# 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 as 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<br>(1.64) | 106.4<br>(14.74) | 113.3<br>(19.36) |
| Controls | 50 | 10.1<br>(1.59) | 103.1<br>(15.86) | 114.9<br>(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<br>(n = 49) | Controls<br>(n = 49) | Total<br>(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 <u>in line with Hypothesis One</u>, 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 = 339.59ms, SD = 10.40) than Control boys (mean RT = 401.39ms, SD = 16.01) 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 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

| | ADHD | | Controls | |
|---|---|---|---|---|
| Measure | 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<br>(n = 50) | Controls<br>(n = 50) | Total<br>(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

| | ADHD | | Controls | |
|---|---|---|---|---|
| Measure | 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 on sequences, 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

| | ADHD | | Controls | |
|---|---|---|---|---|
| Measure | 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) x 2 (Mode) x 2 (Distraction) x 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.

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).

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 <u>partial support for Hypothesis Six (part c)</u>, and the findings of Tannock (2001).

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 x Mode x 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.

## 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.