such a great idea, because there aren't too many species that have them. So we have to ask where did that come from? Now one answer, which I think is a very glib answer, is that it required a certain amount of intelligence and cognitive abilities to develop first before these would be possible. Well I grant you that but the fact is there are other primate species, there are other mammalian species, and they have the cognitive hardware to do this. Why didn't they go down this road and why did we?

I think the answer has to lie in the fact that we are social creatures. That we are one of the few primates that organises ourselves into social groups - some primates do, some don't - we're one of the few that does. And our ancestors were - I'm talking about our homonid ancestors. So social groups may help to understand why the executive functions developed in us and not elsewhere. Now ask yourself, what are the long term consequences that people are attempting to maximise through the executive functions - 95% of them are social consequences. You know the world doesn't care whether or not I retire with a million dollars. Socially I do, but notice that what we're trying to maximise are social rewards, tokens, money, esteem, prestige, status, property - things that in a non-social creature would be laughable, but in a social creature would be highly desirable. So I think both of those point to the fact, first of all we're a social creature, secondly that the long term consequences that we're trying to maximise have a social function, in a culture, in a society - those long term consequences are crucial to your survival in a social group.

Now, if that's the case, then what is it that is universal to all humans that involves social groups and long term consequences. And there's one that comes to mind immediately that we do that very few other species do - there are two others that do it besides us by the way. And that is social exchange. Humans enter into by virtue by being in social groups, promises and commitments about future consequences. It's the basis of economics - you can't have an economy without this executive, this cognitive function. So any creature that is

going to evolve social exchange as one of its social mechanisms of social behaviour, has to have neuropsychological hardware that allows it to evaluate the past and anticipate the future. But notice what the past is: it's economic past and economic future. The executive functions may have as their initial purpose my ability to evaluate any proposal you make that involves a social exchange. You come to me and say, Russ, I'll babysit your kids today, if you will cut my grass tomorrow. Or I'll let you use my lawnmower now, but I need your stepladder tomorrow. I want you to work for me today, I will give you X amount of money next week. You have to have a near immediate ability to first of all evaluate past experiences with me and with similar proposals of an economic nature of this kind, and be able to project into the future the worth of that exchange in economic terms – I don't mean dollar terms, I mean in terms to you – what it means to you. Is my ladder tomorrow worth your lawnmower today? And that's an instantaneous or a near instantaneous one. It requires first of all a reflection back over previous exchanges of this kind and specifically with me and as Leda Cosmides says, there also has to be embedded within this cognitive mechanism a cheater detector. Because that's the person you want to detect - it's not the person who's going to pay you more, it's the person who's going to cheat. And they've done their work on cheater detection. But if you'll read Leda Cosmides' work on social exchange and the evolved cheater detector as they call it, you'll see that she has a table in her paper with John Tooby that lists the mental mechanisms that would need to be in place to allow social exchange to occur. And if you read the list it is: sense the past, project to the future, evaluate the changing value of a consequence over a period of time, and enter into a commitment with another person and then follow the commitment. You've just described each of the executive systems. Working memory is referencing the past to project the future – I will bet you it has an economic basis to it – that the reason we have it is to be able to detect these kinds of exchanges and evaluate whether they are a good deal for you and I or not. Notice it's a selfish reason which fits with selfish gene theory. The second thing is that you have to have language that controls behaviour and that makes reference to a past and to a future and you have to be able to follow that language. I make a commitment with you, I damn well better follow it or the social consequences of breaking a promise are pretty serious. The third thing I have to be able to do is to sense the economic worth of the exchange. And especially the ability to increase or decrease its value over a temporal duration. You've proposed to me a temporal duration: one day, seven days, three months. I have to be able to very quickly sense the reinforcement value of your offer - and this is of course the work that Len Green and Meyerson and others have done on disability to delay gratification and as you know they have a whole mathematical formula for how reinforcers are evaluated and decline as a function of time. And I think that's part of this system - that's the somatic marker system I think. And then of course you need some flexibility because there's a give and take - the need to I think - I'll counter propose.

So notice what I'm saying. I think if you were to look at these executive functions from the standpoint of economics and consequences, you would find that that's what they're designed to do best, that we may have exacted them, as Stephen Gould says in an evolutionary phrase, for other (means) such as playing chess and you know anticipating - you know science would be exactation of the executive system for more of a non-social purpose. But I think that playing chess is a good example. The executive system wasn't designed to play chess - but it can be used to play chess - but it was designed to play chess with real people; and that is I need to anticipate your moves, and your past, and I need to keep 150 social people in mind at once - that's about our archive limit.

And I need to be able to predict values of consequences over time and we do this all the time - every culture - it's universal. Social exchange is a universal human ability.

M: It makes us an unusual creature I suppose?

Yes it does. Except there are two other creatures that have a modicum of social exchange. One is the chimpanzee, the other is dolphins. They are the only other creatures that we know of that engage in what is called reciprocal altruism. One chimp will do one for one now for instance, team up with that chimp to overthrow the lead chimp in exchange for sexual opportunities or economic consequences as a payback for that help. Dolphins do the same thing by the way. If I'm right, I would predict that both chimps and dolphins have to have a working memory system to be able to do that. That's been studied in chimps as you know because that's where a lot of the primate research on working memory has been done. I don't know if anyone has tested working memory in dolphins. But I would bet you that if this is correct, and this is how the working memory system got started, that dolphins have to have a primitive working memory system, because they keep track of who helped who steal what mate and they return favours in mate stealing - it's very specific around mate stealing - but there would have to be at least some area of the brain that does this keeping track of your debts. It's almost like having a mental spreadsheet is how I try to explain it to other people. If you know Lotus and some of these other spreadsheets, it really is this ability to go back and forward in time with projections of economic - and then to keep track of them. You know that's a very good accounting system. Notice what we know: we never forget our debts, and we always remember our promises, we know who we owe, how much we owe, when we owe, what it's worth, and we do it like this [snaps fingers]. I would bet you that's the purpose of the executive system.

Now extend that to ADHD. It says that ADHD, by disrupting the executive system, that the greatest impairment that ADHD will lead to in life is a disruption in the ability to engage in social exchange with other people. What would they be like? Selfish, self-centred, immature, cheaters, live for the moment, not follow through on promises, can't engage in social exchange and be counted on to come through.

M: At the same I guess those are good survival characteristics.

Well in the short run, yes, but in the long run they're not.

M: Not in a social climate.

Well, not in a social climate, that's right.

So if you think that through which is the work I am doing now, I mean if I was to rewrite Self-Control which I probably will do, the next chapter will be a Darwinian perspective on the executive system and its implications for ADHD. I think ADHD is so devastating, not because you're so hyperactive and move around, but because you cannot engage in reciprocal altruism with other people reliably and they are ruthless at rejecting you as a consequence. They want nothing to do with you. You are unreliable, you are a cheat.

But notice that's a testable hypothesis. Because it would mean that if I wanted to set up an executive function task - Card Sort is probably not the best thing to

do, neither is the Tower of Hanoi, although they're good but that's like using chess to evaluate it. Put in some economic aspects of the Tower of Hanoi – of a real chess game – and I would bet you that you would find that ADHD individuals are even more impaired on those kinds of tasks than on others. In fact, that's what I've sort of started doing, is taking notes about what kind of a lab task, what kind of a rating scale gets at social exchange – can your child keep their promises?

And yet you and I both know from the work that's been done on peer relationships and interactions of ADHD children, at least what has been done so far, which isn't a lot, but it's enough – that this is exactly where they break down. And why within twenty minutes of entering a peer group that this kid has been labelled by the other kids and rejected. Because he can not engage in even the minimum give and take of children such as in a social exchange, such as in taking turns in a game, such as "Oh, I've had this toy now, you take that I'll play with yours". None of that - it's "Me, me, me, me, me", "Now, now, now, now, now" and to hell with everybody else - that's a devastating social profile right there.

[End of Interview]

Interview transcript: Associate Professor Rosemary Tannock

Moderator (M): How would you describe your conceptualisation of ADHD?

I think my conceptualisation has changed dramatically since I first started working with this population of youngsters. I think now my conceptualisation is "boxy" - as everybody would say it's a very heterogeneous condition. It's most likely I think that what we're picking up is clearly a neurodevelopmental problem, so although we still define it behaviourally, I believe that's just the observable consequences if you like, of some underlying problems in dealing with information processing that these youngsters are showing. And I think one of the challenges is that it's so hard to know when we're really talking about ADHD versus when we're really talking about concurrent disorders, because ADHD typically occurs with other types of problems. So whenever we start to draw or make a conclusion about what we think about ADHD, I'm always sort of hesitant now thinking am I sure it's ADHD per se? So I think it really is a manifestation of a complex system of cognitive impairments - difficulty processing information - that in turn give rise to some of these observable behavioural symptoms that we see like inattention, disorganisation, the so-called behavioural impulsiveness et cetera. Whether or not I think it's any specific one deficit, no is the answer. I don't think we can really narrow it down and adopt this reductionist position that it can be a single, fundamental deficit. That's too simple. I think that we're going to have a group of them - in my head right now I would say I could think of about four or five difficulties with processing information. And I think that in the ADHD population you're going to get some of these children - some of these individuals - showing only one of these problems, or two or three of those problems. On the other hand, if I also took another population of say children who are dyslexic, with reading disorder, or those with quote "specific language impairment" - I think that's where we're going to see the overlap - that they also may show one of the same types of problems that are shared with ADHD.

M: O.K., so you've talked about those key features like inattention and the other things that might manifest as behaviours. Can you describe your current view of the subtypes and how they are delineated?

The subtypes I think are intriguing. The first thing I think it's important to note is the division of the two symptom clusters that I think is probably the most informative, and that I think this has been a useful advance in conceptualisation in the field. I think there has always been this notion of something to do with these behaviourally inattentive symptoms that seemed to somehow separate out from the very fidgety/overactive type of impulsive behaviour. So I think those two clusters are informative. And what becomes difficult now is when you say theoretically these two clusters may give rise to three subtypes - and that is where I think you run into problems. And why is that? Because essentially how it's operationalised in DSM is that you've got to have at least six of the inattentive and fewer than six of the hyperactive-impulsive to be called the Predominantly Inattentive Type. But in reality, you're going to get kids who have six of the inattentive and five of the hyperactive-impulsive. It also depends which informant you're going to base that on, because if you look at parents and teachers - we've known for years that parents and teachers don't agree. That they'll see a very different perspective. So in school a youngster

may manifest as Predominantly Inattentive if you interviewed the teacher, but at home, the child might manifest as either a Combined Type or primarily Hyperactive-Impulsive. So what do we call that type of youngster? How do we integrate information from two individuals?

On the other hand, I think there are some intriguing genetic findings - or findings from twin studies - that do suggest that there may be something important to take into account that these clusters of symptoms may differentiate. And it brings to mind a recent study by Willcutt and Pennington looking at twin study who were recruited for Reading Disability, not ADHD. But on that study, it was quite intriguing, they showed that in a community sample, with a wide range of problems, the individuals who have extreme levels of inattention, show high heritability, irrespective of what their level of hyperactivity-impulsivity is. On the other hand, in that sample, individuals who showed extreme levels of hyperactivity-impulsivity, that was not highly heritable if it did not occur with a lot of inattention, which suggested that hyperactive-impulsivity alone may be something completely etiologically distinct from the hyperactivity-impulsivity that occurs with inattention. And Barkley has argued that the inattention of the Inattentive Type is not the same as the inattention in the Combined Type. So it's a very - at that level - it's pretty much descriptive phenomenology, but I think there may be something in these divisions - we're not quite sure how to divide the pie yet.

M: That's one of the ideas that I discussed with the others as well - one of them was the idea that the Predominantly Inattentives and Combined Type may represent a separate disorder. One of the other suggestions was that what we've seen clinically is that perhaps the hyperactive-impulsive just don't appear on their own - this idea that there might only be the two subtypes.

I actually think that - we certainly see kids with hyperactive-impulsive only. Even when we take into account information from parents and teachers. They are relatively few sure, and they're not always the young kids. So it's not that they're just up to six and seven year olds, we also see some of the nine, ten and eleven year olds like this too. What's intriguing though is that in our dataset with this clinical sample - but I've also seen it in other samples, for example, presented by the Biederman group in Massachusetts - that the hyperactive-impulsive only group of youngsters, recognising that they all use different methods to diagnose and classify, seem to be protected in terms of, for example, their IQ scores or achievement - they don't seem to show the cognitive difficulties that the Combined Type or the Inattentive Type do. So that's intriguing, together with that twin study data that I've just talked about by Willcutt and Pennington. In terms of the others, the Inattentive and Combined Type, it's fascinating - we have not found robust differences between the Predominantly Inattentive and Combined Type in terms of behavioural inhibition, yet according to both Barkley's model and the model proposed by Quay based on Gray's model, they both argue that in fact the inhibition-impulsivity - the inhibitory control problems - would be restricted to this Combined Type, and primarily that's therefore being accounted for by the hyperactive-impulsive symptom clusters. And we don't find evidence for that.

M: Just going back to what you were saying before about the subtypes, and as Barkley has said, that there might be a difference between the inattention in the PI's and the CT's. Would you distinguish the nature of the attentional problems between the two subtypes?

Not clearly. We've actually tried this by looking at just what I call the behavioural phenomenology. In other studies, where we were looking at an objective measure of activity - so we were using actigraphs. We didn't find on this measure, any difference between the Predominantly Inattentive Type and the Combined Type. And it's puzzling because you'd assume if everybody's describing that the Combined Type are the fidgety/restless ones, that should be picked up on an actigraph, which measures movement. So then we thought that maybe it's because the Inattentive type show some of the hyperactive symptoms or something - and they clearly do - it's the fidgetiness that is picked up there. But we also looked just to see if we could find any difference - we looked at the sustained type of attention and the selective, focussed attention - and in terms of just the symptom count and what's been endorsed, we really didn't see any difference there. But I think that's because we're just looking at these surface behaviours. So I think the next step is we clearly need to be looking at more of the cognitive processes, and this is where I think we're beginning to get some evidence of some separation. As soon as we go to the cognitive processing, then I think we might be seeing some differences for example in working memory.

M: One more thing on that point. Do you think that attentional impairment is central to ADHD?

Yes, absolutely. I think this is probably the key area. And why do I think that - for several reasons. First that these symptoms of the inattention - if we look at the actual symptoms, they incorporate many critical cognitive - or suggest or reflect critical cognitive processing. And we know that they persist into adolescence and adulthood, whereas the kinds of fidgety/restless behaviours typically decline at least in observable fidgety/restlessness with increasing age. So I think the inattentive type has always been associated, even in the first DSM, the DSM-III, with more likely to show the manifestation of cognitive impairments, whereas the hyperactive-impulsive haven't. And if we look at the comorbidity, that may also be informative. The comorbidity that's associated with the hyperactive-impulsive only type and the combined type is typically Oppositional Defiant Disorder and Conduct Disorder. By contrast learning disabilities typically go across the board. If for example, we consider the study just recently reported by the British group from London, from Eric Taylor's group - who looked at just inattention on the dimensional note but clearly also had major impairments cognitively, particularly in terms of the difficulties. So I think this is probably the key element and my one proposition that I have is perhaps some of the hyperactive-impulsive symptoms that we see - could they perhaps be an artifact of a kid who has been severely oppositional and conduct disordered? So more that line and that automatically inflates ratings of these restless behaviours in a classroom or in the home setting.

M: A recent theory has response inhibition as the core deficit in ADHD, which in turn leads to impairments in specific executive functions.

Well first of all I really have been excited by this model, because it's the first time we've ever had a model that's a theoretical model for ADHD and we haven't had anything like this. This has truly been a major, major advance in the field because it's put out a model - and a model is there to be tested empirically, to be supported, or challenged. So this is where I think that is the first major step. Logically what we know from the basic clinical presentation - from the neuropsych findings to date it lent itself to the notion that inhibition may be the core feature. However, it's really intriguing, because certainly our

group's been proactive in trying to put this to the test, and we've been working even prior to the model on this notion of inhibition. And whereas this has certainly been within our group, believed to be a major component of ADHD, our recent findings are really challenging that. But I'm not convinced that inhibition, at least as we've measured it, with this one particular method, is indeed the fundamental deficit. In fact what's most disturbing is that we're finding that children with ADHD per se, actually aren't any different from random controls in this type of inhibition. Whereas children - the subtype of children who have other types of problems - so those with concurrent reading problems - are the ones who are showing the problem. And also children with language impairment without ADHD are showing this type of problem, measured in this method. So I'm not convinced any longer that it's the case.

M: So how do you conceptualise the executive functions, their range and their role?

The executive functions is a woolly concept - fuzzy. You can't define it - nobody can agree on what they are. Rather I think we assume that executive functions are the superordinate processing involving wide distributive networks - neural networks - that integrate a whole range of more basic processes - like perception and so on. I do think there's a construct called inhibition, but I think there are other constructs such as working memory, that in the Barkley model has a very different interpretation to current cognitive models of working memory, of which there are many. And they all vary to some extent, but they don't map easily onto the Barkley model of working memory. So I do think these type of processing - neural networks are the key. And I think that what we may be detecting is evidence of developmental anomalies in the networks that support constructs like inhibition or like working memory.

M: In that case, how would you expect these impairments to manifest in children with ADHD?

I think it's hard now because obviously you're always driven by two aspects. One is your data - hopefully you're driven by your data - but also it's necessary to check back to see whether your data match with your clinical understanding or observation of the clinical condition. And currently I really believe that we have underestimated several aspects of ADHD. One is this notion of working memory - which I do believe it plays a major role - and in fact many of the tasks that we use to measure inhibition and a whole range of other more complex processes, for children - if you take a developmental perspective - make heavy demands on working memory. The models we're using often come from adult psychology, so the demands on working memory may be minimal for adults, but for the young child - they're major. So I think we're often detecting problems in working memory, but we're thinking - because our task is purported to measure for example inhibition - that we're kind of interpreting it in that framework, and I think it's working memory. Moreover I think another area that we've really overlooked and that is the notion of many of these more early types of neural systems involving the more basic parts of the brain systems like the cerebellum, the basal ganglia, which are going to play an important role in timing and synchronisation of responses.

M: So what are those sorts of impairments that you might see coming out in working memory?

Working memory literally is two - I'm not sure - there are several constructs that we need to kind of balance and consider. One is in working memory you've got the notion of something to do with maintenance of verbal - it could be modality specific - so maintenance and manipulation of verbal information versus maintenance and manipulation of spatial information or form or information about shapes and so on and spatial locations. So it could be that we've got an impairment first of all just in the amount of information one could hold momentarily - the span - and it also could be in fact manipulating information. What seems to be the problem with ADHD that's emerging in the literature now is that if we take the verbal span (that ability to hold a certain amount of information on-line - verbal information), it doesn't seem to be a problem - when we manipulate it in some way, there is a problem. On spatial information - that has not been part of it and it hasn't been raised as a possibility in ADHD until very recently. And suddenly there is evidence in the literature that's with the adults with ADHD and children that the ability to hold and represent spatial information and manipulate it seems to be quite impaired in ADHD. I don't believe it's specific to ADHD, but it is strikingly impaired. And I think as human beings we might process information and represent it spatially - image it - to a greater extent than we realise. And I think in children, this may be the primary mode of working with information.

M: Children with ADHD, and in particular the Combined Type, appear to have difficulty inhibiting their immediate responses, even when deferring a response would lead to future gratification. Can you give some examples where this might happen?

With difficulty these days. I think at one time I would have said yes. I'm really struggling with this notion - do they really have difficulty withholding responses? I look at these youngsters in our laboratory situation, and I look at them doing any of our so-called tasks - they don't actually seem to have difficulty withholding - in fact they're often slow to respond. And I can't find many instances where they respond too quickly. On the other hand, a child who is anxious can often respond too quickly. So I'm not really sure what I'm seeing any longer. I think for example, a situation where we might see a child is calling out an answer in class - that may be considered as difficulty withholding. However when you talk and observe the children - the children who call out fast in class - some of them - a large proportion of these youngsters, most of the time their answer is correct. If it was truly impulsive, they would be acting on inadequate information - but they don't appear to be. Rather often these youngsters have said to me "If I don't say it now, I won't remember it," - because they can't hold it on line. So maybe what we're thinking is difficulty to withhold, may actually reflect this difficulty holding information on line.

M: Can you think of any examples where perseveration might occur?

Oh, frequently. In some ways it's a fascinating issue - because to what extent are perseveration and inhibition related - if you fail to inhibit, you'll continue doing the same thing. So one the one hand, that could be perseveration. So one the one hand, if I looked in a classroom situation, I can recall clearly one child who had a topic on his mind. And he kept reintroducing this topic over and over again at the most bizarre moments and he couldn't let it go. Parents likewise often tell us that they often - although the kids don't seem to pay attention - they'll suddenly get stuck with something and won't let go of it and

it can go on and on and they don't want to stop, which to me is that perseveration. And yet it that also a failure to inhibit? I don't know.

M: We come to suggestion now that some researchers have said that children with ADHD may experience an impaired sense (or perception) of time. What do you understand that to mean?

In many ways. Indeed many youngsters do appear to be unaware of how to tell the time - which is an important start - they don't seem to have a concept of time - and I'll give you an anecdote. A youngster was trying to learn to tell the time using an analogue clock and he'd been struggling and struggling for weeks. And he suddenly said "Oh, you mean to tell me that sometimes that number one isn't number one? Only sometimes it's one for one o'clock, other times it could be a number five - it means it's five minutes?" And for this child - this notion, this actual concept of time was in terms of telling it. But the children seem to have difficulty in terms of working out how much time will be required to complete a task, to allow themselves to prepare for a project - each component. And I think maybe what's happening is that the children don't seem to have the appropriate language to use to represent those concepts of time. So if you don't have a tool to use to talk about it or to think about it, it may be difficult. But the notion of awareness of time is again a bit of a woolly construct. We've actually examined the children's use of time concepts in their language. And the one area that we find strikingly difficult is that children often fail to use what we call these critical linguistic terms called conjunctions - which are things like "because" and "instead of" - and these are concepts, not exactly temporal, but they actually require you to order those two ideas in time and sequence them. And we find that the children are much less likely to use these more temporal-type conjunctions, and to string things together with "and". Another area we've found where they have difficulty is when we actually measure the perception of time. So if we use a cognitive method to measure perception of time, they do seem to have - and this is with short intervals - they seem to have remarkable difficulty distinguishing between intervals that are very brief - like less than half a second. They seem to need - if you have two intervals of about half a second - they need for these intervals to be very much wider apart to distinguish between them. Likewise if we ask them to reproduce an interval and you actually present them with an interval of about half a second, what happens there is that they produce a much longer interval. However when we ask them to produce a longer interval, say two seconds or six seconds, they actually reproduce it as though it was much shorter. Is this time perception or is this actually again - my belief again that comes back to this construct of working memory - you've got to hold that representation on-line momentarily in order to compare two intervals or to represent that interval. So I think all these are intimately and intricately inter-related.

M: How do you think that problem with timing, and organisation of behaviour with respect to time, and integrating time and space - how does that affect their attention and their performance across dual tasks?

Very much. I think this is a major element because much of what is required is the precise mapping of - if we're using an experimental task - the youngster has to be able to map reliably the timing parameters of the task in order to respond and prepare fast responses - whether they're only required to give one response or shift between two responses. In the real life situations, everyday life or conversation has a temporal pattern to it. So the child has to be able to extract

and represent this typical rhythm and timing of things. And so what is required is to be able to first be aware of and represent and store those temporal patterns and secondly, to be able to synchronise your responses with the existing temporal pattern. This is where I believe the major problem is - and if you think of ADHD youngsters, it's not that they cannot do something - they don't have a deficit or absence of behaviour - but it's unreliable. Sometimes they respond right on time, and other times they're too slow, and other times they're too fast. It's the variability that's the most remarked problem.

M: How would you describe the ADHD child's ability to make use of their past experiences and knowledge?

I think they have great difficulty. And again in order to do that - in order to really use that information - how you know they can is whether in a particular situation they're responding in the same old way again and have not learned. And I think again, if we think of what is required to do that, you're typically on-line moment by moment bringing up from your long term memory information that you have learned from consequences or whatever, or your previous experience doing something - to work out how to integrate it with the current moment or how to work it with the planned future action. And I think again, if you cannot either rapidly retrieve this knowledge that you actually have and can't access it quickly, or that you can't integrate it rapidly enough to make an appropriate decision, it will appear that you can't utilise and learn from past mistakes or past behaviour. And again I think often it's that the children seem to have difficulty using language that seems to allow them to reflect and to map their representations.

M: What do you see as the role of language in ADHD?

I think this is a crucial element. Don't forget that obviously as soon as we get to school-age children, how we are determining whether a child has the symptoms of ADHD is often heavily based on the children's everyday language. Many of the symptoms and descriptions in the DSM-IV currently explicitly refer to the problems in the children's use of language day to day, as indicating symptoms of impulsiveness for example. And I think one of the notions of the language is that it allows you to map and sequence and store in your mind these representations but it really brings - slightly going off at a tangent there but I think for a good reason - and that is what we do know is that the problems with language manifest very early and a disproportionate number of children with ADHD are reported to be slower to talk and often manifest these delays in language development. Seemingly when you talk to a youngster of school age, they're fine, but again when you actually probe more deeply, they don't have some of these solid constructs. And certainly this ability to sequence seems to be very crucial both in terms of utilising language to explain ideas and utilising language to represent sequencing, and therefore also to guide one's behaviour in an orderly, sequenced manner.

M: Do you see "Attention-Deficit/Hyperactivity Disorder" as an appropriate name for the disorder?

No. I don't know what to call it. And I think it's because at the moment it's very hard not only for us as professionals and scientists but I think also for parents, it's hard when you have a very dreamy, inattentive child to know that this child also has the same label as a child who's bouncing off the walls - just that alone doesn't make sense. But also because it's trying to work out what is the

difficulty in attention these youngsters manifest and I've seen in the literature terms like executive dysfunction disorder emerging in the adult literature, and I wouldn't be surprised if this doesn't sort of filter down to the child level. What we call it I don't know because we simply don't know what the fundamental problems are with ADHD.

M: Do you agree with the placement in the disruptive behaviour disorders category of the DSM-IV?

Absolutely not. I think this is probably the greatest disservice we're doing to these youngsters. And it also leads to a different type of treatment, which is the biggest concern. And if indeed this condition or at least a huge chunk of it - a group of individuals with this condition - are truly showing these neurodevelopmental/cognitive impairments, this really is simply doing them a major disservice, because we're misunderstanding why this child may be being inattentive or impulsive or disorganised. And therefore by just using these treatment approaches - behavioural modification techniques - sure we can using various response costs you can train even animals to respond appropriately, but that's not getting at the core problem. And I think it's truly blaming a child for misbehaving when it's truly a processing problem.

[End of Interview]

Interview transcript: Dr Thomas Brown

Moderator (M): How would you describe your conceptualisation of ADHD?

I think probably it's most useful to begin by saying I think of the cognitive impairments associated with ADHD as the central impairments, as I described in the manual of my assessment instruments. The main things are - the prime clusters of symptoms that I've found in my study of people with ADHD are problems with being able to get organised and get started, problems with being able to stay tuned and screen out distractions, problems with being able to sustain alertness and effort, processing speed to complete tasks in a reasonable time, being able to manage affect so that it doesn't interfere too much, and problems with short term working memory. And I see these as a cluster of functions that I think of as important in executive function. And I would differentiate my point of view from that of Russ Barkley on the grounds that I think of his model as a very good one in terms of describing executive function except when he gives primacy to the specific function of behavioural inhibition and I think of that as just one more along with it. My model as I originally published it and just outlined it needs to have his behavioural inhibition added to it and I think his model needs to be levelled so that you don't have that behavioural inhibition as the chief among equals. So with that modification I would pretty much join him in thinking of this as Attention Deficit Disorder as being essentially developmentally impaired executive function.

M: What's your view regarding the subtypes?

The way I see it is that the PI type symptoms are present in those that we would diagnose as Predominantly Inattentive Type but they also are present in virtually all of the people who have the Combined Type. And really the Predominantly Hyperactive-Impulsive Type is essentially a category for talking about preschoolers who aren't expected to be able to attend very much anyhow. I disagree sharply with Russ Barkley when he talks about how those Predominantly Inattentive Type are a whole different thing - I think that's something which is central to both subtypes.

M: Do you think that attentional impairment central to ADHD?

Yes. But I also would say that it's attentional impairment broadly defined. If you take a look at the cluster of symptoms under attention what you see is that there is a wide range of cognitive impairments associated with them. It's not just paying attention in the sense of listening to a speaker, but it involves - you know - being able to get organised, being able to activate - that certain energetic, affective component to it, and modulating that affect, and there's a problem with short term memory that's a crucial element of it. These are all things that I would include under the inattention rubric - and the studies have been done - for example, the Hart, Loeber, Lahey study that appeared in the Journal of the Abnormal Child Psychology in '95 and the study that Flo Levy did down your way, both helped point to the persistence of the cognitive and inattentive symptoms over time in contrast to the hyperactive-impulsive symptoms which drop off as one gets a little bit older.

M: Can we talk a bit more about the executive functions - obviously they form a part of your view. How do you conceptualise those - their range, their role?

I think the most important is working memory. And I think that the aspect of working memory that's most important for most people is verbal working memory. And we have found that the use of the logical memory subtest from the Wechsler Memory Scale (either the WMS-R or the WMS-III) is a very simple, economical test to assess the problems with short term verbal memory in patients and with the kids. We used to use the WRAML, didn't like it very much, and then now are using the Children's Memory Scale and find that if we use the Story Memory there that we often get better registration of short term working memory impairments in people with ADHD than we do if we were using digit span alone. So we tend to use digit span and verbal working memory as measured by that subtest. So working memory is the thing that I think I would place first and then problems with activating and organising as probably most central - and most frequently neglected in most of the formulations.

M: Children with ADHD appear to have difficulty inhibiting their immediate responses even when deferral of the response would lead to future gratification. Can you give some examples where this may happen?

Well often they'll say the first thing that comes to mind in a conversation, and in the process sometimes even interrupt people because what they'll tell you is that if they don't say it when they think of it, they're not going to remember it later. And it's sort of a way of trying to compensate for their short term working memory. But the other thing is that it's part of their cognitive style - they tend to often think quickly and be thinking about a lot of different things all at one time, and will sort of respond as the spirit moves them at a particular time. And in some tasks, where you need to be able to think in this multi-tasking way, their ADHD style is really an asset. In a conversation once with one of the psychologists for our air force and he said that some of their best fighter pilots were very, very good and had ADHD type symptoms, and were very good at paying attention to many, many things all at one time - as you have to when you're in combat - but that they made lousy commercial aircraft pilots where they're just flying from one end of the country to the other in a straight line.

M: There are also the problems with persistently giving incorrect responses - perseverating -

Yes, they'll sometimes get stuck on things and I think sometimes it's just the ADHD and sometimes they've got an unrecognised OCD problem where they have trouble getting stuck on things and can't let go. But there again you're talking about a dimensional variance of executive function which has to do with being able to shift gears, which you could subset under prioritising, or you could deal more specifically with it in terms of Russ Barkley's notion of reconstituting - of being able to shift from one task to another.

M: We've already talked a little about working memory. Does it play a significant role in ADHD?

I think that it is central. The stuff that I've found most useful in thinking about that is the work that Bruce Pennington has done on working memory - the Pennington and Ozonoff paper. And Martha Denckla I think has done some

work on that, but also the work that's been done in the U.K. - particularly Alan Baddeley at Cambridge has a books and articles that I've found useful. I don't think I want to go whole-heartedly with his model, but I think he's on to something that's very important. And then there's some work that Patricia Goldman-Rakic at Yale has been doing and there's some important implications in working memory for studying schizophrenia for example.

M: Some researchers have suggested that children with ADHD may experience an impaired sense of time. In what ways might you see that occurring?

That's not something I've studied very much. I know Russ Barkley's been emphasising it recently. I certainly have seen the problem that many of these folks have in estimating correctly how much time it's going to take them to do things - for example, they'll plan an errand and need to get from - they're here at 3:00 and they want to be someplace else at 3:30 - and they have no problem in thinking about themselves as being there at 3:30 but allow no time for travel.

M: How would you describe the ADHD child's ability to make use of their past experiences and knowledge and bring it forward to new situations?

Well that depends on what they're doing. If it's one of those domains in which they have special interest they often make very good use of their past experience. And if it's something where there's been a big jolt of positive or negative reinforcement on it they may very well remember - it's the routine stuff they have trouble with. And often they don't remember the stuff that's not dramatic.

M: What do you see as the role of language in children with ADHD?

I think it's complicated. I think the link between ADHD and language impairments is short term working memory. A lot of the people we see who have ADHD also have a Disorder of Written Expression where working memory is crucial but I think it's also important in the development of language skills - particularly in reading. And I think there's some peculiar problems that many people with ADHD have in their reading where they have difficulty retaining what they've read and being able to remember what happened in the first half of the sentence when they read the second half of the sentence. You know the last sentence of the paragraph relative to the first two or three sentences in the paragraph.

M: Have you noticed any patterns in the verbalisation of children with ADHD?

Well I know they tend to have a little more trouble with narrative - the work that Rosemary Tannock herself - and has been summarised in the book that Brooks published on language and behaviour and attentional impairments - I think addresses this pretty well. Often they sort of jump around in the details that they give you and have a little difficulty in sequencing their accounts so that you end up with fragments as they talk with you about things and you have to sort of weave the pieces together yourself.

M: Finally, do you see "Attention-Deficit/Hyperactivity Disorder" as an appropriate name for the disorder? Do you agree with its placement in the Disruptive Behaviour Disorders category of the DSM-IV?

No. No. I think that we ought to separate out the term "hyperactivity" from the name of the disorder. Some people want it to come to things like "Executive function impairment" or "Mild neurological impairment" or something like that. And I think that because of the history of research that it makes sense not to depart completely from the notion of attention and say "look - we're defining attention in a rather specific and broad way" and so it makes sense I think to think of it as an attentional disorder rather than as a disruptive behaviour disorder because it's not always accompanied by disruptive behaviour. But I also think that there are cases where we certainly see hyperactive-impulsive behaviour accompanying it, so I think what we need is language that basically tears apart the two elements of the current formulation so we have attention deficit disorder and then a hyperactivity-impulsivity disorder and then combined attention-deficit/hyperactivity disorder. But I think that the term "Hyperactivity-Impulsivity" or even just hyperactivity in the name of the Predominantly Inattentive Type is an oxymoron.

[End of Interview]

Interview transcript: Dr Annemaree Carroll

Moderator (M): Briefly, how would you describe your conceptualisation of ADHD? (i.e., what are the key features, what sort of disorder is ADHD?)

ADHD appears to be a disorder of response inhibition. Whilst it was once thought that attention was the key element of the disorder, it is now more likely that response inhibition is the key element with other features being hyperactivity, impulsivity, inattention plus problems with self-regulation.

M: Would you please describe your current view of the ADHD subtypes.

In the DSM-IV there are three subtypes - the Predominantly Inattentive, Predominantly Hyperactive-Impulsive and Combined Type.

M: A number of researchers have suggested that there may in fact only be two ADHD subtypes, that is the ADHD Combined Type, which subsumes the Predominantly Hyperactive-Impulsive Type, and the Predominantly Inattentive Type. How would you respond to this?

Yes. In examining the most recent research in this area it would seem that the Predominantly Hyperactive and Combined Type children are on the same continuum or display similar features compared with the Predominantly Inattentive Type children.

M: It has been proposed that the PI and CT represent separate disorders entirely. What are your views?

Given that the features of the Predominantly Inattentive children are so different in many aspects (e.g., daydreamers) from the Hyperactive and Combined, then yes, this could well be a likely view.

M: Please differentiate the characteristics of these subtypes.

The Predominantly Inattentive children appear as daydreamers, with high levels of inattention, and in particular poor sustained attention. In contrast, the Combined Type have problems with withholding responses, and are often hyperactive, clumsy, with problem solving difficulties, inattention, problems with sequencing and time concepts, and distractibility.

M: Please distinguish the nature of any attentional problems between the subtypes?

Where the Combined type may rapidly flit from one task to the other (i.e., selective attention difficulties) and may have problems screening out unnecessary information and are easily distractible, the Inattentive's have more difficulties with sustained attention.

M: Is attentional impairment central to ADHD? If not, what is?

No. I would see that behavioural inhibition is the central component of ADHD.

M: A recent theory has response inhibition as the core deficit in ADHD, which in turn leads to impairment in specific executive functions (EF). What is your view on this?

Yes. This sounds very plausible and again in examining empirical evidence on the neuropsychological functioning of individuals, it seems that the ability to inhibit responses to a task is a central problem in children with ADHD.

M: How do you conceptualise the range and role of the executive functions (EF) in ADHD?

Executive functions are basically those strategies or processes that exist to help us self-regulate our behaviour - our ability to problem solve, shift from one thing to another, self-monitor, inhibit responses, sustain attention, and set maintenance.

M: Are the EF manifested differently or impaired in ADHD?

Yes.

M: How would you expect EF impairments to be manifested in children with ADHD?

You would expect to see perseveration on the Stroop and interference for the Combined Types only.

M: Our recent research has suggested that children with ADHD (and in particular those who display symptoms of both inattention and hyperactivity-impulsivity) may be impaired on tasks involving inhibition or interference control, and may perseverate (even in the presence of negative feedback). Can you give some examples where this happens?

Interference: giving a set of instructions and then someone saying something which throws out the ability to complete what has been asked.

Inhibition: not being able to stop yourself calling out, hitting the person next to you, or throwing the rubber. If someone tells you something is hot, you can't stop yourself from touching it.

M: Recent research has suggested that working memory may play a significant role in ADHD. What are your thoughts about this?

I agree.

M: Could you explain how working memory might manifest differently in children with ADHD?

If the kids have poor response inhibition and they have a problem with selective attention, then they most certainly would have working memory deficits because it would be hard to keep in short-term memory exactly what the task at hand is.

M: Please comment on the possibility that children with ADHD may have an impaired sense of time. In what ways might this be demonstrated?

Children with ADHD have very poor time management and organisational skills. They have difficulty sequencing activities - for example they will not know in the morning to do the necessary activities in time to get to school. They have little concept of distance in time, and have difficulties pacing their work so they finish it in the time given.

M: It has been suggested that children with ADHD may be less proficient at analysing their previous experiences, and using this information to formulate appropriate responses in new situations. Have you seen any evidence of this?

Children with ADHD will often make the same mistake over and over again although they have had negative consequences given to them. So basically they either forget this has happened or don't learn from the mistakes they have made.

M: What do you see as the role of language in children with ADHD?

They have problems sequencing the language. If given a set of instructions or giving a set of instructions, they will often have problems getting them in the correct and sequenced order.

Actual verbalisation of sequences may actually assist children with ADHD to complete tasks in the correct order.

M: Have you noticed any patterns in the verbalisation of children with ADHD?

They have difficulties thinking silently rather than actually rehearsing things out loud. Therefore, they often need to talk to themselves out loud if they are faced with a task.

M: It has been suggested that children with ADHD appear to have difficulty inhibiting their prepotent responses, even when deferral of these response would lead to future gratification. Can you think of any examples of this situation?

Yes. An example of this would be if they were told they could play on the computer for five minutes now or if they waited until after lunch they could play for half an hour.

M: In the light of this discussion, do you see "Attention-Deficit/Hyperactivity Disorder (ADHD)" as an appropriate name for the disorder?

ADHD has been fraught with so much controversy over the past decade or more. If it could be established that there are two distinct disorders and the underlying etiologies of both of the disorders could be established, then I think a change in name could be useful to distinguish the two disorders from each other. My only concern in this however, is that there have been so many name changes over the past four decades, that people may just think here we go again without truly understanding the major breakthroughs that have been made in the field.

M: Do you agree with its placement in the Disruptive Behaviour Disorder category of the DSM-IV?

Where else do you put it? Some researchers would suggest that ADHD would be better placed under the Pervasive Developmental Disorders because of the links that have been found to Autistic Spectrum Disorder. More research needs to be done.

[End of Interview]

Interview transcript: Dr Trevor Parry

Moderator (M): Briefly, how would you describe your conceptualisation of ADHD?

I guess the first thing that I want to say is that I think the terminology is becoming to me increasingly inappropriate and unhelpful, in terms of the complexities of problems that I see children struggling with. But for that part of their problems which I would see as ADHD, by DSM-IV criteria, I guess I understand it as a developmental, genetic, neurobiochemical disorder of organisational processes.

M: What are the key features?

I think the key one is the issue of difficulty with organisational processing and then again there are outcomes of that and there are behavioural manifestations associated with that - so of course the classical difficulties are with concentration, impulsivity, and distractibility - issues in all of those that we all know about. But I suppose the kinds of things that we are much more aware/alert to these days is the issue of underachievement compared to known ability for no other identifiable reason. With usually a - an intermix of disorganisational features of which application to task in the presence of multiple demands on the child would be what you see. Maybe the difficulty of problems with being organised with fine motor, gross motor, sometimes with speech and language, certainly with learning, maybe with perception - there is in other words an amalgam, an interplay, of disorganisational, developmental delay, of which attentional deficiency, and to use Barkley's concept of executive decision or function, is the key.

M: Do you have a view on the subtypes as they are laid out at the moment in DSM-IV?

Yes I do. It's inadequate and I'm pleased that at least that it's getting to hint at three, but clinically you would certainly see more than that - I suspect there are probably four or five subgroups. And the difficulty with that is whether they are pure subgroups or whether you are seeing the core of the problem at a neurological level meeting certain temperament types, or whether you are seeing the core of the problem being made more complex by comorbidity. And that I think isn't well defined yet.

M: Of course there have been some suggestions that there are only a couple of subtypes and that one of them is a separate disorder altogether - the Inattentives might be completely different from the Combined.

I would certainly hold that view, at least that view that you know kids where there is no evidence clinically - at all - at any time of there having been a hyperkinetic component and I would part company with Barkley and Joe Sargeant, with whom I've had discussions about this issue. And certainly there is a group of - I believe of - what might be called if not have to be called Inattentive ADHD that are not just a burned out Combined. And I think that the nearest that you get to that - and this is where DSM-IV has not yet come out of its toddler stage probably - and that's Gillberg's concept of what he calls

DAMP, by which he means disorders of attention, motor control, and perception. Now I think that's getting closer - and those kids do extremely well with stimulant medication in exactly the same kinds of ways which is suggesting to me if you've got neurological disorganisations which are enhanced by improving neurotransmitter deficiency with stimulant medication.

M: Would you distinguish the nature of any attentional problems between these subtypes and do you think attentional impairment is central to ADHD?

No, no I don't. I think disorganisation is.

M: A recent theory has response inhibition as the core deficit in ADHD, which in turn leads to impairment in specific executive functions (EF). Would you like to comment on that?

Yes, I am familiar with that and I think that that's appropriate for hyperkinetic forms of ADHD and of course that's all that Barkley explained - and in that context I am comfortable, but I am not comfortable in that where either of the other groupings are not allowed in the spectrum and that clearly is meant to transpose across because I clinically don't think you'd see it.

M: Can I pin you down about those other groupings? I'm not sure - are they sort of defined or are they just you've seen them but they haven't been labelled?

Well I think we - well I would recognise the Combined - where you've certainly had an early history of some kind of kinesis or Barkley's inhibitory/impulsivity and that is no longer current in the primary school child as he gets older, and inattentive disorganisation is. So you would see that. But none of that allows for more widespread developmental disorganisation which is frequently in partnership with just those learning and attentional aspects that Barkley speaks about. And that's what I think Gillberg was referring to in the DAMP concept and what we here in WA are trying to write about as multiple stimuli disorganisation syndrome (MSDS). And we've published it under that concept. Where we're trying to account for those kids who are not necessarily equally but very significantly disadvantaged in their developmental progress in other areas such as gross motor, fine motor, language, and perception. But unless you deal with what seems to be a neurotransmitter deficiency, the fact is you don't begin to see progress in those areas either nor in that which may be more classically of ADHD type. So I guess that though the Barkley theory fits well for classical hyperkinetic disorder which is not necessarily associated with these other areas of disorganisation, that's fine, but it doesn't allow for what I think actually in our experience is probably a much larger group of kids who have the ADHD part without hyperkinesia as a component.

M: Children with ADHD (and in particular, the Combined Type) appear to have difficulty inhibiting their immediate responses even when deferral of the response would lead to future gratification. Can you give some examples where this may happen?

Well I think that again it's certainly similar to Barkley's defining the delay in the development of a concept of time. In the younger child particularly, who has great, great difficulty understanding in a formal way of what is anticipated, which might be going to the pictures - you know - having a reward, waiting for a birthday, having a holiday, or playing Nintendo - if it's got to be in two days'

time rather than now - so you certainly see that in the younger children. I think linked to that you see a very characteristic feature of all of the groups but particularly the inattentive of an over-focusing on the issue of the now to the exclusion of all other things. You see that in the choice of their sports where they tend to choose single track activities like swimming or abseiling or surfing, but can't cope with the big arena things - you know they do the sharp burst issues, which is partly instant gratification and instant feedback as opposed to waiting maybe for the ball to come out to the boundaries in cricket. Or - and getting constant feedback by my repetitive need to talk about whether or not I will buy this particular model car compared to that model car and they'll go on talking about models of cars beyond what is socially pleasant for other people.

M: These children may also persist in giving incorrect responses (perseverate) even when corrected. Can you think of any examples where this may occur?

Well you see that particularly in the - parents find it in their parenting. You know, "Can I buy such and such?", "No, you can't", and it goes on and on and on and on. Or again, just a concept, just something they've seen or something which has happened. An injustice that has been done for the older child when they've reached that sort of moral stage of awareness of that which is just and unjust and will be exaggerated in their sense of affront, without any awareness of what their participation in that issue might be. We see it when the kids get into trouble with school for disciplinary reasons and they're absolutely outraged or even just confused and puzzled as to why something which was last Tuesday which they've now not remembered is having to have its detention Friday, or not being allowed to go on the school trip or the school camp or whatever else. And I remember a four year old whose parents - intelligent professional parents - who had tried to prepare the child - for example, tomorrow we might be going to the barbers or something but the very fact of preparation caused such anxiety because it was implying an absence of routine and couldn't be grasped because that doesn't fit into my schema - who found that the child from a management point of view was remarkably helped by not being told what was going to happen other than immediately at the time.

M: It appears that working memory may also play a significant role in ADHD. What are your thoughts on this?

Well I guess I've probably been talking a bit about that haven't I? I mean they certainly have well developed if not exaggeratedly developed long term memory for amazing detail and things which are sharp. One wonders almost - I don't know whether that is substantiated whether that's almost adaptive and protective. Well I look at the issue as not - if we could forget ADHD as terminology - and if I'm looking at the multiple stimuli disorganisation which confuses these children, one to one they can focus, one channel, screen, computer, track, subject, routine small amounts, all of those management things.

M: Can you describe any circumstances under which these children might have difficulty maintaining their interference control?

Well, the whole of life, I mean particularly classrooms. And you see this in both groups but strongly in the inattentives - at the subtlest levels. The teachers teaching. They're interested in the subject and 1, 2, 3, 4, but idea 2 was very interesting so sidetracking to explore everything else and then they come back in at point 7 or 8 and they've missed what's inbetween. And about 90% of the

kids will then say when you ask "How do you feel about that?" they'll say "Confused".

Or the teacher that will sort of say open your maths book and turn to page such and such and look at example whatever it is and now will you do five. And apart from all of that multiple informational instruction, there's the multiplicity of numbers of tasks, or while that's going on they've then got to cope with the gardener who's gone outside I mean all of that, or what the kid's doing or what so and so is doing, or someone else has said something interesting and I want to explore that as well. Or just when I go into my school bag to get the maths book out I see my apple - and so on. And the kids say at the end of the day that they are exhausted and they are exhausted, uncommonly so, by simply trying to maintain everything on a uni track. It can be - one of the speech pathologists doing a research project of kids with learning difficulties in ADHD found that when they were - and these were kids improving - that if she gave them what she called a quiet passage that is, just descriptive, reading was progressing and it was fine. Give them what she called a busy passage - lots of action things happening - they just lost the sequence. So it can be as subtle as that or it can be as gross as I can't cope in a class of 30, but give me a tutor that sits beside and helps me.

M: Some researchers have suggested that children with ADHD may experience an impaired sense (or perception) of time. What do you understand this to mean?

I think I've already commented on that. They're people of the immediacy - is the number one factor and it's very difficult to extrapolate beyond the immediate. But there's also that which is compounded in the now by the multiple. So tonight how much homework have you got to do? Well I've got to do some maths and I've to do some English and I've got to this and I've got to revise the other because the exams are coming up. And can't get started, can't finish, can't plan, whereas if they have been helped to break it into manageable aliquots both of time and of subject and they need to learn that because it just doesn't come. It's more organisation. That's why I personally think this is much more a struggle that relates to difficulty with organisation rather than time per se.

M: How would you describe the ADHD child's ability to make use of their past experiences and knowledge (i.e., hindsight)? Are these children able to apply this experiential knowledge to new situations?

At a cognitive level they would have long term memory which gives them prompts, but in terms of the application of that into choices of the now, they are people of the now.

M: What do you see as the role of language in children with ADHD? (for example, with respect to sequencing, rule-governed behaviour)

Yes I don't know that I know enough about that. Except that it's - and this again is where you get the compounding issues that are needing to be carefully teased out - there is no doubt that a lot of kids with ADHD also have a specific difficulty with language processing. So you have to be quite clear and they do need to have a careful evaluation by a speech pathologist as part of their workup but is this bit that we're seeing here intrinsic to call it ADHD or is it in fact one of the comorbid issues as I would label it, where whatever it is 35-55% of the kids have specific learning disability and that's mostly in language based

areas - you're looking at something that is also and but not necessarily intrinsic. And I suspect that it's that - I don't think that there is an intrinsic language processing difficulty which is part of what I would understand as ADHD. I think it is one of these other developmental things which is why the concept is inadequate.

M: Have you noticed any patterns in the verbalisation of children with ADHD? (that is, internalisation of speech?). We've noticed that sometimes when they're performing tasks like the Wisconsin Card Sort and things like that they can tend to verbalise out loud and wondered if that was sort of common.

Prompting themselves. I wouldn't recognise that as such, no. And if I did, I think you may see that in the - reflecting on it, it doesn't stand out in my clinical memory really at all. And when we're taking the younger ones through some developmental testing I haven't any impression of that.

M: It's just that coming from an educational perspective, I was wondering if the idea of actually telling these children to be quiet and actually think silently and things like that whether that is actually counterproductive.

I think that's a very important thing. Yes, where they need the prompts. I've not seen that other than in - certainly not in the inattentives. I've seen it in kids who are needing to do something like that though as their organisational reminders to keep their routines going.

M: Do you think that's something they pick up naturally or that is something that has to be taught?

Some pick it up because they're intelligent - and it's interesting to hear some of the strategies some of them spontaneously come to - and some of course have been shown. So I think that it can occur. In the prompt sense maybe, but I wouldn't have put it is a characteristic.

M: In the light of this discussion, do you see "Attention-Deficit/Hyperactivity Disorder" as an appropriate name for the disorder? Do you agree with its placement in the Disruptive Behaviour Disorders category of the DSM-IV?

No. No to both of those.

[End of Interview]

Interview transcript: Dr Christopher Green

Moderator (M): Briefly, how would you describe your conceptualisation of ADHD? What are the key features? What sort of disorder is ADHD?

ADHD is a frontal lobe problem. A problem of self-monitoring, self-monitoring behaviour, self-monitoring learning, causes children to be out of step in their behaviour and out of step in their learning.

M: And the key features?

The main problem with ADHD is that it varies dramatically from child to child and the key features, if you're looking at behavioural presentation in the school age child, are impulsivity - why does such a clever child do such stupid things? - and insatiability - demand - the mosquito that buzzes you and doesn't give you space. Those would be the key things that are not present in other conditions. And the learning ones are a circling brain which is self-distraction, a problem of getting the focus on the right thing, a problem of moving focus from one thing to another, a problem of an over-focus, a problem of short term memory, and a problem of organisation.

M: With respect to the subtypes, what's your idea of how the subtypes are composed and how they are distinguished?

All ADHD - there are very few pure one or others - most are a mix and most of the mixes are different to other mixes - so it is a very varied thing. I see the majority are a mix of behaviour and learning but the balance of whether it is more behaviour or more learning varies dramatically from child to child. And I see that there are very, very, very few pure ADHD inattention only - of those dreamy, off-the-air, slow-moving cogs ones, who may have a specific learning disability - there is a very small number of those. There is probably a very great number of those who've got a predominantly learning problem - the ADHD Predominantly Inattentive - but they've nearly all got a little bit of impulsivity and 'stupid' behaviour with it. There are very few who don't have that edge - you may think they haven't got ADHD but when you start looking at them most have got that slight of edge of stupidity in it.

M: Do you think that attentional impairment central to ADHD?

I think that attention is a bad word - like hyperactivity. I think it is the self-monitoring, which means it is the control of the attention (that is, the coming in and out of attention, moving focus from one thing to another, regrouping after a distraction) - it is the moving of attention - it isn't inattention. It isn't that they don't concentrate, it's that they find it hard to select - home in on - and keep homing in on the right thing - that's where it's all at.

M: Do you believe the executive functions - those control processes - are central to ADHD?

Well, executive function is the business of frontal lobe - it is the business of self-monitoring - that is absolutely central to ADHD.

M: Children with ADHD appear to have difficulty inhibiting their immediate responses even when deferral of this response would lead to gratification in the future. Can you give some examples of situations where this may happen?

Well if you were to listen to parents, probably the number one thing that they would tell you - of certainly young ADHD children - is an inability to take frustration. It's maybe not exactly the answer, but it's the business of - life is full of frustrations - but when things don't go well, we can walk away from them. When the ADHD child's brother takes their toy, they wallop them. When things don't go to plan - when it's raining and they can't play - they can't take that. It is that business of inability to take frustration that would be one of the classic things that you would see.

M: Many of these children also persevere - they continue to give the incorrect response again and again even in the presence of feedback. Can you give some examples of situations where you would see that?

Well the perseveration is part of their demand-insatiability and also part of their problems of focus. And that is that there is a mix of two things that I don't fully understand the difference between. Some of these children have got not an attention deficit but in fact they've got attention surpluses - i.e., they get an idea in their mind and they're like a dog with a bone you can't budge them. So there is - there is an attention surplus in ADHD - which isn't in every child - but if it's there it makes their behaviour quite difficult to manage. And also with ADHD there is this insatiability of not knowing when to back off - you know "Can we have it, can we have it, can we have it?" - when most people look their mother in the eye and think "This is inappropriate, back off!" So it's a mixture of two things and I don't quite know how they fit in - one is part of the attention-learning bit of it - i.e., an over-focus or focussing on the trees and missing the wood - that, and another part of it is just not knowing when to take a step back which is a major part of ADHD.

M: What do you think about working memory as playing a significant role in ADHD?

Working memory - short term memory is a symptom that parents talk of and working memory is a major problem with the learning part of this which teachers complain about. But not all ADHD children necessarily have problems with working memory - most probably do - but it certainly causes problems with reading, and I believe there's probably almost a specific form of dyslexia in ADHD where you see the words but you've forgotten by the time you get to the end of the page. It causes problems with mental arithmetic. So in many ways it is causing problems.

M: A lot of the recent research has suggested that these children may demonstrate an impaired sense of time. In what ways can you see that demonstrated?

ADHD people are - one of their greatest problems is a problem with organisation. And ADHD adults will tell you that if they get on top of their organisation - that is when their life comes together. Now central to organisation is time. So I wouldn't see it as a specific thing - it is a problem of organisation.

M: How does it affect their performance of dual tasks and attention?

Well dual tasks are complicated because that is again going back to the business of ADHD is not attention deficits, it is the focusing. It is the business of focusing from one to another and not losing the plot in the middle of it - so there's a problem in there with dual tasks. And then there's a second problem with dual tasks that gets complicated - that one of the comorbidities of ADHD is motor planning. And a lot of these children find it very hard to - motor-wise, do two things at the one time - and that's tying shoelaces, rights, lefts, aerobics, swimming - those things.

M: How would you describe the ADHD child's ability to make use of their past experiences and knowledge and then apply them in the future?

Well it varies again dramatically. I mean sometimes they can be remarkably sensible and sometimes they can - the problem with ADHD is just when you think you're on top of them they then do something utterly bloody stupid. It's not predictable at every time. Their frontal lobe is working, it just keeps letting things slip through. So it is one of their great problems that they walk into difficulty because they do not use their frontal lobe to say "Is this wise? What happened last time I did it?" - so it's a big problem.

M: Can you think of any specific examples where that might occur?

Well it's just in every day.

M: What do you see as the role of language in children with ADHD?

That's a complex one. I mean first of all, language disorder is a much more common comorbidity than we would realise. Secondly, language is often, as spoken, circuitous - slips off target. If you listen to some of these adult ADHD experts talking - there will be one talking this afternoon - you will go mad because he's all over the place - it is like an interrogation, so there's a big problem there. And of course language is the basis of dyslexia and dyslexia is another comorbidity so certainly it's tied up with it all.

M: Have you noticed any patterns in the verbalisation of these children - the way they use language or pick up language as they are developing?

I don't know of any patterns other than - my main interest is children very young with extreme ADHD - and if you're looking for the worst-behaved young children, at least 50% of them have got a language problem. Language plus ADHD is not a combination you want.

M: Do they have trouble internalising speech?

I'm not sure. Some people say that the reason that all of us don't get into trouble is that we internalise our language like a pilot before he takes off saying "Have I got the fuel, are the flaps working?" - this way - and that is what stops pilots crashing and it's what stops you and I crashing. But ADHD it is said maybe they don't internalise, maybe they don't do a dry run in their head - they just crash.

M: Finally, do you see "Attention-Deficit/Hyperactivity Disorder" as an appropriate name for the disorder? Do you agree with its placement in the Disruptive Behaviour Disorders category of the DSM-IV?

Well it's a major problem of disruptive behaviour. My interest with ADHD is I think its number one problem is that it's a wrecker of relationships. It wrecks relationships between mothers and children and children and mothers, children and peers. It breaks up adult relationships - a massive break up in relationships of ADHD adults - so it's a disruptive one most certainly. And the name will change and I predict it will change next time to BID - behavioural inhibition disorder - for the short fused, and ADD for the learning problems.

[End of Interview]

APPENDIX H

Permission letter and consent form



The University of Western Australia

Graduate School of Education

Nedlands, WA 6009, Australia

Facsimile (08) 9380 1052

Telephone (08) 9380 2391

Internet: shoughto@ecel.uwa.edu.au

March 1999

Dear Parent/Guardian,

I am writing to request permission for your son/daughter to participate in a research project being undertaken by The Graduate School of Education, The University of Western Australia, in conjunction with consultant paediatricians and the Learning and Attentional Disorders Society of Western Australia (LADS). The project is entitled "Attention and Inhibition in Children with Attention-Deficit/Hyperactivity Disorder According to Subtype".

Our current understanding is that ADHD arises from a deficit in response inhibition which results in impairments in specific abilities (called executive functions) required for self-regulation and goal-directed behaviour. These impairments may appear as deficits in attention, the ability to perform more than one task at the same time, working memory, rule-governed behaviour, and in the perception of time. If we can develop a better understanding of the role of inhibition, attention and the executive functions in ADHD then we can devise more efficient educational interventions or management programs to assist children with ADHD.

The research will involve your child participating in a number of short game-like tasks. We would like to emphasise that these are not written tests and there are no right or wrong answers. Rather they involve tasks where an individual is required, for example, to manipulate small blocks of wood, sort a stack of cards, or press a series of buttons on a computer. Our previous experience suggests that the children find these activities enjoyable. The study will be conducted at UWA or at your child's Paediatric clinic if you prefer. Any information that you (or your child) may provide will be treated as strictly confidential and will not be made available to anyone else.

If you are willing to allow your child to take part, please complete the attached consent form and return it in the reply-paid envelope provided. If you would rather your child did not take part, you are free to decline, and your child will not be included. Should you or your child decide to withdraw from the study, you may do so at any time without prejudice. Your participation in this study does not prejudice any right to compensation which you may have under statute or common law.

The Committee for Human Rights at the University of Western Australia requires that all participants are informed that if they have any complaint regarding the manner in which a research project is conducted, it may be given to the researcher or alternatively to the Secretary, Committee for Human Rights, Registrar's Office, University of Western Australia, Nedlands, WA 6907 (telephone number 9380 3703). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.

If you have any questions that you would like to raise with me about the study, I will be pleased to answer them. You can contact me on 9380 2391. Your co-operation is greatly appreciated.

Yours sincerely,

Dr Stephen Houghton MAPsS, AFBPsS.
Registered Psychologist
Associate Professor of Educational Psychology
Professional Advisory Board LADS

John West
PhD Research Student



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PERMISSION TO PARTICIPATE IN A RESEARCH PROJECT

"Attention and Inhibition in Children with Attention-Deficit/Hyperactivity Disorder According to Subtype"

I _____ (the parent/guardian) have read the information above and any questions I have asked have been answered to my satisfaction.

I am willing to allow my son/daughter _____ (name/s) to participate in the research project conducted by Dr Stephen Houghton and Mr John West, realising that I (or my child) may choose to withdraw at any time without prejudice.

I understand that I can telephone Associate Professor Stephen Houghton on 9380 2391 and request additional information about the study.

I understand that all information provided will be treated as strictly confidential.

I agree that research data gathered for the study may be published provided that names or other identifying information is not used.

Parent/Guardian's signature

Date

Participant's signature

Contact Telephone Number

Contact Postal Address

The Committee for Human Rights at the University of Western Australia requires that all participants are informed that if they have any complaint regarding the manner in which a research project is conducted, it may be given to the researcher or alternatively to the Secretary, Committee for Human Rights, Registrar's Office, University of Western Australia, Nedlands, WA 6907 (telephone number 9380 3703). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.