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## Attentional Problems and Subtypes of Attention Deficit Hyperactivity Disorder

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### **Abstract**

*This study aimed to compare children with different ADHD subtypes and controls on measures of attention, and to examine the relationships between measures of attention and reading and spelling ability. Thirty-eight children with ADHD and sixteen controls were administered tests of four components of attention (viz., attention span, focused attention, selective attention and shifting attention) and two subtests (viz., reading and spelling) from the WRAT-3. The children with ADHD-Combined subtype were found to show deficits in attention span and focused attention, while the children with ADHD-Inattentive subtype were found to show deficits in shifting attention, and subtler deficits in attention span and focused attention. Measures of attention span were found to be significant predictors of reading ability, and measures of attention span and selective attention were found to be significant predictors of spelling ability. These results suggest that different ADHD subtypes show different patterns of attentional problems that have different neuroanatomical bases. Furthermore, academic problems in children with ADHD may be related to their attentional problems.*

**Keywords:** *Attention, Attention Deficit Hyperactive Disorder, Children.*

Of all childhood disorders, Attention Deficit Hyperactivity Disorder (ADHD) is currently one of the greatest challenges facing paediatric clinicians and researchers. Not only does this disorder account for a large and growing proportion of presentations to clinicians but its characteristic problems of inattention, impulsivity and hyperactivity are associated with significant behavioural, social, emotional and academic consequences for such children and their families.

The current Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR; American Psychiatric Association, 2000) describes ADHD as a childhood disorder characterised by pervasive and developmentally inappropriate inattentiveness, overactivity and impulsiveness. The DSM-IV includes three subtypes of this disorder, with separate criteria for ADHD predominantly hyperactive-impulsive type (ADHD/H) and ADHD predominantly inattentive

type (ADHD/I). A combined subtype (ADHD/C) is also available for those individuals who meet both sets of criteria.

Historically, one important goal of research in this area has been to establish whether the attention problems displayed by the ADHD subtypes are different. Barkley (1990; 1997) argued that if the subtypes are found to be different in the nature and extent of these deficits, it may be more useful to consider each subtype as a discrete disorder with a distinct aetiology and, presumably, different prognosis and treatment requirements.

Evidence from studies that used qualitative measures of attention suggests that ADHD subtypes do show different patterns of attentional deficits. Whereas the ADHD/H and ADHD/C subtypes have been rated by teachers and parents as impulsive, overactive, acting in ways appropriate for younger children, disturbing others, and having messy work, the ADHD/I subtype was found to be more likely to have problems such as being confused or “lost in a fog”, daydreaming, or being apathetic or unmotivated (Barkley 1998).

In recent years, researchers have sought to determine whether ADHD subtypes show different patterns of impairment on psychological tests selected on the basis of various models of attention (Mirsky, 1989; Posner & Petersen, 1990; Shum, McFarland, & Bain, 1990). Common to these models is the idea that attention is a multi-component rather than a unitary construct. These components are considered different in nature, mediated by different neuroanatomical areas, and typically include constructs such as attention span, focused attention, selective attention and shifting attention.

The attention span component refers to the ability to encode and reproduce, in correct order, the stimuli presented and is mediated by the inferior parietal lobule (McCarthy & Warrington, 1990). Using the Digit Span subtest from the Wechsler Intelligence Scale for Children (WISC) to assess this component of attention, researchers have found that, compared to controls, children with ADHD (all subtypes grouped together) are significantly impaired on encoding/attention span (Assemany, McIntosh, Phelps, & Rizza, 2001; Karatekin & Asarnow, 1998). To date, however, no study has examined whether ADHD subtypes are differentially impaired on this component.

Focused attention is the ability to scan stimuli for a specific target and respond to it. The superior temporal and inferior parietal cortices and structures that make up the corpus striatum have been found to be associated with this component (Mirsky, Fantie, & Tatman, 1995). The Trail Making Test, Letter Cancellation Test and the Coding subtest from the WISC are representative measures of focused attention. Using these tests, some studies have found that children with ADHD (all subtypes grouped together) are impaired on this component (Grodzinky & Diamond, 1992; Shue & Douglas, 1992). Whether ADHD subtypes are differentially impaired on this component is less clear. One study found that neither the ADHD/C nor the ADHD/I subtypes were impaired on focused attention as measured by the Trail Making Test (Houghton et al., 1999). In contrast, other studies found that the ADHD/I but not the ADHD/C subtype was impaired on the Trail Making Test (Nigg, Blaskey, Huang-Pollack, Rappley, 2002).

Selective attention refers to the ability to maintain cognitive or response sets in the presence of distracting stimuli. The Stroop Colour-Word Interference Test is commonly used to assess this ability and the cingulate cortex has been found to mediate this ability (Bush et al., 1999; Pardo, Pardo, Janer, & Raichle, 1990). Evidence is mixed in terms of whether children with ADHD are impaired on the selective attention measure of this test, namely, the interference score. Although a significant difference between controls and children with ADHD on interference has been reported (Reeve & Schandler, 2001), this difference was not found by others (Seidman, Biederman, Faraone, Weber, & Ouellette, 1997). A number of studies have examined whether ADHD subtypes are differentially impaired on selective attention using the Stroop but failed to find any significant differences between the groups (Houghton et al., 1999; Nigg et al., 2002).

The ability to change the focus of attention from one stimulus characteristic or one task to another is the shifting component of attention and is thought to be mediated by the prefrontal cortex (Mirsky et al., 1995). Children with ADHD (all subtypes grouped together) have been found to be impaired on shifting of attention as measured by the Wisconsin Card Sorting Test (WCST; Reeve & Schandler, 2001; Seidman et al., 1997). However, research evidence is less clear with regard to whether ADHD subtypes are differentially impaired on this component. Although one study did not find any significant differences between ADHD/C, ADHD/I, and controls on any of the WCST measures (Klorman et al., 1999), another reported that the ADHD/C subtype was impaired on the number of categories completed, perseverative responses and total errors of the WCST but the ADHD/I subtype was impaired only on total errors (Houghton et al., 1999).

From the above review, it is apparent that researchers have attempted to employ objective tests based on models of attention to study the nature and extent of attentional deficits in children with ADHD. In addition, some of these studies have grouped the children with ADHD into subtypes based on the latest DSM-IV criteria. Unfortunately, to date the findings reported from these studies are mixed and inconclusive. It is unclear whether ADHD subtypes are differentially impaired on the components of attention, because most of these studies did not examine all the major components of attention together and because some of these studies had significant methodological shortcomings. These included inadequate procedures for classifying children with ADHD into subtypes, failure to control for the effect of medication on the day of testing, and failure to control for the effect of age on test performance in data analysis.

It was the aim of the present study to employ representative measures for all four components of attention (*viz.*, attention span, focused attention, selective attention and shifting of attention) in comparing the performance of children with ADHD to that of controls and to contrast the deficits exhibited by ADHD subtypes. Evidence of different attentional deficits among the DSM-IV subtypes of ADHD would further support the validity of these diagnostic categories.

As mentioned earlier, children with ADHD are usually found to have academic problems. In the literature, however, few studies have examined whether these

problems are related to the children's attentional difficulties. Moreover, the results that have been reported are inconclusive, with some studies showing a relationship and others not (Barkley, 1998). An additional aim of the present study, therefore, was to examine the relationship between measures of attention and measures of academic achievement.

## **Method**

### **Participants**

Clinical participants in this study consisted of 40 children who had been diagnosed with ADHD by paediatricians at a major metropolitan hospital and were receiving outpatient treatment from them. None of these children suffered from severe neurological, psychiatric or developmental disorders. Responses of the parents of participants on the DSM-IV ADHD subscales on the Conners' Parent Rating Scale (Conners, 1997) were used to classify them into ADHD subtypes.

Three males, with an average age of 10.00 years ( $SD = 2.83$  years), were classified as ADHD/H. Because of the small numbers of ADHD/H participants, this subtype was not included in the subsequent data analyses. Eleven males, with an average age of 11.18 years ( $SD = 1.83$  years), were classified as ADHD/I. The remaining 26 participants met the criteria for the ADHD/C. Among these, 22 were male ( $M = 10.50$  years,  $SD = 2.87$  years) and 4 were female ( $M = 10.25$  years,  $SD = 3.30$  years). The proportion of each ADHD subtype is similar to that previously reported (Eiraldi, Power, & Nezu, 1997).

The control group consisted of 16 children. Eight of these were siblings of the clinical participants and the remainder were volunteers from the general community. Nine of the children in the control group were males ( $M = 10.33$  years,  $SD = 2.87$  years) and seven were females ( $M = 10.00$  years,  $SD = 2.52$  years). No participants in the control group suffered from severe neurological, psychiatric or developmental disorders. In addition, responses of the parents of these participants on the DSM-IV ADHD subscales of the Conners' Parent Rating Scale (Conners, 1997) indicated that none of them met the criteria for ADHD. Participants in the ADHD/I, ADHD/C and control groups were not significantly different in age,  $F(2, 50) = 0.48, p > .05$ .

### **Measures**

#### **Attention Span**

The Digit Span subtest from the Wechsler Intelligence Scale for Children, Version 3 (WISC-III; Wechsler, 1991) was used to measure this component of attention. In Digits Forward, the examiner reads aloud random number sequences at a rate of one digit per second and the test taker is required to repeat the sequences orally. In Digits Backward, the test taker is required to repeat similar number sequences in reverse order. Measures obtained for this test were the total number of sequences correctly repeated for Digits Forward and Backward.

#### **Focused Attention**

To measure the focused attention component of attention, the Trail Making Test (Reitan & Wolfson, 1993) was used. This test consists of two parts (A and B). Part A requires a test taker to draw lines connecting consecutively numbered circles on a sheet of paper. Part B is similar but requires the test taker to connect consecutively numbered and lettered circles, alternating between the two series (e.g., connecting circle 1 to circle A to circle 2 to circle B). Measures for this test were the times taken to complete Parts A and B.

### Selective Attention

The Stroop Color-Word Test (Golden, 1978) was used to measure selective attention. There are three trials in this test. Each trial uses a different card on which five columns of 20 items are printed. In the first trial (W) a test taker is asked to read, as quickly as possible, rows of colour names (viz., red, green and blue) printed in black ink. In the second trial (C) the test taker is asked to name as quickly as possible the colour of four Xs printed on a card. Finally, in the third trial (CW), the test taker is required to name the colour of the ink in which words are printed. All words were printed in a colour conflicting with the name indicated (e.g., the word 'red' printed in green or the word 'blue' printed in red). Each trial has a time limit of 45 seconds and the measure obtained for this test was the interference score calculated using the following formula suggested by Golden:

Interference score =  $CW - CW'$  where

CW = number of items correctly named in the third trial

$CW' = \text{expected CW score} = (C \times W) / (C + W)$

W = number of items correctly read in the first trial

C = number of items correctly named in the second trial

### Shifting Attention

The Wisconsin Card Sorting Test (WCST; Heaton, 1981) was used to measure the shifting component of attention. It consists of 128 cards containing sets of geometric designs varying in colour, form and number. Four key cards are placed on the table and a test taker is asked to sort the 128 cards by matching each card to one of the four key cards. The test taker is not told which aspect of the stimulus cards to match when sorting but is given feedback following the placement of each card. Initially, the "right" criterion is colour but following 10 correct matches this criterion changes to form. Similarly, after 10 correct form matches the criterion changes to number before reverting back to colour, form, and number again. Testing terminates following the achievement of all six categories or after placement of all 128 cards. Measures obtained for this test were: (a) number of categories sorted (i.e., number of correct run of 10 sorts) and (b) percentage of perseverative errors (i.e., errors due to continual sorting based on a previously successful sorting principle).

### Wide Range Achievement Test – 3 (WRAT-3;Wilkinson, 1993)

This test was used to assess the participants' level of academic achievement. It

is suitable for children aged 5 and older and comprises three subtests: reading, spelling and arithmetic. To limit testing time, only the reading and spelling subtests were administered.

### Procedure

All participants were tested individually in a quiet room at the hospital or at the university and standardised instructions were used for all tests. The tests were administered in the following fixed order: Trail Making Test, Digit Span, Stroop Color-Word Test, WCST, and the WRAT-3. All of the clinical participants had been prescribed stimulant medication such as Ritalin or dexamphetamine as part of their treatment. Parents of these participants were asked not to administer medication to them for 24 hours prior to testing to ensure that the medication did not interfere with their performance on the tests.

### Results

To evaluate whether the three groups of participants (*viz.*, ADHD/I, ADHD/C and control) differed in performance on measures of the attention tests and on the two subtests of the WRAT-3, a number of planned comparisons using age as a covariate were conducted. The covariate was included because age has been found to be related to performance on attention tests (Seidman et al., 1997).

**Table 1. Performance of Three Groups of Participants on Measures of Four Tests of Attention and the WRAT-3 (Adjusted Means and Standard Deviations)**

| Measures            | Controls (1) |           | ADHD-I (2) |           | ADHD-C (3) |           | Planned Comparisons<br>( <i>t</i> 49) |         |        |
|---------------------|--------------|-----------|------------|-----------|------------|-----------|---------------------------------------|---------|--------|
|                     | <i>M</i>     | <i>SD</i> | <i>M</i>   | <i>SD</i> | <i>M</i>   | <i>SD</i> | 1 vs 2                                | 1 vs 3  | 2 vs 3 |
| Digits Forward      | 8.97         | 1.74      | 8.62       | 1.75      | 7.34       | 1.74      | 0.51                                  | 2.94**  | 2.04*  |
| Digits Backward     | 6.00         | 1.25      | 4.43       | 1.25      | 3.74       | 1.24      | 3.19**                                | 5.70*** | 1.53   |
| Trail Part A        | 16.71        | 6.57      | 19.58      | 6.60      | 23.32      | 6.56      | 1.11                                  | 3.17**  | 1.58   |
| Trail Part B        | 33.78        | 27.95     | 65.32      | 28.06     | 55.84      | 27.88     | 2.85**                                | 2.47*   | 0.89   |
| Stroop Interference | -1.46        | 5.37      | 0.42       | 5.39      | -2.12      | 5.35      | 0.89                                  | 0.39    | 1.31   |
| WCST no. of cat     | 4.85         | 1.71      | 3.56       | 1.71      | 4.32       | 1.70      | 1.92*                                 | 0.99    | 1.23   |
| WCST % per error    | 16.07        | 13.87     | 26.43      | 13.93     | 21.62      | 13.84     | 1.89*                                 | 1.26    | 0.96   |
| WRAT-3 reading      | 36.76        | 5.94      | 29.40      | 5.96      | 30.37      | 5.92      | 3.14**                                | 3.39*** | 0.45   |
| WRAT-3 spelling     | 30.63        | 4.66      | 25.27      | 4.68      | 25.77      | 4.65      | 2.92**                                | 3.29*** | 0.29   |

Note: \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$

Table 1 summarises the adjusted means and standard deviations for the three groups of participants on measures of attention tests, on measures of the WRAT-3, and the results of the planned comparisons. For Digits Forward and Digits Backward, age was found to be a significant covariate. Results of planned

comparisons indicated that participants in the control and the ADHD/I groups recalled significantly more number sequences than participants in the ADHD/C group on Digits Forward and that participants in the control group recalled significantly more number sequences than the two ADHD groups on Digits Backward.

For both trials of the Trail Making Test, age was found to be a significant covariate. Results of planned comparisons indicated that participants in the control group took significantly less time to complete Part A of this test than participants in the ADHD/C group and that participants in the control group took significantly less time to complete Part B than participants in the two ADHD groups.

Age was not found to be a significant covariate for the interference score of the Stroop Color-Word Test. Results of planned comparisons indicated that the three groups of participants were not significantly different on the interference score of this test.

Age was not found to be significant covariate for the two measures of the WCST. Results of planned comparisons, however, indicated that participants in the control group were able to sort significantly more categories and made significantly fewer perseverative errors than participants in the ADHD/I but not the ADHD/C group.

For the reading and spelling subtests of the WRAT-3, the age covariate was found to be statistically significant. As expected, participants in the control group were found to perform significantly better than participants in the ADHD/I and ADHD/C groups on these two subtests.

To examine the relationships between academic achievement and the four components of attention, a number of hierarchical multiple regressions were conducted. The dependent variables for the analyses were the Reading and Spelling scores of the WRAT – 3 and the independent variables were age, diagnosis (dummy coded) and eight measures of attention. The two measures for attention span and the two measures for focused attention were included in separate regression analyses because Digits Backward and Part B of the Trail Making Test assess more complex processes than Digits Forward and Part A of the Trail Making Test (Lezak, 1995). For shifting attention, percentage of perseverative errors rather than the number of categories sorted in the WCST was used as the independent variable because the latter measure is restricted in range, thus making it less suitable for regression analysis. Altogether, therefore, two sets of measures of attention (*viz.*, Digits Forward, Trail Making Test Part A, Stroop Interference Score and percentage of perseverative errors on the WCST; and Digits Backward, Trail Making Test Part B, Stroop Interference Score and percentage of perseverative errors on the WCST) were used in four multiple regression analyses. To evaluate the unique contribution of the measures of attention, age and diagnosis were entered into the regression equations first.

Table 2 summarises the results of the hierarchical regression of the first set of measures of attention on the Reading score of the WRAT – 3. After step 1, with age in the equation,  $R^2 = 0.37$ ,  $F(1, 51) = 29.61$ ,  $p < .001$ . Diagnosis was added to



**Table 3. Hierarchical Multiple Regression of Measures of Attention Tests (Set 1) on WRAT-3 Spelling Score**

| Step | Variable   | WRAT-3 Spelling | Age   | Diag1 | Diag2 | DF   | Trail A | Stroop I | WCST % per | B     | $\beta$ | $s^2$ (incremental)  |
|------|------------|-----------------|-------|-------|-------|------|---------|----------|------------|-------|---------|----------------------|
| 1    | Age        | .62             |       |       |       |      |         |          |            | 1.41  | .56***  | .38                  |
| 2    | Diag 1     | -.08            | .13   |       |       |      |         |          |            | -5.09 | -.32**  |                      |
|      | Diag 2     | -.20            | -.03  | -.50  |       |      |         |          |            | -3.55 | -.28*   | .12                  |
| 3    | DF         | .59             | .54   | .19   | -.35  |      |         |          |            | .78   | .26     |                      |
|      | Trail A    | -.49            | -.62  | -.14  | .33   | -.52 |         |          |            | -.02  | -.02    |                      |
|      | Stroop I   | -.09            | .25   | .21   | -.15  | -.03 | -.25    |          |            | -.23  | -.19    |                      |
|      | WCST % per | -.10            | -.16  | .17   | .05   | -.27 | .14     | -.10     |            | .05   | .11     | .10                  |
|      | Mean       | 27.32           | 10.53 | 0.21  | 0.49  | 8.10 | 20.56   | -1.47    | Intercept  | 7.95  |         |                      |
|      | SD         | 6.49            | 2.60  | 0.41  | 0.51  | 2.18 | 8.91    | 5.44     | 20.87      | 14.11 |         |                      |
|      |            |                 |       |       |       |      |         |          |            |       |         | $R^2 = .60$          |
|      |            |                 |       |       |       |      |         |          |            |       |         | Adjusted $R^2 = .53$ |
|      |            |                 |       |       |       |      |         |          |            |       |         | $R = .77$            |

Note: \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$



**Table 5. Hierarchical Multiple Regression of Measures of Attention Tests (Set 2) on WRAT-3 Spelling Score**

| Step | Variable   | WRAT-3 Spelling | Age   | Diag1 | Diag2 | DB   | Trail B | Stroop I | WCST % per | B     | $\beta$     |
|------|------------|-----------------|-------|-------|-------|------|---------|----------|------------|-------|-------------|
| 1    | Age        | .62             |       |       |       |      |         |          |            | 1.44  | .58***      |
| 2    | Diag 1     | -.08            | .13   |       |       |      |         |          |            | -2.38 | -.15        |
|      | Diag 2     | -.20            | -.03  | -.50  |       |      |         |          |            | -.59  | -.05        |
| 3    | DB         | .60             | .25   | -.01  | -.52  |      |         |          |            | 1.91  | .47***      |
|      | Trail B    | -.42            | -.53  | .14   | .15   | -.33 |         |          |            | -.01  | -.04        |
|      | Stroop I   | -.09            | .25   | .21   | -.15  | -.02 | -.34    |          |            | -.26  | -.22*       |
|      | WCST % per | -.10            | -.16  | .17   | .05   | -.32 | .22     | -.10     |            | -.07  | .16         |
|      | Mean       | 27.32           | 10.53 | 0.21  | 0.49  | 4.56 | 51.22   | -1.47    | Intercept  | 20.87 | 2.67        |
|      | SD         | 6.49            | 2.60  | 0.41  | 0.51  | 1.61 | 34.80   | 5.44     |            | 14.11 |             |
|      |            |                 |       |       |       |      |         |          | Adjusted   |       | $R^2 = .68$ |
|      |            |                 |       |       |       |      |         |          |            |       | $R^2 = .63$ |
|      |            |                 |       |       |       |      |         |          |            |       | $R = .82$   |

Note: \*  $p < .05$ , \*\*\*  $p < .001$

the equation in step 2. After this step,  $R^2 = .51$ ,  $F(3, 49) = 17.00$ ,  $p < .001$  and  $R^2$  change = .14,  $F$  for change (2, 49) = 7.14,  $p < .01$ . Four measures of attention were added to the equation in step 3. After this step,  $R^2 = .77$ ,  $F(7, 45) = 9.21$ ,  $p < .001$ . The  $R^2$  change for the last step was .08 and was not statistically significant,  $F$  for change (4, 45) = 2.16,  $p > .05$ .

Table 3 summarises the results of the hierarchical regression of the second set of measures of attention on the Spelling score of the WRAT – 3. After step 1, with age in the equation,  $R^2 = 0.38$ ,  $F(1, 51) = 31.09$ ,  $p < .001$ . After diagnosis was added to the equation,  $R^2 = .49$ ,  $F(3, 49) = 15.92$ ,  $p < .001$  and  $R^2$  change = .12,  $F$  for change (2, 49) = 5.56,  $p < .01$ . After the four measures of attention were added to the equation in step 3,  $R^2 = .77$ ,  $F(7, 45) = 9.43$ ,  $p < .001$ . The  $R^2$  change for step 3 was .10 and  $F$  for change (4, 45) = 2.81,  $p < .05$ . From Table 3, it can be seen that Digits Forward was an important predictor of the WRAT – 3 Spelling score,  $\beta = .26$ ,  $p = .06$ .

Table 4 summarises the results of the hierarchical regression of the second set of measures of attention on the Reading score of the WRAT – 3. After step 1, with age in the equation,  $R^2 = 0.37$ ,  $F(1, 51) = 29.61$ ,  $p < .001$ . Diagnosis was added to the equation in step 2. After this step,  $R^2 = .51$ ,  $F(3, 49) = 17.00$ ,  $p < .001$  and  $R^2$  change = .14,  $F$  for change (2, 49) = 7.14,  $p < .01$ . Four measures of attention were added to the equation in step 3. After this step,  $R^2 = .77$ ,  $F(7, 45) = 9.61$ ,  $p < .001$ . The  $R^2$  change for the last step was .09 and was close to being statistically significant,  $F$  for change (4, 45) = 2.51,  $p = .055$ . From Table 2, it can be seen that Digits Backward was an important predictor of the WRAT – 3 Reading score,  $\beta = .30$ ,  $p < .05$ .

Table 5 summarises the results of the hierarchical regression of the second set of measures of attention on the Spelling score of the WRAT – 3. After step 1, with age in the equation,  $R^2 = 0.38$ ,  $F(1, 51) = 31.09$ ,  $p < .001$ . After diagnosis was added to the equation,  $R^2 = .49$ ,  $F(3, 49) = 15.92$ ,  $p < .001$  and  $R^2$  change = .12,  $F$  for change (2, 49) = 5.56,  $p < .01$ . After the four measures of attention were added to the equation in step 3,  $R^2 = .68$ ,  $F(7, 45) = 13.51$ ,  $p < .001$ . The  $R^2$  change for step 3 was .18 and  $F$  for change (4, 45) = 6.42,  $p < .001$ . From Table 3, it can be seen that Digits Backward, and the Stroop interference score were important predictors of the WRAT – 3 Spelling score,  $\beta = .47$  and  $-.22$ ,  $p < .001$  and  $.05$ .

## Discussion

The primary aim of the study was to investigate the nature and extent of attentional deficits in children with two different types of ADHD by adopting a contemporary model of attention (Shum et al., 1990; Mirsky, 1987). It was expected that children with the two ADHD subtypes and controls would differ in performance on measures of four components of attention, namely, attention span, focused attention, selective attention and shifting attention.

Attention span was assessed using the Digit Span subtest from the WISC-III. Participants in the control and ADHD/I groups were found to perform significantly better than participants in the ADHD/C group on Digits Forward. On Digits Backward, participants in the control group were found to perform

significantly better than participants in the ADHD/C and ADHD/I groups. As mentioned in the Introduction, children with ADHD (all subtypes grouped together) have been found to be impaired on attention span (Assemany et al., 2001; Karatekin & Asarnow, 1998) but prior to the present work no study had reported whether ADHD subtypes are differentially impaired on this component of attention. Compared to Digits Forward, Digits Backward is a more complex and demanding task in that examinees are required not only to attend to and repeat the stimuli presented but also manipulate them (Lezak, 1995). While the inferior parietal lobule mediates the former, the prefrontal lobe mediates the latter. The results of the present study, therefore, suggest that the two subtypes of ADHD might have different aetiological bases.

In the present study, focused attention was assessed using the Trail Making Test. On Part A of this test, participants in the control group were found to perform significantly better than participants in the ADHD/C group. On Part B, participants in the control group were found to perform significantly better than participants in both the ADHD/C and ADHD/I groups. A number of previous studies have found that children with ADHD (all subtypes grouped together) are impaired on focused attention as measured by the Trail Making Test (Grodzinky & Diamond, 1992; Shue & Douglas, 1992). Results regarding whether ADHD subtypes are differentially impaired on this component, however, are mixed. Compared to Part A, Part B of this test is more demanding because, in addition to visuo-motor scanning, it involves monitoring and switching between two sequences (numbers and letters). While Part A is mediated by the superior temporal and inferior parietal cortices and structures that make up the corpus striatum, Part B is mediated by the prefrontal lobe. Again, results of the present study suggest that the two subtypes of ADHD might have different aetiological basis.

Selective attention was assessed using the interference score of the Stroop Colour-Word Interference Test in this study. Participants in the two ADHD groups were not found to score significantly more poorly than participants in the control group on this test. This suggests that children with ADHD are not impaired on selective attention and that the neuroanatomical area associated with this function (*viz.*, the cingulate gyrus) is not likely to be dysfunctional in these children. This finding is consistent with those reported by most previous studies that used the Stroop Colour-Word Interference Test (Houghton et al., 1999; Nigg et al., 2002).

The WCST was used in this study to assess shifting attention. Participants in the control group were found to perform significantly better than participants in the ADHD/I but not the ADHD/C group on the two measures of the WCST. These results suggest that one subtype of ADHD (*viz.*, the ADHD/I) shows a problem in the shifting component of attention. As mentioned in the Introduction, children with ADHD (all subtypes grouped together) have been found to be impaired on this component as measured by the WCST, but evidence for a different pattern of impairment among the subtypes is unclear. Results obtained in this study also suggest that this problem in the ADHD/I subtype

might be due to abnormality in the area (*viz.*, the prefrontal lobe) that mediates this component of attention.

Taken together, results support the hypothesis that the two ADHD subtypes included in this study show different patterns of attentional problems. Among the four components of attention, the two ADHD subtypes were found to show deficits on three of them, namely, attention span, focused attention and shifting of attention. Whereas the ADHD/C subtype was found to show deficits in attention span and focused attention, the ADHD/I subtype was found to show deficits in shifting attention and more subtle deficits in attention span and focused attention. The finding that different subtypes of ADHD show patterns of differential impairment on components of attention is important. This is because, as mentioned in the Introduction, few studies in the literature have attempted to examine attention deficits in ADHD subtypes by adopting a contemporary model and utilising representative psychological measures for all the main components of attention. Results obtained in this study, therefore, provide evidence to clarify results of other studies that examined the nature and extent of attention problems in different subtypes. Furthermore, patterns of differential impairment shown by ADHD subtypes suggest that the two subtypes included in this study (*viz.*, ADHD-I and ADHD-C) might be discrete disorders with distinct aetiologies, different prognoses, and treatment requirements. Results of the present study indicate that the type of attention problems shown by children with ADHD/C is commonly associated with damage to structures of the posterior cortex (*viz.*, the temporal and parietal lobe) but the problems shown by children with ADHD/I is typically associated with damage to structure of the anterior cortex (*viz.*, the prefrontal lobe).

A second aim of this study was to examine the relationships between academic achievement and attention. It was found that measures of attention significantly contribute to prediction of reading and spelling ability in children, after controlling for age and diagnosis. In addition, measures of attention span (especially Digits Backward) was found to be an important predictor of reading and measures of attention span (especially Digits Backward) and selective attention were found to be important predictors of spelling. Whereas significant relationships between academic skills (*e.g.*, reading and spelling) and attention span have been reported in a study that included both children with ADHD and children with reading disability (Kroese, Hynd, Knight, Hiemenz, & Hall, 2000), the significant relationship between spelling and selective attention is a new finding. The former relationship is likely to be due to the fact that, during reading and spelling, children are required to hold and manipulate a number of letters of the alphabet or words in their attention span. The latter relationship is likely to be due to the fact that during spelling children are required to select the letters of the alphabet for a word (in correct order) from an array of competing letters.

As mentioned in the Introduction, it has been suggested that poor academic problems found in children with ADHD might be linked to their problems of attention. However, few studies have directly investigated these relationships. By

showing that academic achievement in reading and spelling is related to attention span and selective attention, results of this study corroborate the importance of attentional processes in academic skills. Knowing these relationships would enable clinicians who work with these children to better understand the nature of their academic problems and to develop treatment procedures to deal with these problems. However, replication is needed to establish these relationships and it is important to extend them by including other measures of academic achievement such as arithmetic, reading comprehension, and writing.

The present study was limited by the size of the samples (particularly the ADHD/I group) and a reliance on the Conner's Parent Questionnaire to classify the children into ADHD subtypes. Replication of these findings, preferably with larger samples and a more equal gender distribution within the sample, is necessary before they can be generalised. In addition, future research should employ a more comprehensive assessment, (e.g., including clinical interviews, parent and teacher ratings, and direct behavioural observation) to determine which subtype a participant with ADHD best represents.

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