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.

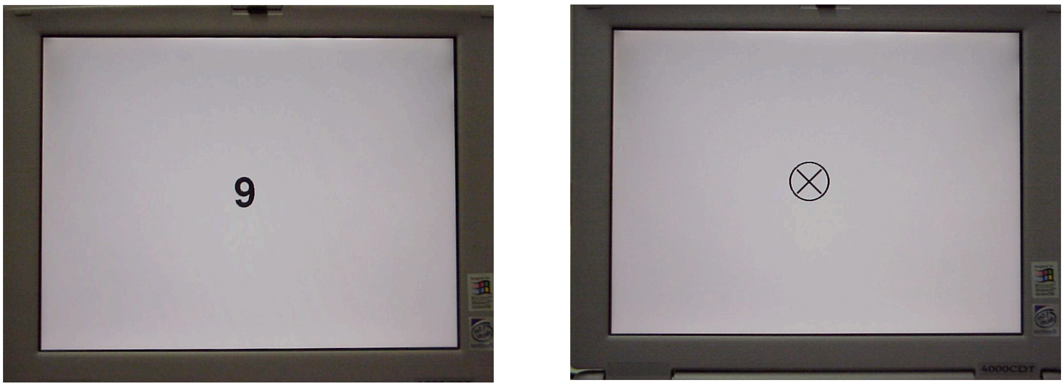

Figure 2. Sample digit (left) and mask (right) for the SART.

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).

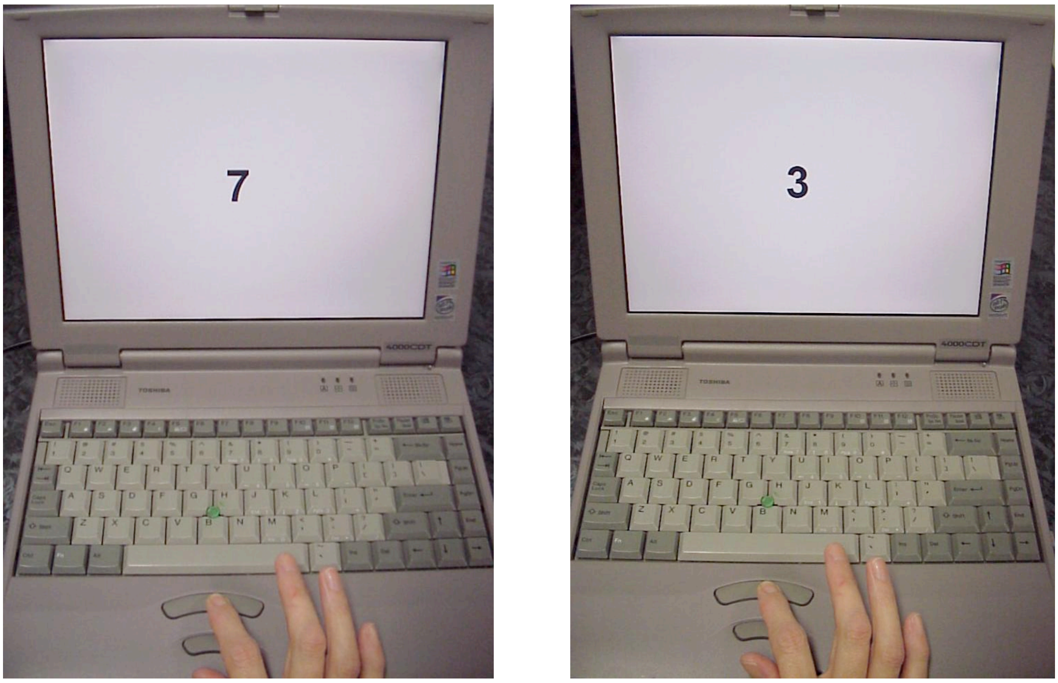

Figure 3. Sample non-target (left) and target (right) digits for the SART inhibition phase.

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 (Moores & 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.

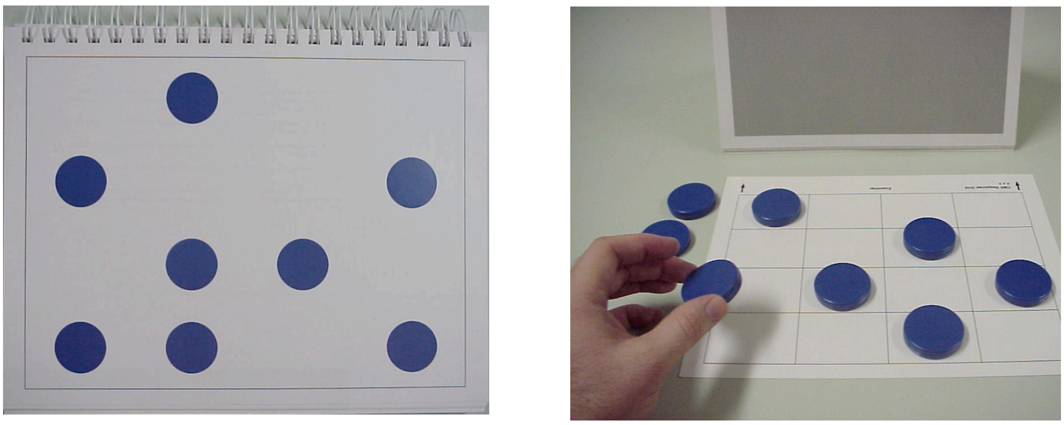

Figure 4. Stimulus (left) and response (right) phases for the CMS Dot Locations subtest.

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; $r = .22$, $p < .05$).

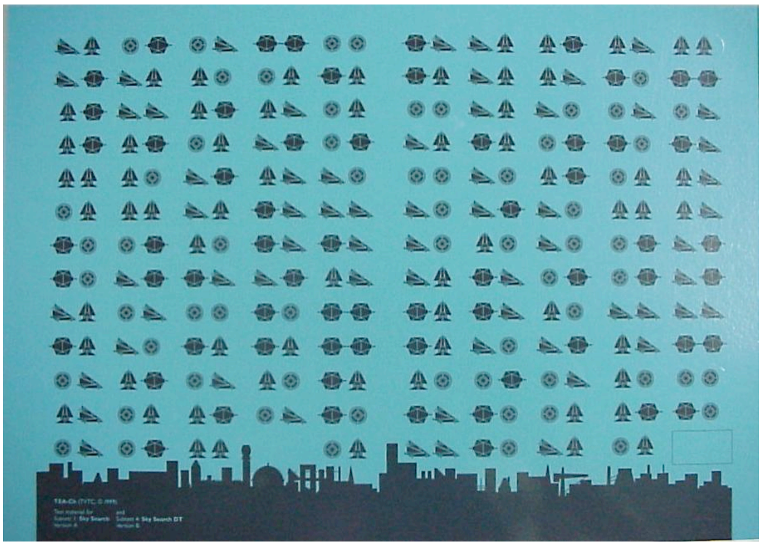

Figure 6. Illustration of the TEA-Ch Sky Search subtest.

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).

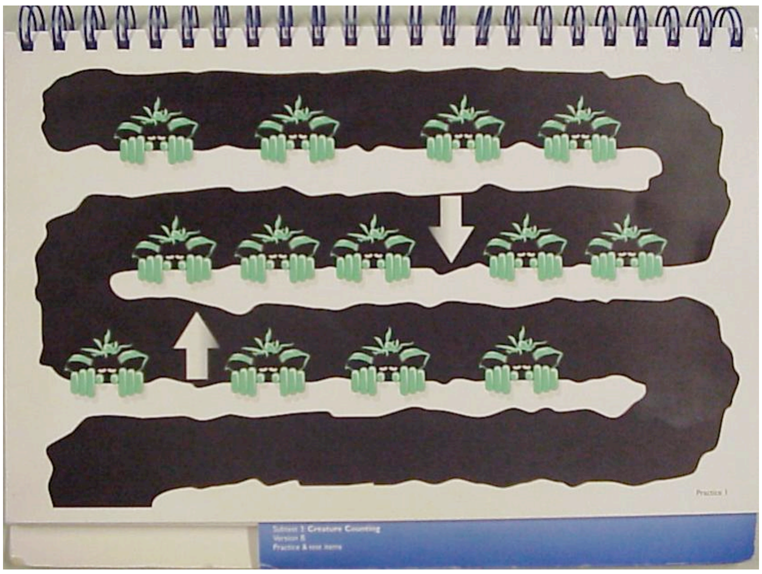

Figure 7. Illustration of the TEA-Ch Creature Counting subtest.

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 (Spreen & 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.

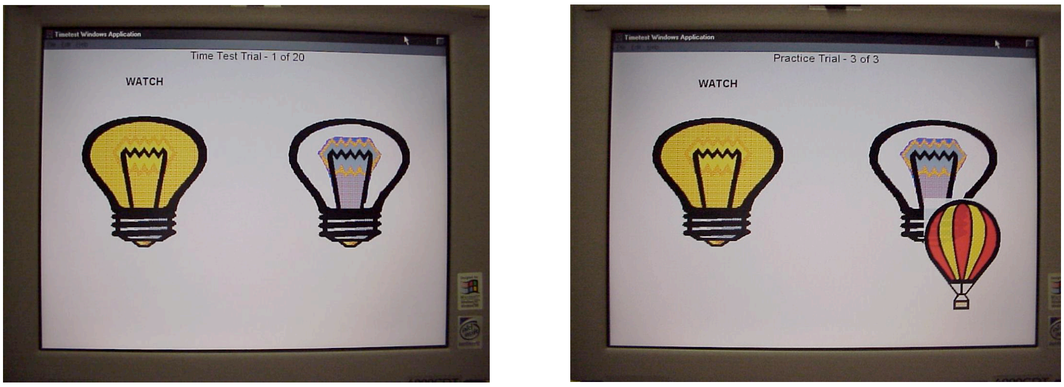

Figure 8. Sample non-Distractor (left) and Distractor (right) conditions for the Timetest Visual time reproduction phase.

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.

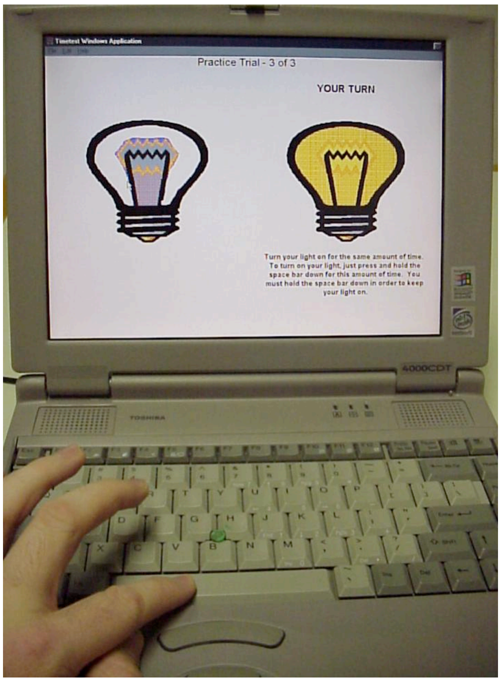

Figure 9. Illustration of the Timetest Visual time reproduction phase.

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.