Motor imagery skills of children with Attention Deficit Hyperactivity Disorder and Developmental Coordination Disorder

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Abstract

Up to 50% of children with ADHD experience motor impairment consistent with DCD. Debate continues as to whether this impairment is linked to inattention or is a genuine motor deficit. This study aimed to determine whether 1) inattention was greater in ADHD+DCD than in ADHD alone and 2) motor imagery deficits observed in DCD were present in ADHD+DCD. Four groups aged 7-12 years – ADHD, combined type, with motor impairment (ADHD+DCD; N = 16) and alone (ADHD; N = 14), DCD (N = 10) and typically developing comparison children (N = 18) participated. Levels of inattention did not differ between ADHD groups. On an imagined pointing task, children with DCD did not conform to speed accuracy trade-offs during imagined movements, but all other groups did. However, on a hand rotation task, both the ADHD+DCD and DCD groups were less accurate than the non-motor impaired groups, a finding not explained by differences in IQ, age, or working memory capacity. Overall, there was evidence that children with ADHD+DCD experience genuine motor control impairments indicating the impact of motor impairment in ADHD and its causal risk factors require more study. Motor impairment in ADHD should not be dismissed as a by-product of inattention.

Keywords: Attention Deficit-Hyperactivity Disorder; Developmental Coordination Disorder; Motor imagery

1.0 Introduction

Attention-Deficit Hyperactivity Disorder (ADHD) occurs in up to 12% of children, has a negative impact on social, behavioural and educational domains, and many of its symptoms are now believed to persist into adulthood (Biederman & Faraone, 2005). As a result, ADHD has been studied extensively and we know much about the presentation of the disorder. One interesting finding regarding ADHD is its high comorbidity or co-occurrence with other developmental disorders in childhood, including Developmental Coordination Disorder (DCD) (Dewey, Kaplan, Crawford, & Wilson, 2002). DCD is defined by the American Psychiatric Association (APA) as an impairment in motor skills, not attributable to a known neurological or physical medical condition, that significantly interferes with a child’s activities of daily living and/or academic achievement (APA, 1994). DCD, or motor impairment, is commonly observed in a large proportion of children with ADHD. Pitcher, Piek and Hay (2003) found that approximately 50% of a sample of children with ADHD, regardless of subtype, had definite or borderline motor impairment. In an earlier study, the same authors had found approximately two-thirds of their ADHD sample was experiencing motor problems (Piek, Pitcher, & Hay, 1999). Despite research showing that children with both ADHD and DCD are likely to experience more long-term negative outcomes in a range of domains than children with either disorder alone (Rasmussen & Gillberg, 2000; Tervo, Azuma, Fogas, & Fiechtner, 2002), DCD in children with ADHD is often overlooked in the clinical context as more prominent behavioural issues involving impulsivity and hyperactivity overshadow the motor issues (Gillberg, 2003).

Although the motor impairment observed in both ADHD and DCD appears to be similar, it is not clear if they stem from the same underlying aetiological risk factors (Sergeant, Piek, & Oosterlaan, 2006). Some researchers argue that the motor impairment present in ADHD is a result of the child’s increased inattentiveness and working memory deficits rather than being a genuine motor deficit (Barnett, Maruff, & Vance, 2005; Ferrin & Vance, 2011). Indeed, the American Psychiatric Association, in the 4th edition of their Diagnostic and Statistical Manual (DSM-IV, APA, 1994), suggests that the motor difficulties of children with ADHD are “usually due to distractibility and impulsiveness, rather than to motor impairment” (pp. 54) in the differential diagnosis section for DCD. Support for this comes from studies that have demonstrated a link between the severity of inattentiveness and motor impairment (Piek et al., 1999; Tseng, Henderson, Chow, & Yao, 2004); research showing that children with ADHD on stimulant medication do not display the same response time slowing that is apparent in those not on medication (Klimkeit, Mattingley, Sheppard, Lee, & Bradshaw, 2005); and recent research showing that neurological soft signs, including those involving fine motor movements, are related to spatial working memory deficits (Ferrin & Vance, 2011).

In contrast, other studies support the presence of a genuine motor deficit in children with ADHD+DCD, unrelated to inattentive symptomatology. Pitcher, Piek and Hay (2003) found that an ADHD+DCD group was significantly more impaired on a manual dexterity task than both ADHD only and control groups, who did not differ. Interestingly, there were no significant differences in the inattentive symptomatology of the two ADHD groups, indicating that the poor manual dexterity of the ADHD + DCD group could not be attributed to increased inattentiveness. Miyahara, Piek and Barrett (2006) used distractor tasks to determine whether an increased attentional load would result in poorer motor performance in children with ADHD, but found that there was no decrease in performance as attentional demands increased. Due to these conflicting findings, it remains unclear whether the motor impairment observed in ADHD stems from the same underlying causal risk factors as that in DCD – this is confounded by the fact that we do not yet know exactly what is causing DCD itself, with researchers continuing to search for underlying deficits that are likely to play a causal role in the disorder (Wilson, 2005).

One line of research has demonstrated consistently that children with DCD have a reduced ability to accurately represent movements in the brain via motor imagery (Deconinck, Spitaels, Fias, & Lenoir, 2009; Maruff, Wilson, Trebilcock, & Currie, 1999; Williams, Thomas, Maruff, Butson, & Wilson, 2006; Williams, Thomas, Maruff, & Wilson, 2008; Wilson et al., 2004; Wilson, Maruff, Ives, & Currie, 2001). Motor imagery (MI) refers to the imagination of a motor task without actual movement execution (Decety & Grèzes, 2006) and is believed to represent one's ability to accurately utilise forward internal models of motor control (Sirigu et al., 1996; Williams et al., 2006; Wilson et al., 2004; Wolpert, Goodbody, & Husain, 1998). Forward internal models provide stability to motor systems, by predicting the outcome of movements before slow, sensorimotor feedback becomes available (Wolpert, 1997). They are important for smooth, accurate movement, reducing the reliance on feedback and allowing corrections to the movement to be made as it unfolds when necessary. A deficit in the ability to utilise such models results in slow, poorly coordinated movements and as such, has been hypothesised to be one of the underlying causes of motor impairment in DCD (Wilson et al., 2004; Wilson et al., 2001).

A recent study examined the motor imagery ability of children with ADHD, combined type (ADHD-C) parsed into those with and without comorbid DCD, and compared them to a sample of children with DCD only and a sample of healthy control participants (Lewis, Vance, Maruff, Wilson, & Cairney, 2008). The study used a test of motor imagery that requires participants to complete a series of real and imagined pointing movements between targets that vary in size – typically, a speed-accuracy trade-off is found in both real and imagined movements, indicating that motor imagery adheres to the same motor control laws as actual movement (Sirigu et al., 1996). It was found that, as in previous studies, the

DCD group did not conform to the speed-accuracy trade-off for the task during their imagined movements, indicating atypical motor imagery performance. In contrast, both the healthy controls and ADHD only group performed typically. Interestingly, the performance of the ADHD+DCD group also conformed to the typically observed pattern, with the group displaying no apparent deficits in motor imagery ability. This is the first study to look at underlying motor control processes in children with ADHD and suggests that the motor impairment present in many children with ADHD might not have the same underlying aetiology as that of children with DCD alone. The authors concluded that the motor impairment often observed in ADHD may stem from executive and attentional control problems, but did not include a measure of either in their study.

The aim of the current study is to extend the work of Lewis et al. (2008) by including 1) measures of attention, and for the ADHD groups, working memory and 2) extending the motor imagery analysis by using another task commonly used with children with DCD – the hand rotation task (Deconinck et al., 2009; Williams et al., 2011; Williams et al., 2006; Williams et al., 2008; Wilson et al., 2004). Although correlations have been identified between attention and motor skills in children with ADHD (Tseng et al., 2004), direct comparisons of attention in ADHD alone versus ADHD+DCD groups have failed to identify group differences (Pitcher et al., 2003). Based on this, we did not expect to find a significant difference between our two ADHD groups on measures of attention, but expected both groups to be significantly more inattentive than the DCD and comparison groups. Based on the recent findings regarding a relationship between working memory and neurological soft signs in children with ADHD (Ferrin & Vance, 2011), we did expect to find that children with ADHD+DCD would score more poorly than children with ADHD alone on measures of working memory. Interestingly, motor imagery has long been recognised as having a working memory component (Decety, 1996), though some tasks have a greater working memory load than others – for example, the hand rotation task requires images of the hand (either the stimulus or the participant's own) to be held in working memory during imagined rotation. Thus, we expected that, in line with Lewis et al. (2008), children with ADHD+DCD would perform similarly to children with ADHD alone and typically developing comparison children on the visually guided pointing task. In the hand rotation task however, with its greater working memory load, we would expect children with ADHD+DCD, like those with DCD alone, to be slower and / or less accurate than children with ADHD alone and typically developing comparison children.

2.0 Method

2.1 Participants

Sixty-nine children (43 males), aged 7-12 years, were recruited to participate in this study. All children, regardless of group, were screened to ensure they did not have any physical or neurological condition that could contribute to motor impairment (e.g. cerebral palsy, Tourette's syndrome) and all were assessed to have an estimated IQ of more than 70 using the two-subtest version of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999).

Children with ADHD-C were recruited through the Academic Child Psychiatry Unit (ACPU) at the Royal Children's Hospital, Melbourne. The ACPU patient database identified children previously diagnosed with ADHD-C who had attended the hospital within the previous two years. Diagnosis of ADHD-C was based on: (a) the DSM-IV (b) a semi-structured clinical interview with the child's parents (c) by the parent and/or teacher report of subscale scores of the core symptom domains of ADHD being greater than 1.5 standard deviations above the mean for a given child's age and gender. Contact was made with 92 families to invite them to participate, of which 32 agreed. Of those that did not, reasons for non-participation included lack of interest, too many other demands on the child and having to travel too far. Of the 32 children, only four were currently taking medication for their ADHD (short-acting stimulant medication in all cases). The parents of these children were asked to withhold medication for 48 hours prior to their assessment. ADHD-C subgroups (ADHD and ADHD+DCD) were formed on the basis of scores on the Movement Assessment Battery for Children 2nd edition (Movement ABC-2; Henderson & Sugden, 2007) – children scoring on or below the 15th percentile for the total score formed the ADHD+DCD group (DCD diagnostic criterion A - DSM-IV-TR; APA, 2000); those scoring on or above the 20th percentile formed the ADHD group; those scoring on or between the 16th and 24th percentiles were excluded. Medical records confirmed that motor impairment was not the result of a medical condition or mental retardation (DCD diagnostic criterion C & D). DCD diagnostic criterion B, that motor impairment should impact on academic achievement and/or activities of daily living was not assessed in this group – deconstructing the impact of ADHD versus DCD on either area would be extremely difficult and there is no current measure to adequately assess this.

Children with DCD were recruited through advertisements provided to paediatric occupational therapists and in local school newsletters. Interested families were asked to contact the research team, who screened the children to exclude those with a diagnosis of ADHD (all subtypes). As recruitment advertisements for the study stated that children with ADHD were ineligible to participate, only two children were actually excluded on this basis. Individual assessments were organised for 15 eligible children, with those scoring on or below the 15th percentile on the Movement ABC-2 forming the DCD group (DCD diagnostic criterion A). DCD diagnostic criterion B was met implicitly, with children either currently involved in therapy (which would not be necessary if their motor impairment was not impacting their daily living activities and/or academic achievement) or through parent report when contacting researchers. Parent reports were used to confirm compliance with diagnostic criterions C and D.

Children from a local primary school in Melbourne were invited to form the typically developing comparison group. Parents of 23 children agreed to participate and completed a screening questionnaire to rule out the presence of ADHD (all subtypes) and / or DCD. One child was excluded due to a previous diagnosis of dyspraxia, leaving a sample of 22, who were assessed using the Movement ABC-2 and included in the comparison group if they scored on or above the 25th percentile.

2.2 Measures

2.2.1 TEA-Ch Score!

The Test of Everyday Attention for Children (TEA-Ch) is a battery of nine game-like tests that assess attention in children aged 6-16 years (Manly, Robertson, Anderson, & Nimmo-Smith, 1999). We included the 'Score!' subset only, which tests a child's capacity to sustain attention over ten trials by keeping count of computer generated beeps. This was used to gain a measure of attention on the day. The number of correct trials was converted to age-standardised scores, with the M = 10 and SD = 3.

2.2.2 Conners' Rating Scale – Revised

The long form of the Conners' Parent Rating Scale – 3rd edition (Conners, 2007) was used to measure ADHD-related symptoms, including inattention and hyperactivity. Parents responded to eighty questions relating to attention, hyperactivity and cognitive problems. T-scores are obtained for each domain, with T-scores between 60 and 69 considered elevated above average and 70 or above very elevated.

2.2.3 Visually guided pointing task (VGPT).

In line with Lewis et al. (2008), the VGPT, first used by Sirigu et al. (1996) was used to examine the relationship between participants' real and imagined movements. Participants were presented with five individual sheets of laminated paper. Each sheet had an 80mm vertical line, as well as a target box with its closest edge 30mm from the vertical line (see Figure 1). The width of the target box varied on each of the five plastic sheets (1.9, 3.7, 7.5, 14.9, or 30mm). Participants were asked to make pointing movements between the vertical line and the target box five times, as quickly and accurately possible. One pointing movement was defined as a hand motion beginning from the far side of the vertical line to touch the inside of the target box and back to the far side of the vertical line. Participants made five of these back and forth movements for each trial (2 trials per target size) of each width using their preferred hand.

Participants were required to complete this task under two movement conditions: 'real' and 'imagined' conditions. The 'real' condition involved making actual hand movements between the line and target box using a pen. The 'imagined' condition required participants to imagine they were performing the same movements as in the 'real' condition, but without making any overt hand movements. The 'imagined' trials always followed the 'real' trials, and the order of the targets presented was counterbalanced across participants.

A stop watch was used to record the duration of participants' hand movements for each trial. Timing of each trial began when then examiner said "Go" and ended when the participant said "Stop" once they completed the actual or imagined movements. If the participant lost count of the number of movements completed or lost concentration during a trial, it was repeated immediately by the examiner.

2.2.4 Hand rotation task.

Single hand stimuli (9cm by 8cm) were presented on a laptop computer using E-Prime software (Psychology Software Tools, Pittsburgh, PA, USA). The left and right hands were represented as high-resolution images presented in the back view (see Figure 2), centred in the middle of the screen. Before commencing, researchers showed the participants example pictures of the hands, explaining how they would appear on the screen in rotated positions. They were asked to decide as quickly and accurately as possible whether the hand was left or right and to imagine their own hand in the position of the hand on the screen to help them decide. They sat resting their left index finger on the D key and right index finger on the K key, which were marked with stickers as a reminder. Stimulus hands were presented randomly, in 45° increments between 0-360°, and remained on screen until a response was recorded by pressing the designated key (D for left; K for right) on the keyboard or 10s had passed. There were five practice trials and 40 test trials (four at each angular increment), each followed by a random delay of 2-3s. Responses were recorded to the nearest 1ms.

2.2.5 Working memory.

Children with ADHD had previously completed the Cambridge Neuropsychological Test Automated Battery (CANTAB; Owen, Downes, Sahakian, Polkey, & Robbins, 1990) as a part of their clinical evaluation. The computerised tests are presented on a high resolution IBM monitor with a touch sensitive screen. We utilised data from two of the subtests to compare the working memory capacity of our two ADHD groups (with and without DCD) – the spatial span and spatial working memory tasks. The *Spatial Span* task is a computerised version of the Corsi block-tapping task, requiring participants to remember a sequence of squares presented on the screen, and assesses visuospatial short-term memory capacity (Milner, 1971). Spatial (short-term memory) span is calculated as the highest level at which the participant successfully remembered at least one sequence of boxes (maximum = 9). The *Spatial Working Memory* task is a self-ordered searching task measuring working memory for spatial stimuli. It requires participants to use mnemonic information to work towards a goal. Returning to an ‘empty’ box already targeted for a particular search constituted a between-search error, with the number of errors in each trial totalled and summed to provide an overall BSE-total score (SWM-BSE). A strategy score was also calculated to reflect how often a searching sequence was initiated from the same box during a trial (SWM-Strategy; range 1-37). Finally, total time to complete the task at each level (from levels 4-8) was recorded (SWM-Time 4-8). More detailed explanations and test demonstrations can be found at www.cambridgecognition.com/cantab-tests.

2.3 Procedure

The study was approved by the Human Research Ethics Committee of the Royal Children's Hospital, Melbourne. A parent or guardian of all participating children provided written, informed consent. All assessments were carried out on an individual basis by trained research staff and occurred at the Royal Children's Hospital or at the child's school. Tasks were completed in an order which was counter-balanced across participants. All children taking stimulant medication for their ADHD underwent a 24-hour washout period prior to their assessment.

2.4 Data Analysis

All analyses were conducted using SPSS Version 17. Group means for descriptive variables were calculated and group comparisons were made using univariate ANOVA with a Bonferroni adjusted critical value for significance of $p = .008$. A chi-square analysis was conducted to identify differences in the gender make-up of the groups. Post-hoc tests were conducted using Tukey's HSD procedure. Descriptive measures were correlated with motor imagery measures (VGPT real and imagined slope and Fisher's z transformation of the correlation between real and imagined movements; hand task response time and accuracy) to isolate potential covariates for inclusion in further analysis. Descriptive measures were included as covariates if they were determined to correlate with imagery measures at a value of $r = .3$ or greater.

To analyse performance on the VGPT, each participants' mean movement duration was calculated for each target width in each movement condition. To determine whether a speed-accuracy trade-off existed in real and imagined movements for each group, group means for movement duration were calculated and plotted against target width for "real" and "imagined" conditions. Logarithmic curves were then fitted to the data points and goodness of fit was determined using a least squares regression. Regression estimates and fit (R^2) were calculated for each group individually.

In line with Lewis et al. (2008), we used Fitts' law to convert the logarithmic relationship between target width and movement amplitude to the linear relationship between movement duration and index of difficulty using the formula:

$$\text{Index of difficulty} = \text{Log}_2(2A/W)$$

where A is movement amplitude (constant) and W is the width of the target. Using this, we calculated the slope of the linear relationship between movement duration and index of difficulty for real and imagined movements for each participant and submitted group means to a 4 (group) x 2 (condition) repeated-measures ANOVA. The multivariate approach to repeated-measures ANOVA was used throughout to protect against violations to the assumption of sphericity. Effect size was calculated using partial eta squared (η_p^2) and pairwise comparisons of estimated marginal means were used to follow-up significant findings.

To determine whether group differences existed in regard to the similarity of real and imagined movement times, and in line with Caeyenberghs et al. (2009), we calculated the Pearson's product moment correlation coefficient and effect size R^2 for each participant's real and imagined movement times across target widths. The resultant correlation was transformed using the Fisher-z transformation and submitted to a univariate ANOVA to determine whether there were differences in this relationship between the four groups.

For the hand task, anticipatory responses (less than 250ms) were removed prior to mean response times (RT) and accuracy (proportion correct) being calculated for each participant at each angle of rotation. To determine whether groups conformed to biomechanical limitations of the task, responses to medially (e.g. right hand at 270°; left hand at 45°) versus laterally (e.g. left hand at 270°; right hand at 45°) rotated hands were examined. Mean response time (RT) and accuracy were calculated for each group in each direction and submitted to two 4 (group) x 2 (direction) repeated-measures ANOVA. The critical value for significance was adjusted to $p = .025$.

To analyse RT and accuracy overall, a commonly used technique in mental rotation studies to increase reliability of estimates by increasing the number of trials at each angle was employed (see, for example, Harris et al., 2000; Roelofs, van Galen, Keijsers, & Hoogduin, 2002). This involved combining data from the same angular rotation, regardless of direction. For example, responses to stimuli at 90° and 270° were combined as both were 90° from the upright. This provided four trials at each of five angles (0° - 180°) for each hand (left/right). A repeated measures ANOVA was conducted to determine group differences in response time across angles, with the multivariate approach to ANOVA used to protect against violations of sphericity. Mean accuracy across angles was also calculated for each participant and again submitted to a univariate ANOVA. For both tests, the critical value for significance was adjusted to $p = .025$.

Group means for the spatial span and spatial working memory task variables were calculated for the two ADHD groups and submitted to a MANOVA. As variables are not standardised, age was included as a covariate. Multivariate and univariate effects for group were examined and significant univariate effects were followed up using pairwise comparisons of estimated marginal means with Bonferroni adjustments. Variables that were identified as differing significantly between groups were included as covariates in follow-up univariate ANOVAs involving imagery variables where the two ADHD groups had differed significantly.

3.0 Results

Of the 69 children who were assessed, 11 were excluded on the basis of their Movement ABC-2 scores - five children recruited as part of the DCD group were excluded after scoring on or above the 16th percentile and in keeping with our exclusion of children scoring on or between the 16th and 24th percentiles, four children recruited as comparisons and two children with ADHD were excluded. Final group numbers, as well as descriptive data for the groups, can be found in Table 1. Significant differences in group means were identified on a number of variables (see Table 1), but importantly, there were no significant differences between the two ADHD groups on the Inattention t-score from the Conners' scale or the standard score for the TEA-Ch Score! task. The differences among groups on Movement ABC scores were not caused by differences in IQ, which did not alter ANOVA results when added as a covariate ($p < .001$). Correlations between descriptive and motor imagery variables identified potential covariates. Age was moderately correlated with mean accuracy on the hand rotation task ($r = .42$, $p = .001$), as was IQ ($r = .44$, $p = .001$). IQ and TEA-Ch Score! were moderately correlated with the Fishers z transformation of the VGPT correlation between real and imagined movements ($r = .35$, $p = .01$ and $r = .30$, $p = .023$ respectively).

3.1 Visually Guided Pointing Task (VGPT).

In all groups, the relationship between real movement duration and target width was described well by a logarithmic function, with R^2 values all above .90 (Table 2). The logarithmic function also provided a good fit for the imagined movements of the ADHD and comparison groups, and in line with Lewis et al. (Lewis et al., 2008), the ADHD+DCD group. In contrast, and in line with previous research (Lewis et al., 2008; Maruff et al., 1999; Wilson et al., 2001), the logarithmic function did not provide a good fit for the relationship between imagined movement duration and target width for the DCD group.

Table 2 indicates that for all groups, the slope of the line fitted to the relationship between index of difficulty and movement duration was greater in the real movement condition compared to the imagined condition. This was supported by the results of the ANOVA, which identified a significant effect for condition, Wilks' $\Lambda = .27$, $F(1,53) = 146.98$, $p < .001$, $\eta_p^2 = .74$. The lower values for slope in both real and imagined conditions for the DCD group did not result in a significant interaction effect between condition and group, or a significant group effect (both $p > .05$).

Both IQ and TEA-Ch Score! were included as covariates in the ANOVA comparing the four groups' transformed real:imagined movement correlation, but were removed from analysis after it was determined that neither had a significant effect ($p = .093$ and .20 respectively). Although ANOVA did not identify a significant group effect for the relationship between real and imagined movement times, $F(3,53) = 1.10$, $p = .36$, $\eta_p^2 = .06$, the effect sizes demonstrate that the proportion of variation that can be predicted from the relationship between real and imagined movements was considerably greater in the two non-motor impaired groups (ADHD and comparison). The effect size was lowest in the ADHD+DCD group, explaining only 29% of the variance, compared to 47% and 57% for the ADHD and comparison groups respectively.

3.2 Hand Rotation Task.

Figure 3 shows the group means for response time and accuracy to medially and laterally rotated hands separately. For response time, the DCD group were the only group not to respond faster to medially rotated hands compared to hands rotated laterally. There was a significant effect for condition, Wilks' $\Lambda = .77$, $F\ (1,52) = 15.73$, $p < .001$, $\eta_p^2 = .23$, but the interaction between group and direction did not reach significance ($p = .084$). All groups were more accurate when responding to medially rotated hands, but ANOVA did not identify a significant effect for condition ($p = .16$) nor an interaction between group and condition ($p = .98$). Group effects for RT and accuracy are described below.

Mean RT and accuracy at each angle of rotation can be viewed in Figures 4 and 5 respectively. Repeated measures ANOVA identified a significant effect of angle on RT, with RT increasing in line with the angular orientation of the stimulus hand, Wilks' $\Lambda = .402$, $F(4,49) = 18.24$, $p < .001$, $\eta_p^2 = .60$. However, there were no group differences identified ($p = .75$), nor any interaction between group and angle ($p = .46$).

Both IQ and age were included as covariates in the ANOVA comparing the four groups' mean accuracy scores, but were removed from analysis after it was determined that neither had a significant effect ($p = .108$ and .114 respectively). Mean accuracy across all angles for each group was 0.92 (SD = .08) for the ADHD group, 0.70 (SD = .20) for the ADHD+DCD group, 0.68 (SD = .10) for the DCD group and 0.86 (SD = .13) for the comparison group. There was a significant effect for group, $F\ (3,52) = 10.09$, $p < .001$, $\eta_p^2 = .37$, with the ADHD group more accurate than the ADHD+DCD and DCD groups (both $p < .001$). The comparison group was also more accurate than both motor impaired groups ($p = .008$ and .007 for the ADHD+DCD and DCD groups respectively). Neither the ADHD and comparison groups, nor the ADHD+DCD and DCD groups, differed from each other (all $p > .05$).

3.3 Working Memory.

Age adjusted means for the working memory variables can be found in Table 3. MANOVA failed to identify a significant multivariate group effect, Wilks' Λ = .73, *F* (6,21) = 1.33, $p = .29$, $\eta_p^2 = .28$. As shown in Table 3, univariate analysis showed that the ADHD+DCD group were slower to complete the spatial working memory task than the ADHD group at the two highest levels - SWM-Time 6 and SWM-Time 8, *F* (1,26) = 4.38, $p = .046$, $\eta_p^2 = .14$ and *F* (1,26) = 4.76, $p = .038$, $\eta_p^2 = .16$ respectively. No other univariate differences were identified (all $p > .05$). As a significant difference between the two ADHD groups had been identified on the total mean score for the hand rotation task, a follow-up univariate ANOVA was conducted using SWM-Time 6 and SWM-Time 8 as covariates to determine whether this difference in accuracy remained after taking working memory into account. Results demonstrated that the ADHD+DCD remained significantly less accurate than the ADHD group after accounting for working memory, *F* (1,24) = 12.59, $p = .002$, $\eta_p^2 = .34$.

4.0 Discussion

The aim of this study was to examine in detail the motor imagery ability of children with ADHD+DCD, extending the work of Lewis et al. (2008) to determine whether 1) inattention was greater in ADHD+DCD alone and 2) whether motor imagery deficits observed in DCD were present in ADHD+DCD. Firstly, our results did not support the theory that motor skill deficits in ADHD are related to inattentive symptomatology. Parent ratings of inattention and hyperactivity were slightly, but not significantly, higher in the ADHD+DCD group compared to the ADHD group. Similarly, scores on the TEA-Ch Score! subtest, our test of sustained attention at the time of assessment, did not differ significantly between the two groups. Interestingly, IQ was considerably lower in the ADHD+DCD group compared to the ADHD group, but the differences in motor performance on the Movement ABC-2 were still present after accounting for this. Although previous studies have identified a correlation between inattentiveness and motor impairment (Piek et al., 1999; Tseng et al., 2004), direct comparisons of the inattentive levels of motor impaired and non-motor impaired ADHD groups, as performed in this study, fail to find a significant difference in inattention between the groups (Pitcher et al., 2003). This suggests that motor impairment in ADHD is independent of inattentive symptomatology and does not support the recommendation of the APA that motor impairment in ADHD is due to distractibility and impulsiveness.

As in previous studies, the motor imagery performance of children with DCD was atypical and will be discussed after first considering the results of the ADHD groups. In line with Lewis et al. (2008), the performance of both the ADHD and ADHD+DCD groups conformed to a logarithmic pattern for their real and imagined movements, and there were no differences in the slope of the linear fit of the data among these two groups and the comparison group. Interestingly, we included an additional variable here that was not included in the Lewis et al. paper – the correlation between real and imagined movement times, transformed using Fisher's z. Although not significantly different, this figure for the ADHD+DCD group was approximately half of that for the ADHD and comparison groups, matching the figure for the DCD group. The effect size for this correlation was also considerably lower in the two motor impaired groups and in fact, lowest in the ADHD+DCD group, suggesting the non-significant finding may actually result from the small sample size. This indicates that although similar in many ways to the non-motor impaired groups, the performance of the ADHD+DCD group may not have been completely typical. It also highlights the importance of variable selection when using the VGPT, in that performance may appear typical using one variable, but less so using another.

For the hand rotation task, both ADHD groups, like the comparison group, were faster and more accurate when responding to medially, compared to laterally rotated hands, in line with the biomechanical limitations of the task. In regard to response time across angle, there were no group differences identified. This is not a surprising finding – although Wilson et al., (2004) found children with DCD differed in their RT patterns compared to their peers, others since have not (Williams et al., 2006; Williams et al., 2008). However, both the ADHD+DCD and DCD groups were significantly less accurate on the hand rotation task than both the ADHD and comparison groups, differences that were not the result of the differences in IQ or age among the groups. This was as we hypothesised and we suggested that working memory capacity may have had some influence on this outcome. However, analysis of the working memory data for the two ADHD groups found few differences in performance after the influence of age was partialled out, with only two variables identified as differing significantly. When these were accounted for, the ADHD+DCD group remained significantly less accurate than the ADHD group. That group differences involving the ADHD+DCD group were far more apparent on the hand rotation task reflects different nature of motor imagery used when compared to the VGPT (the correlation between performances on the two tasks was $r < .20$). Briefly, the hand rotation task requires implicit imagery judgements on hand position whereas the VGPT requires a more explicit form of imagery, providing visual guidance and involving speed-accuracy components. It is unclear why the ADHD+DCD group showed greater deficits on the VGPT, but this is an area for further investigation.

Taken together, these findings indicate that although often not as apparent as the impairment observed in children with DCD alone, children with ADHD+DCD do have genuine motor control deficits that do not result from increased levels of inattention or decreased working memory capacity. Accurately imagining the outcome of a motor plan is an important part of motor planning and a crucial component of forward internal modelling

(Blakemore, Wolpert, & Frith, 2002; Flanagan, Vetter, Johansson, & Wolpert, 2003). The results of this study suggest that deficits in motor imagery ability may underlie, or at least contribute to, some of the motor skill deficits observed in many children with ADHD. It is important to note that these results do not provide evidence that motor impairment is caused by motor imagery deficits, which may instead occur as a by-product of the motor impairment itself. That is, it may be difficult for children with motor skill impairment to form accurate internal representations of a given movement if their motor abilities have never been sufficient to accurately perform that movement. Intervention studies to determine whether imagery ability is enhanced when motor skills are improved and whether improvements in motor imagery capacity result in improvements to motor skills are the only way to resolve such an issue. Of note, it has been demonstrated that motor imagery training programs can have a beneficial impact on the motor skills of children with motor impairment (Wilson, Thomas, & Maruff, 2002), favouring the hypothesis that an inability to accurately represent movements internally plays a contributing role in motor skill impairment in children.

The results of the DCD group in this study generally followed the expected pattern of performance for this group on motor imagery tasks and is in line with previous work by ourselves and others (Deconinck et al., 2009; Lewis et al., 2008; Maruff et al., 1999; Williams et al., 2006; Williams et al., 2008; Wilson et al., 2004; Wilson et al., 2001), and provides further evidence of deficits to represent movements internally in this group of children. The only exception to this was the finding that the DCD group did not show the RT advantage when responding to medially versus laterally rotated hands that has been observed previously (Deconinck et al., 2009; Williams et al., 2011). This might indicate that the children were not engaging in motor imagery (see Wilson et al., 2004, for a discussion on the use of visual imagery as an alternative technique), or that if they were, this was not restricted by the biomechanical limitations of actual movement. If they were not engaging in motor imagery, we would argue that this was the result of their deficits in motor imagery ability – there is clearly no advantage to engaging in another, less accurate technique and we can assume that based on the results of their peers, using motor imagery to complete the task is the most efficient, and perhaps even default, method. Switching, then, to another technique would suggest an inability to accurately complete the task using motor imagery.

An interesting aside to the motor imagery results in this study were the findings relating to the descriptive measures. The difference in IQ among the groups was striking, particularly between the two ADHD groups. Remembering that these children were drawn from an academic child psychiatry unit with no prior information on their motor skill status, the large difference in estimated IQ between the two groups is quite remarkable, providing further evidence that the presence of the two disorders combined is likely to be more detrimental than either disorder alone (Rasmussen & Gillberg, 2000; Tervo et al., 2002). Another intriguing finding related to the DCD group and their inattention and hyperactivity scores. These children were carefully screened to ensure that they had no history of a suspected or actual diagnosis of ADHD and, in addition, their parent/guardian completed a screening questionnaire based on the DSM-IV criteria for ADHD to rule out those with levels of inattention or hyperactivity that were suspected to be elevated. Despite this careful screening, parent ratings on the full version of the Conners' Parent Rating Scale indicated elevated scores on both factors. Further, their scores on the sustained attention test during their assessment were also quite low, and in fact lower than the ADHD group, although these differences were not significant. This is not unprecedented, with previous research indicating that levels of inattention can often be high in children with DCD without a diagnosis of ADHD (Kaplan, Wilson, Dewey, & Crawford, 1998), but indicates that inattention levels should be carefully considered when researching children with DCD.

Though we were able to isolate clear group differences on the motor imagery tasks presented here, a limitation of these findings is that these tasks are implicit measures of motor imagery. We expect that most participants engaged in motor imagery based on their pattern of performances, which generally fall in line with previous research using neuroimaging to support their findings (e.g. Kosslyn, Digirolamo, Thompson, & Alpert, 1998). Without neuroimaging to support our findings, it should be clear that participants could potentially have been utilising some other method to complete the tasks. Further limitations include the limited sample size, particularly in the DCD group, and that working memory data was not available for all groups.

5.0. Conclusion

In conclusion, this study demonstrated that children with ADHD+DCD experience genuine motor control impairments (manifest by a reduced ability to accurately represent movement at a neural level) that do not appear to be linked to increased levels of inattention or decreased working memory capacity (relative to children with ADHD alone). On the VGPT, this group’s imagined movements conformed to the same laws as their actual movements, unlike those with DCD alone, but the correlation between their real and imagined movements was very low, indicating performance may not have been completely typical. Clear deficits in motor imagery ability were noted for the ADHD+DCD group on the hand rotation task, with performance as poor as that for children with DCD alone. Though it is unclear whether motor imagery deficits play a causal role in motor impairment in ADHD or are in fact a symptom of such impairment, an inability to accurately represent movements internally is likely to result in problems with motor planning and the efficient use of feedforward models of motor control (Blakemore et al., 2002; Flanagan et al., 2003). In DCD, this is reflected not only in motor imagery as it is here, but also in motor planning (van

Swieten et al., 2010) and online movement control (Hyde & Wilson, 2011a, 2011b). It is critical therefore that clinically, motor skill assessments are included in assessments of children with ADHD and impairments are considered seriously, with interventions provided. It is also vital that researchers continue to explore motor control in ADHD+DCD to further delineate the underlying aetiological risk factors of motor impairment, which will enhance not only interventions provided, but also improve clinical recognition.

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Table 1.

Group descriptive data – Means (SD) unless otherwise specified.

	ADHD N = 14	ADHD+DCD N = 16	DCD N = 10	COMP. N = 18	p	Post-hoc results
Age (years)	10.11 (1.41)	9.07 (1.65)	8.45 (1.21)	10.20 (1.31)	.006	DCD < ADHD & Comparison
Age range (years)	8.19-12.86	7.32-11.33	7.03-10.51	7.56-11.84	--	--
Percentage of males	57%	87.5%	60%	56%	.19	--
M-ABC2 Total SS	10.21 (2.91)	4.38 (1.71)	3.00 (1.16)	11.33 (2.00)	<.001	DCD & ADHD+DCD < ADHD & Comparison
Manual Dexterity SS	8.29 (2.92)	3.50 (1.32)	3.44 (1.17)	8.39 (2.70)	<.001	DCD & ADHD+DCD < ADHD & Comparison
Aiming & Catching SS	11.36 (2.59)	8.44 (2.63)	6.60 (2.95)	12.61 (2.43)	<.001	DCD & ADHD+DCD < ADHD & Comparison
Balance SS	10.79 (2.99)	6.13 (2.34)	4.10 (1.66)	13.94 (8.46)	<.001	DCD & ADHD+DCD < ADHD & Comparison
WASI IQ	104.50 (9.31)	88.73 (8.99)	96.78 (19.34)	110.59 (10.55)	<.001	ADHD+DCD < ADHD & Comparison; DCD < Comparison
Inattention t-score	78.14 (9.57)	86.54 (12.90)	65.00 (19.98)	45.36 (8.18)	<.001	Comparison < all others; DCD < ADHD
Hyperactivity t-score	87.14 (17.33)	91.92 (14.54)	60.50 (15.12)	44.50 (4.83)	<.001	Comparison < all others; DCD < ADHD & ADHD+DCD

TEA-Ch Score! SS	8.36 (3.41)	6.38 (2.83)	7.40 (4.03)	9.78 (2.18)	.016	ADHD+DCD < Comparison

Note: COMP. = Comparison; M-ABC2 = Movement Assessment Battery for Children 2; SS = Standard Score; WASI = Wechsler Abbreviated Scale of Intelligence.

Table 2.

Visually-Guided Pointing Task (VGPT) outcomes.

Group	Condition	Logarithmic equation	R^2 *	*p*	Slope	Fisher's z - correlation	R^2 **
ADHD	Real	y = -1.21x + 7.5	.96	.004	.97 (.33)		
	Imagined	y = -0.31x + 4.63	.91	.013	.25 (.23)	.82 (.72)	.47
ADHD+DCD	Real	y = -1.14x + 8.67	.93	.008	.90 (.47)		
	Imagined	y = -0.43x + 5.63	.92	.011	.35 (.28)	.44 (.57)	.29
DCD	Real	y = -0.94x +8.36	.97	.002	.74 (.37)		
	Imagined	y = -0.01x + 5.03	.55	.151	.09 (.34)	.47 (1.00)	.36
Comparison	Real	y = -1.11x + 7.20	.97	.002	.89 (.41)		
	Imagined	y = -0.30x + 4.79	.91	.011	.24 (.25)	.88 (1.00)	.57

Note: Slope and Fisher's z – correlation = group means and (SD); * R^2: describing fit of logarithmic relationship; ** R^2: mean effect size for correlation between real and imagined movements.

Table 3.

Mean and standard error (adjusted for age) and univariate significance value for the CANTAB test for the ADHD and ADHD+DCD groups.

Variable	ADHD	ADHD+DCD	*p*
Spatial Span	4.62 (0.30)	3.96 (0.29)	.14
SWM-BSE	49.96 (5.93)	63.50 (5.72)	.12
SWM-Strategy	38.19 (0.95)	38.16 (0.92)	.98
SWM-Time 4 (s)	68.42 (11.44)	97.33 (11.03)	.090
SWM-Time 6 (s)	125.48 (19.26)	183.32 (18.56)	.046
SWM-Time 8 (s)	190.00 (26.28)	272.32 (25.33)	.038

Note: SWM = CANTAB spatial working memory task; BSE = between search errors.

Figure captions

Figure 1. Visually Guided Pointing Task (VGPT) example.

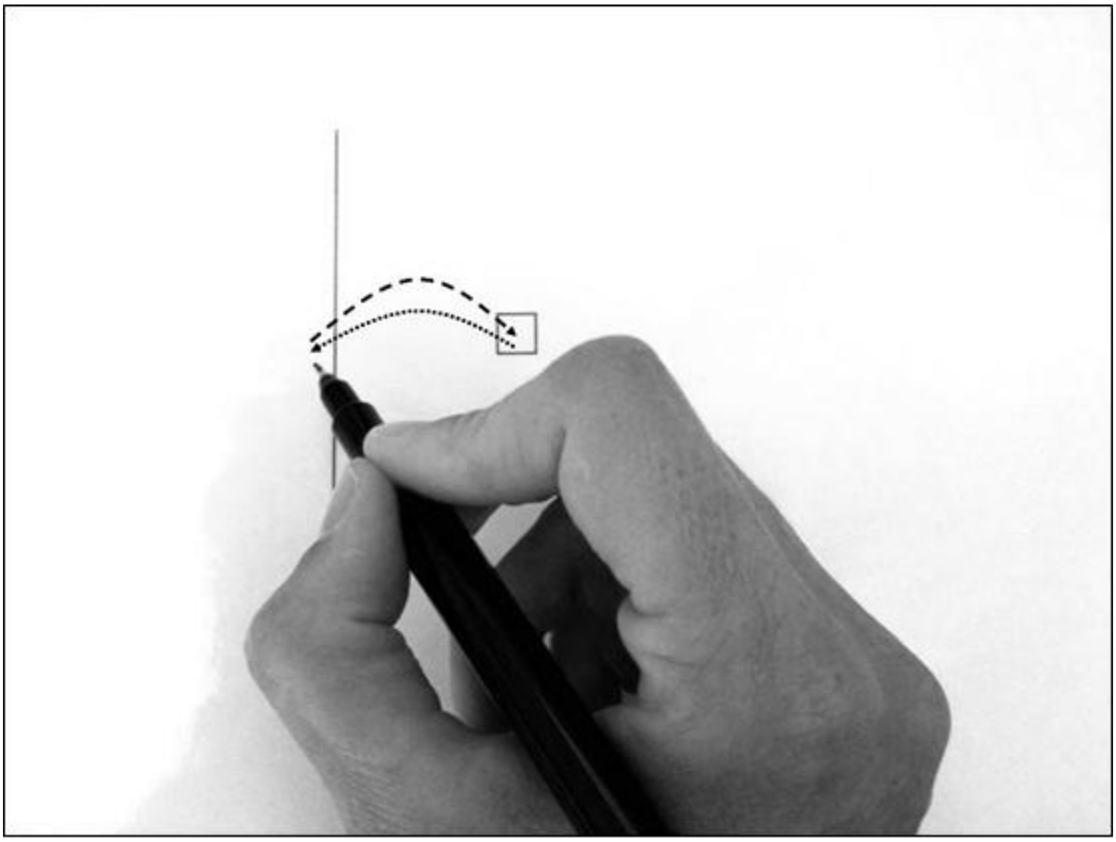

Figure 2. Hand stimuli: left hand at 45° and right hand at 225°.

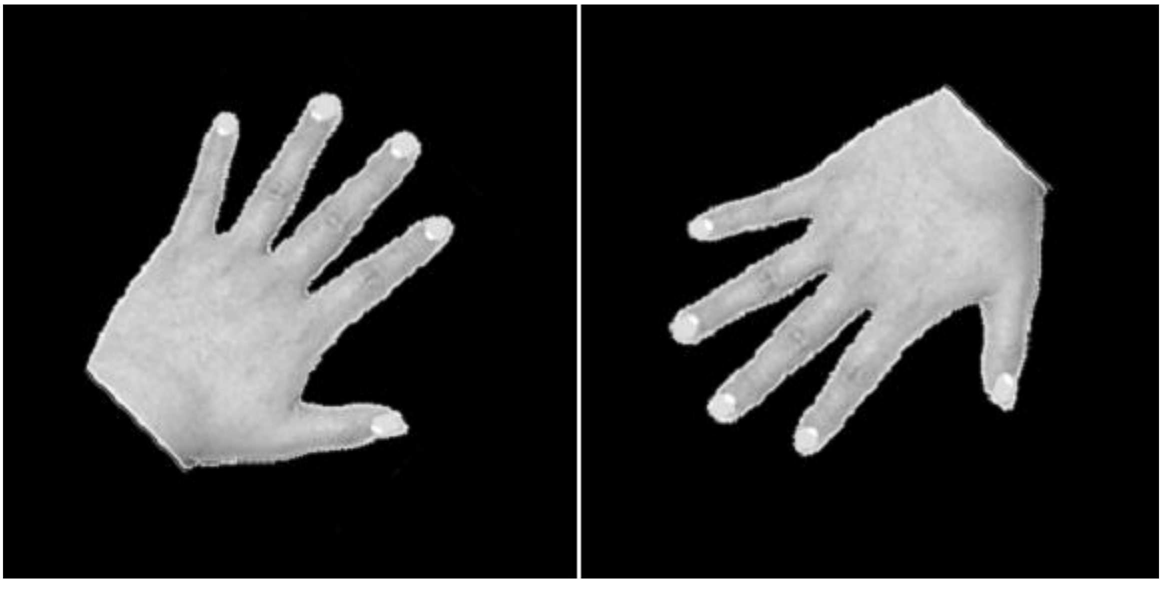

Figure 3. Group means for hand task RT and accuracy - medial and lateral stimuli rotations.

Note: Dotted bars represent medial rotations; Solid bars represent lateral rotations.

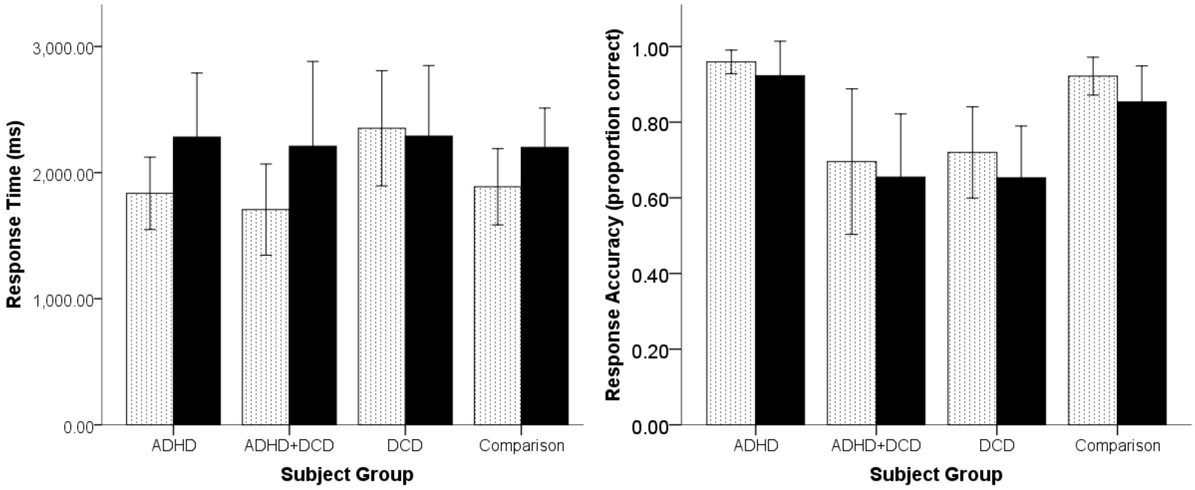

Figure 4. Group means for hand task RT – stimuli rotations 0-180°.

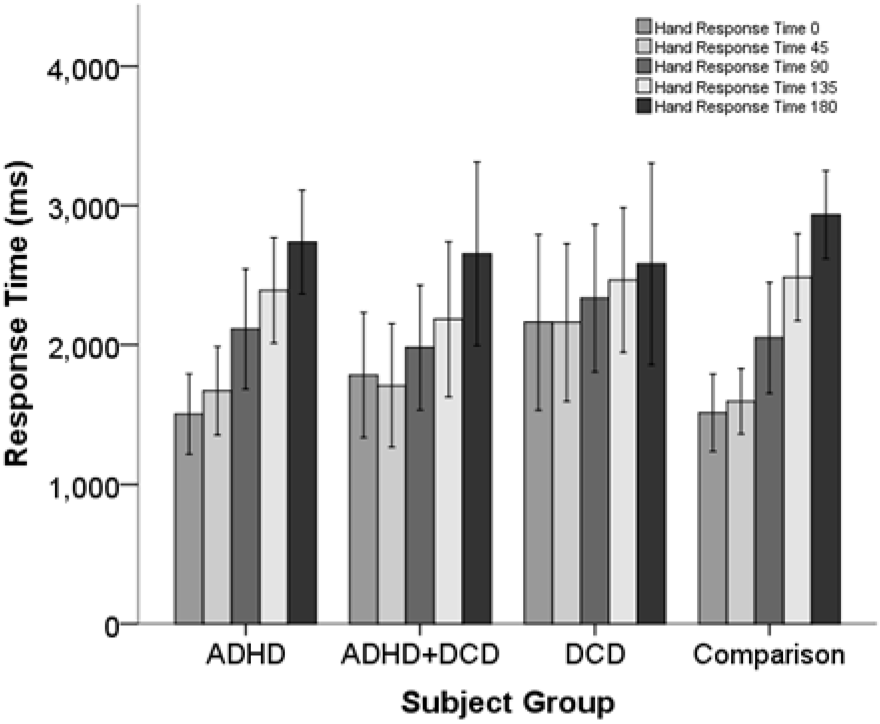

Figure 5. Group means for hand task accuracy – stimuli rotations 0-180°.