

The Relationship Between Motor Coordination, Executive Functioning and Attention in School  
Aged Children

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Running title: Motor coordination and executive functioning

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## Abstract

Given the high level of comorbidity of attention deficit hyperactivity disorder (ADHD) and developmental coordination disorder (DCD), deficits in executive function (EF), shown to be present in children with ADHD, may also be implicated in the motor coordination deficits of children with DCD. The aim of this study was to explore the relationship between EF and motor ability. A sample of 238 children, 121 girls and 117 boys, aged between 6 and 15 years was recruited for this project. Motor ability was assessed using the McCarron Assessment of Neuromuscular Development (MAND), level of inattention using the Child Behavior Checklist, and verbal IQ was estimated using subtests of the WISC-III. A reaction time task and 3 EF tasks measuring response inhibition, working memory and the ability to plan and respond to goal-directed tasks were administered. It was found that motor ability significantly accounted for variance in tasks measuring speed of performance, whereas inattention appeared to influence performance variability. Despite past evidence linking poor motor ability with inattention, there was little overlap in the processes that are affected in children with motor coordination or attention problems.

Keywords: Executive functioning; Developmental Coordination Disorder; Motor ability; Attentional deficits, Attention Deficit Hyperactivity Disorder; Reaction Time.

## The relationship between motor coordination, executive functioning and attention in school aged children

### Introduction

Executive functioning (EF) is the term given to the aspects of information processing that manage complex, controlled behaviors as opposed to automatic actions. EF is an ‘umbrella term’ that incorporates all the complex cognitive processes required to perform novel or difficult goal-directed tasks (Hughes & Graham, 2002), including the ability to delay or inhibit a particular response, develop a plan of action sequences, and hold a mental representation of the task through working memory (Welsh & Pennington, 1988). EF has been closely linked to the prefrontal cortex (e.g., Bradshaw, 2001; Pennington & Ozmun, 1996).

Executive functioning has been studied intensely over recent years in relation to developmental disorders (Hughes & Graham, 2002). In particular, research into mechanisms underlying attention deficit hyperactivity disorder (ADHD) has identified deficits in EF with the focus primarily on deficits in inhibitory control (e.g., Barkley, 1997; Sergeant, 2000). Pennington and Ozonoff (1996) reviewed the studies in which EF tasks were administered to children with ADHD. It was found that of 60 EF measures used across studies, children with ADHD performed significantly worse on 40 tasks. Whilst this may be evidence of a generalised EF deficit, the tasks differed in their sensitivity to the ADHD impairment. Results showed that children with ADHD consistently obtain lower scores on measures of motor inhibition and working memory measures such as the sequential memory task and the self-ordered pointing task (Pennington & Ozonoff, 1996).

Several information processing models linking ADHD and EF have been postulated (e.g., Barkley, 1997; Conners & Wells, 1986; Schachar, Tannock & Logan, 1993; Sergeant & van der Meere, 1990). Barkley (1997) emphasizes behavioral inhibition, whereas Sergeant (2000) has described a three tiered information processing system incorporating the child's energetic state, which includes effort, arousal and activation. The first level is a set of lower level cognitive processes including encoding, central processing and response organization. There is evidence that this level is not impaired in ADHD but is implicated in motor organization (Sergeant & van der Meere, 1990). The second level is the energetic pools, consisting of arousal, activation and effort; ADHD children display deficits in the latter two aspects (Sergeant, 2000). The third level consists of the management or executive functioning system that reviews performance and corrects errors.

One developmental disorder that has received little attention in terms of its relationship to EF is Developmental Coordination Disorder (DCD). DCD appears as a diagnostic category both in the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV; American Psychiatric Association, 1994) and the International Classification of Disease and Related Health Problems (ICD-10; World Health Organisation, 1992). DSM-IV (APA, 1994) defines this disorder as motor coordination that is significantly lower than would be expected given the child's age and intellectual ability. Children who have DCD may display a wide range of motor problems including delays in achieving motor milestones such as walking and sitting, dropping things, poor performance in sports or poor handwriting. Research has suggested that around 6% of children aged 5 to 11 years old will have motor problems that can be diagnosed as DCD (DSM-IV, 1994).

Studies of children with developmental disorders have repeatedly shown that children with motor problems often have problems with attention (e.g., Kaplan, Wilson, Dewey & Crawford, 1998). In addition, children with attention problems often have coexisting coordination problems (Piek, Pitcher & Hay, 1999; Pitcher, Piek & Hay, in press). This link between attention and coordination problems is not surprising considering both disorders were included in the original classification of Minimal Brain Dysfunction (MBD; Kalverboer, 1993). In Sweden, this overlap has been categorised as Deficits in Attention, Motor control and Perception (DAMP; Gillberg, 1992). DAMP is defined as a neurodevelopmental dysfunction syndrome with a high degree of psychiatric comorbidity. Children with DAMP have attention deficits (diagnosable as ADHD in about half of all cases) and motor-perceptual deficits (MPD). Data from longitudinal research showed that children with attention, motor and perceptual problems experienced significant difficulties throughout their childhood and adolescence (Hellgren, Gillberg, Gillberg, & Enerkskog, 1993).

Recently research has begun to explore the association between ADHD and motor coordination problems in more depth. Piek et al. (1999) compared the movement ability and kinesthetic ability of boys with two different subtypes of ADHD with control children. One of the subgroups consisted of boys diagnosed with predominantly inattentive ADHD (ADHD-PI) and the other group had been diagnosed with the combined subtype (ADHD-C), which includes both hyperactive/impulsive and inattentive symptoms. The findings suggested that inattentive symptoms were most strongly associated with motor performance deficits, a finding which supported earlier research by McGee, Williams and Silva (1985). While it is important to maintain diagnostic categories such as ADHD and DCD, it is clear that motor problems and attention problems are frequently associated with each other. In fact, many studies of ADHD and

DCD have not acknowledged the likelihood of comorbid motor or attention problems in ADHD and DCD respectively. While the comorbidity is evident, it is not known whether the motor problems have a similar pathophysiology in children with DCD and in ADHD.

There are several possible explanations for observations of comorbidity between attention and motor coordination disorders. The first explanation is simply that the tests used to measure motor skill also tap attention ability: motor control tests require attention for good performance. For instance, children with ADHD may perform less well on tests of motor ability because they are penalized for being unable to attend or remember instructions. However, our recent research (Piek et al., 1999; Pitcher et al, in press) indicates that this explanation is unlikely. Another possible explanation is that one disorder causes the other. For instance the deficits associated with ADHD may affect the learning of motor coordination skills and thus result in motor coordination difficulties. Conversely, motor control problems could be responsible for behavioral symptoms of ADHD such as hyperactivity and impulsivity. If this were the case, a high correlation between the severity of ADHD and motor coordination would be expected. Pereira, Eliasson and Forssberg (2000) compared ADHD children with and without DCD on a precision grip-lift task. They found that children with ADHD as their only diagnosis performed better on these tasks than children with an additional DCD diagnosis. The two groups showed similar levels of hyperactive and attention problems as reported by teachers and parents. The severity of ADHD does not appear to mediate performance on motor tasks, suggesting that one condition does not cause the other. The third possible explanation for the high rate of comorbidity is that ADHD and DCD have some shared mechanism. As the overlap between DCD and ADHD is not complete, other factors would need to be incorporated to account for this pattern of occurrence.

Several researchers have provided generalized neurodevelopmental explanations for this comorbidity. Kaplan et al. (1998), who found a high level of comorbidity between ADHD and DCD, postulated that these and other childhood developmental disorders (such as Reading Disorders) show a high comorbidity because they all reflect a generalized heterogeneous neurodevelopmental condition known as Atypical Brain Development (ABD). Kaplan et al. (1998) argued that impairments in attention, motor skill and other developmental tasks are caused when the early development of the brain is disrupted. Furthermore, discrete syndromes occurring in isolation are the exception rather than the rule because of the wide variation in the extent and nature of the underlying neurological abnormality (Kaplan et al., 1998). ABD may express itself in a wide variety of behavioral symptoms and comorbid syndromes depending on factors such as the timing, location and severity of the disruption in brain growth and development. Hill (2001) also attributed the overlap between DCD and specific language impairment to neuromaturational delay and postulated that the behavioral expression of each is dependent on timing and severity of disruption to brain development.

It appears that there are generalized neurodevelopmental deficits present within developmental disorders such as ADHD and DCD. However, this explanation does not account for the fact that symptoms of developmental disorders appear mostly as patterns of recognizable syndromes. Sometimes syndromes appear comorbidly with other developmental disorders and sometimes in isolation. Furthermore, each different neurodevelopmental disorder has a different likelihood of co-occurring with each other disorder. For instance, a child with ADHD is more likely than a non-ADHD child to have Oppositional Defiant Disorder (ODD), whether or not they also have DCD (Kadesjö & Gillberg, 1999). However, DCD children are more likely to have Asperger's syndrome if they also have comorbid ADHD (Kadesjö & Gillberg, 1999). The

fact that symptoms generally form clusters or syndromes and also that certain syndromes have a tendency to be comorbid with particular syndromes is evidence against a purely generalized and diffuse explanation for developmental disorders. It suggests that neurodevelopmental delay may have at least semi-specific effects on particular aspects of information processing.

The high level of comorbidity of attention and motor coordination disorders suggests that they may share a common underlying neurocognitive mechanism. Could EF deficits be implicated in DCD? There are several convincing lines of evidence for this hypothesis. For example, children with DCD display greater problems in motor coordination when the task is more complex (Piek & Coleman-Carman, 1995), involves cross-modal integration (Wilson & McKenzie, 1998), involves greater demands for speed or accuracy (Vaessen & Kalverboer, 1990) or a time delay (Dwyer & McKenzie, 1994). Tasks with greater requirements for information processing between the receptor and effector stage, such as those described above, require executive functions such as inhibition of a prepotent response and working memory to enact the correct motor response. Children with DCD also have deficits in the detection of errors (Lord & Hulme, 1988) and have difficulty anticipating aspects of the task or forward planning (Rösblad & von Hofsen, 1994). The detection and correction of errors are associated with executive functioning (Sergeant, 2000), as is strategic planning (Pennington & Ozonoff, 1996).

None of the above studies controlled for comorbid attention problems. Therefore, it is possible that the information processing deficits observed in children with DCD were due to the comorbid attention problems likely to be present in approximately 30% of the sample. However, Wilson and colleagues (e.g., Wilson et al., 1997; Wilson & Maruff, 1999), in conducting research into aspects of information processing in children with DCD, excluded children with ADHD diagnoses from their sample. Wilson et al. (1997) tested children with and without DCD



on the covert orienting of a visuospatial attention task (COVAT), a computer task in which the child must respond to viewing the target stimulus, the location of which is cued by either visual cues (exogenous) or probability information (endogenous). The DCD group displayed difficulties in two conditions. Firstly, when attention was directed by visual cues, children with DCD directed attention as efficiently as controls but had difficulty using the information from the cue to prepare motor responses accordingly. The inability to use advance information to prepare or program motor responses, particularly exacerbated by the increased processing demands of more complex responses, has been previously reported in children with DCD (Smyth, 1991; van Dellen & Geuze, 1988; 1990). Secondly, when attention was directed by endogenous probability cues they showed a deficit in disengaging attention from invalid cues. Wilson et al. (1997) suggested that these results imply impairments in the endogenous control of visuospatial attention, which are independent of motor deficits in DCD. Children with DCD have previously been found to perform poorly on other attentional tasks requiring the endogenous processing of visuospatial information, including 4-choice reaction time (van Dellen & Geuze, 1988) and figure-ground discrimination tasks (Ayres, 1965).

The second argument for a link between DCD and EF is within models of EF. In most of these models, motor behavior plays a central role. In Barkley's model of ADHD, which has evolved from earlier theories of EF (e.g., Bronowski, 1977; Fuster, 1989), behavioral inhibition permits the effective performance of four executive abilities, which then influence the motor system in the service of goal directed behaviour. Since the effector or motor output stage is dependent on the antecedent stages of processing, motor behavior is inextricably linked to EF. Sergeant's (2000) cognitive-energetic model of information processing also links EF to motor behavior. The computation factors include encoding, search, decision and motor organization. In

addition, in goal directed behavior, the management or EF level of processing is responsible for the planning, monitoring and correction of errors which influence the other computational and state factors including motor organization (Sergeant, 2000).

In summary, current theory and research within ADHD, highly associated with DCD, focuses on EF deficits. There is also evidence to suggest that impairments in DCD can, retrospectively, be accounted for by deficits in EF. In order to address this issue, we explored the link between motor coordination and aspects of EF in a representative sample of children, that is, across the full range of EF and motor coordination abilities. In addition, this normative sample included a number of children with movement scores that are within the range for mild to moderate DCD (McCarron, 1997). These children formed a participant group of children with motor coordination problems who were compared with children who have normal motor coordination, on aspects of EF. The measures of EF in the current study were drawn from the group of measures that consistently distinguish ADHD from non-ADHD samples, according to a review by Pennington & Ozonoff (1996). The Go-No Go task (Shue & Douglas, 1992) is the seminal operationalization of response inhibition, and measures the ability to inhibit or prevent a prepotent response. It has been closely linked to children with attention problems (Sergeant, 2000). The second measure of EF is a measure of working memory, and measures the ability to update the working memory as the task progresses to respond correctly. The final test used is the Goal Neglect task (Duncan, Emslie, Williams, Johnson & Freer, 1996) which measures the ability to use instructions to maintain goal directed behavior. These tests are accepted operationalizations of executive function and encompass the aspects of EF associated with ADHD. In addition, these tasks contain low demands on motor performance so to minimize the

possible confounding of the results. In addition to the EF tasks, a two-choice reaction-time task was also used as a general measure of information processing speed.

The McCarron Assessment of Neuromuscular Development (MAND; McCarron, 1982) was used to measure of motor coordination. This measure was chosen because it measures the full range of motor abilities in children, which is the appropriate for the representative sample in the current study. As attention problems and coordination problems are frequently comorbid (e.g., Kaplan et al., 1998), it was necessary to measure and control for attention difficulties. Many of the previous studies finding information processing deficits in DCD children have not controlled for attention problems, obscuring whether the deficits are related to DCD or undetected and comorbid attention problems. However, there is good clinical evidence that children with DCD do exhibit EF deficits. In this study, attention problems were measured by parent report of attention using the attention subscale of the Child Behavior Checklist (CBCL; Achenbach, 1991).

We predicted that there would be a significant relationship between motor coordination, attention and EF. If attention deficits are primarily responsible for poor performance in EF tasks, then, when attention is controlled, the impact of motor ability on EF would disappear.

## Method

### Participants

The participants were 238 children (117 boys, 121 girls) between 6.67 and 14.83 years of age. Table 1 describes the number of boys and girls for each age category. Participants were recruited from 42 schools in the Perth metropolitan region, which were chosen to represent the

distribution of academic achievement within the state of Western Australia. Children who had an estimated Verbal IQ below 80 were excluded from the study.

INSERT TABLE 1 ABOUT HERE

From the total sample 28 children (8 girls and 20 boys) were identified as being at risk of DCD by scoring at or below 80 on the McCarron Assessment of Neuromuscular Development (MAND; McCarron, 1982). Children who scored at or above 100 (43 girls and 33 boys) were included in the control group. Table 2 displays the cell means for the DCD group, Control group and the total sample on the variables of age, Neurodevelopmental Index (NDI; standardised score from the MAND), estimated Verbal IQ and the inattention score from the Child Behavior Checklist (Achenbach, 1991).

INSERT TABLE 2 ABOUT HERE

### Measures and Apparatus

Wechsler Intelligence Scale for Children (WISC-III; Wechsler, 1991). In order to estimate verbal IQ (VIQ), the Vocabulary and Information subtests of the WISC-III were administered. Performance IQ was not included to assess full IQ as previous research has demonstrated a strong relationship between poor motor ability and Performance IQ (e.g., Coleman, Piek & Livesey, 2001). Both subtests have good reliability (Vocabulary:  $r = .78$ ; Information:  $r = .75$ ). Combined, they are the two best measures of  $g$ , which is thought to be the underlying general intelligence factor (Sattler, 2001).

McCarron Assessment of Neuromuscular Development (MAND; McCarron, 1982, 1997). The MAND comprises 10 tasks, five that assess fine motor skills (putting beads in a box, putting beads on a rod, finger tapping, putting a nut on a bolt, and moving washers along a rod) and five assessing gross motor skills (touching the nose and the finger of the opposite extended

arm, jumping, heel to toe walking, standing on one foot, and hand clasp). The scaled scores on each of these tasks are added and age norms, provided for children aged 3.5 to 18 years, are used to determine a Neuromuscular Developmental Index (NDI) with a mean of 100 and standard deviation of 15. A score below 55 is classified as a severe disability, 55 to 70 a moderate disability and 71 to 85 a mild disability. Test-retest reliabilities after a month interval over the 10 tasks range from 0.67 to .98 (McCarron, 1997). Tan et al. (2001), using an Australian sample, found the MAND to have good specificity, good sensitivity and to be a valid measure for the identification of motor impairment.

Child Behavior Checklist (CBCL; Achenbach, 1991). This is a standardized questionnaire designed to measure internalizing and externalizing behavior problems in children aged 4 to 12 years. The parent form of the CBCL was used, where parents indicated the presence and degree of each of 118 child behaviors which are grouped into 8 subscales. Only the attention subscale was used in the current study. It consists of 11 items related to symptoms of attention problems. The alpha coefficient for the attention subscale is .84 and the one-week test retest reliability is .92 (Achenbach, 1991). The attention subscale of the CBCL has been shown to capture the inattentive symptomatology in ADHD in a population sample (Graetz, Sawyer, Hazell, Arney & Baghurst, 2001).

Choice Reaction Time Task (CRT). This was a line-length discrimination task which was designed to assess visual inspection time (Anderson, 1988). The task requires test-takers to press, as quickly as possible, a blue key if two lines (antennae on ‘aliens’) are the same length, and to press a red key if they differ in length. The task comprises 120 stimulus presentations, and there were two trials (CRT1 and CRT2). This task yields two scores: total reaction time and the reaction time to correct responses only (rtcr).

Tasks measuring Executive Functioning (EF): The capacity to control attention and inhibit responses was assessed with a set of three computer-administered executive functioning tasks. The Go/No-Go Task (Shue & Duncan, 1992), Trailmaking/Updating Memory Task (Rabbitt, 1997) and Goal Neglect Task (Duncan et al., 1996) were selected because of their known relations to ADHD (Pennington & Ozonoff, 1996) or because of their clear face validity.

Go/No-Go Task (GNG) was modified from the Go/No-Go task of Shue and Douglas (1992) to assess simple motor inhibition. In this task, letters are designated either as ‘go’ (respond) or ‘no-go’ (do not respond) stimuli, and are presented at one second intervals. When a go stimulus is presented, the child is required to press a response key as quickly as possible, and when a no-go stimulus is presented, the test-taker is required not to press a response key. Test-takers complete two trials of the task (GNG1 and GNG2). Each trial consists of 120 stimuli, of which 60 are ‘go’ and 60 are ‘no-go’ stimuli. Responses to the ‘no-go’ stimulus are scored as commission errors, and failures to respond to the ‘go’ stimulus are scored as omission errors. This test consistently discriminates between ADHD children and non-ADHD children (Pennington & Ozonoff, 1996; Shue & Douglas, 1992).

Trailmaking/Memory Updating Task is a simplification of a more complex task (Rabbitt, 1997) and is designed to assess working memory and behavioral inhibition. In this task, the first

four letters of the alphabet are designated as the ‘target set,’ and within this target set, the actual target changes with successive stimulus presentations (i.e., from A to B to C to D to A). Test-takers are required to discriminate whether a letter, presented on screen, is part of the target set, and if it is, whether the letter is the current target. Test-takers complete two trials (TMT1 and TMT2), and each trial consists of 120 stimulus presentations, of which 20 presentations are the target stimulus. For each presentation, test-takers press a blue key if the stimulus is the target stimulus and press a red key otherwise. Scores include the mean time taken (MN), standard deviation (SD) and the number correct out of 20 (NC).

Goal Neglect Task (GNT) measures the ability to formulate and respond to goal-directed plans (Duncan et al., 1996). It requires that a test-taker disregard a task requirement which has been understood and remembered in order to achieve some other goal. This is a typical executive functioning task insofar as it involves novel behavior, concurrent tasks, and the absence of verbal feedback (Duncan et al., 1996; Rabbitt, 1997). In the Goal Neglect Task, letters and numbers are presented to the left or the right of a fixation point. Test-takers are asked to read out the stimuli on either the left or the right of the screen, and then either switch to the opposite side if a + sign is presented, or stay on the same side if a – sign is presented. The task has a total of twelve trials (six ‘switch’ and six ‘stay’ trials). In each trial, the presentation of 10 sets of stimuli (letters/numbers) is followed by the switch or stay cue, and then three additional sets of stimuli. A trial is ‘passed’ if, before and after the cue, there are more letters called from the correct than the incorrect side. Performance on the Goal Neglect Task has been found to be positively related to age and IQ (Duncan et al., 1996).

### Procedure

Children in grades 2 to 7 (aged 6 to 12 years) in Perth primary schools were invited to participate in 'Project KIDS' which is a large-scale, long running project in which data are collected for child-related research in school holiday periods. Therefore, the data relevant to the current study were collected along with information pertaining to other projects. The older children were recruited through participating Perth high schools. All testing was carried out with the informed consent of both the participants and their parents in accordance with the guidelines set out by the Australian National Health and Medical Research Council.

Principals were contacted by mail seeking permission to contact parents via the school to recruit children. Parents who gave permission for their child to participate returned the completed registration and consent form in the prepaid envelope. A letter confirming the enrolment of the child/children was then sent to the parent/s with a CBCL form and a prepaid envelope. Parent/s were asked to return the completed CBCL in the envelope supplied as soon as possible.

After parents had given consent, children for Project KIDS were allocated to a day within the school holidays yielding 10 groups of 12 participants, for each of two holiday periods. Testing took place on the campus of the University of Western Australia, in the Child Study Centre. In the Centre, a number of rooms were set up for individual testing and others for group testing. In order to maintain the children's interest and motivation, and to maximize their enjoyment of the day, the children were provided with a scenario at the beginning in which their job was to colonize a fictional planet. For each puzzle or game (test) completed, participants were given colored tokens that could then be redeemed for items that could be used to colonize the planet at the end of the day. For the computer tasks, the instructions were embedded within scenarios relating to the planet colonization theme such as 'zapping aliens'. Testing was



conducted in three 90-minute sessions. The first test session was followed by a 30-minute recess, and the second by a 60-minute lunch break. Testing was administered by a team of researchers conducting related studies with the data collected. During these breaks, children were provided with coloring books, pencil puzzles, and age-appropriate movies; they were also given access to an outdoor playground. The order of test administration was not uniform. Rather, each child had his/her own schedule so that while some children were completing the computer-administered tasks in a computer room, other children might be completing the WISC or the MAND. For most children, testing was completed within 4.5 hours, but in some cases, testing required up to 5.5 hours.

For the older children not participating in Project Kids, testing was conducted at the school from which the child was recruited. For these children, testing was less rigidly scheduled to minimize disruption to children's regular school activities.

## Results

### Total Sample

Bivariate correlations between the NDI score, Inattention, age, sex, estimated VIQ, and the EF variables were calculated on the total sample of 228 children. These results are presented in Table 3. As expected, there was a significant negative relationship between the NDI score and Inattention ( $r = -.193, p < .01$ ). It should also be noted that when the 'clumsy' item from the CBCL, part of the attention problems subscore, was excluded, the significant relationship remains ( $r = -.180, p < .01$ ). A surprise finding was the correlation between sex and estimated VIQ, with the boys scoring better on this measure.

INSERT TABLE 3 ABOUT HERE

Age was significantly correlated with all the EF measures, whereas estimated VIQ correlated only with the GNT (as found by Duncan et al., 1996) and with one of the CRT measures (CRT2). Sex was found to be an important variable to consider for the CRT2 task (rtcr), where girls were faster than boys. On the TM2 task, both mn and nc correlated with sex. Overall, girls were slower than boys but produced more correct responses. Of the 15 EF measures, NDI was found to correlate with 7 of these. In all cases, better performance on the EF task was linked with higher NDI scores. Inattention correlated significantly with only three of the EF measures. Higher inattentiveness was related to poorer EF performance. For the GNG1 task, higher inattention scores were linked with a greater error score. The other two measures were measures of variability (CRT2var and TM1sd), and the positive correlations revealed that the higher the inattention the greater the variability of the measures. Of particular interest is that in only one case did the EF measure that correlated with NDI also correlated with Inattention, namely TM1 (sd).

Hierarchical regression analyses were used to investigate the relationship between EF measures and motor ability (NDI) when Inattention and other relevant variables were taken into account. Only those EF measures that were significantly correlated with NDI and/or inattention were included. When variables such as age, sex or VIQ were found to have a relationship with the EF measure, these were entered into the regression equation on the first step. In all cases, age was entered as it was related to all EF measures. The Inattention measure was entered in the second step, followed by NDI in the third step. The findings are described below for CRT and each EF task separately.

Choice Reaction Time Task (CRT). NDI was correlated with two measures in this task, namely CRT1rtcr and CRT2rtcr. Inattention correlated with CRT2var. The results for the regression

analyses are given in table 4. It can be seen that for the CRT1rtcr, Age and NDI were significant predictors, whereas for CRT2rtcr, these were Age, Sex and NDI. When the variance measure for trial 2 was examined, only Age and Inattention were significant predictors.

INSERT TABLE 4 ABOUT HERE

Go/No-Go Task (GNG). Only the first GNG trial was investigated using hierarchical regression as the only variable found to impact on the second trial was Age. For GNG1, Age was entered on Step 1 and found to be statistically significant ( $R^2 = .019$ ;  $F(1, 236)=4.551$ ,  $p=.034$ ). On Step 2, Inattention was entered but did not have a significant effect ( $R^2_{\text{Change}} = .016$ ;  $F_{\text{Change}}(1,235)=3.872$ ,  $p=.0502$ ). Likewise, NDI was not a significant predictor ( $F_{\text{Change}} < 1$ ).

Trailmaking/Memory Updating task (TM). Table 5 summarises the findings for the hierarchical regression analyses conducted on the TM task. In all four measures examined, NDI was a significant predictor of the EF measure once the other variables were accounted for. Inattention was a significant predictor for TM1sd only.

INSERT TABLE 5 ABOUT HERE

Goal Neglect Task (GNT). The three step analysis was carried out for the GNT task. In the first step, both Age and VIQ were entered and were statistically significant predictors of GNT ( $R^2 = .391$ ;  $F(2, 235)=75.346$ ,  $p=.000$ ). In step 2, Inattention did not add significantly to the variance accounted for Age and VIQ ( $R^2_{\text{Change}} = .008$ ;  $F_{\text{Change}}(1,234)=2.992$ ,  $p=.085$ ), nor did NDI in Step 3 ( $R^2_{\text{Change}} = .007$ ;  $F_{\text{Change}}(1,233)=2.91$ ,  $p=.089$ ).

#### Control versus DCD group

A MANCOVA was conducted to examine the difference between the two groups for the dependent variables of CRT and EF. Covariates were age, sex, VIQ and the score on inattention problems. The main effect of Group was statistically significant ( $F(17,81) = 2.112$ ,  $p=.000$ ).

Each dependent variable was examined using univariate ANCOVA. Statistically significant differences were found for CRT1(rtcr),  $F(1,97)=5.27$ ,  $p=.024$ , TM1(mn),  $F(1,97)=19.0$ ,  $p=.000$ , TM1(sd),  $F(1,97)=22.52$ ,  $p=.000$ , TM2(mn),  $F(1,97)=12.45$ ,  $p=.001$ , and TM2(sd),  $F(1,97)=6.19$ ,  $p=.015$ . These findings are consistent with those found using hierarchical regression analysis.

### Discussion

The present study explored the link between inattention, motor ability and aspects of EF. Deficits on particular EF tasks have been associated with ADHD and are thought to be etiologically important in the disorder. As DCD and ADHD are highly comorbid (e.g., Piek et al., 1999; Pitcher et al., in press), the current study examined whether EF deficits would also be implicated in motor coordination problems. As the association between attention problems and EF predicted the association between EF and motor ability, the former will be discussed first.

The expected link between attention problems and EF was found to be quite weak in the current study. This is surprising given that the EF tests used in this study are those which had been found to discriminate between ADHD and non-ADHD children (see Pennington & Ozonoff, 1996). If EF deficits were present, it is likely that they would have been captured by at least some, if not all, the measures. One possible explanation is that the CBCL attention subscale was not a suitable measure of attention problems, despite past evidence to support this (Graetz et al., 2001). However, the expected negative correlation between the NDI and inattention (e.g., McGee et al., 1985; Piek et al., 1999) was found in the current study, providing some evidence that the CBCL did capture the attention problems. Furthermore, the only two EF variables that were affected by inattention once age was accounted for were both measures of variability.

Again, this would be expected as the inattentive symptoms would lead to greater variability in performance.

Apart from this relationship, there did not appear to be any link between attention problems and EF, despite the fact that research has established a strong association between EF and ADHD (Pennington & Ozonoff, 1996). However, most of these studies failed to distinguish between the subtypes of ADHD (impulsive/hyperactive, inattentive or combined) which may have obscured the pattern of associations (Pennington & Ozonoff, 1996). Furthermore, most of these studies have used clinical samples of ADHD for their participants. It has been established that clinical samples are dominated by ADHD-HI and ADHD-C whilst ADHD-PI is the most frequently occurring ADHD subtype in the population (Faraone, Biederman, Weber & Russel, 1998). The results of previous studies showing an association between ADHD and EF may have sampled primarily ADHD-HI and ADHD-C, and therefore the findings may only generalize to these populations. One exception is a recent paper by Nigg, Blaskey, Huang-Pollock and Rappley (2002), who compared children with ADHD-C and ADHD-PI with control children on EF and general timing tasks. Although the two groups had similar deficits compared with the control group on the speed measures, both boys and girls with ADHD-C were significantly poorer at the Stop task measuring motor inhibition compared with control children. For the ADHD-PI group, gender appeared to be an important factor as boys performed as well as the control children, yet girls with ADHD-PI were significantly poorer than the control children at the motor inhibition task.

An association between EF and hyperactive/impulsive symptoms is intuitively appealing, as it is simple to see how aspects of EF, such as poor response inhibition, manifests as these symptoms. There is theoretical basis for the argument that ADHD predominantly inattentive

subtype is etiologically different from ADHD hyperactive/impulsive and combined subtypes.

Barkley (1997) clearly states that his unifying model of ADHD links EF only to the ADHD hyperactive/impulsive or combined subtype. Sergeant's (2000) model of ADHD utilizes the ICD-10 system of diagnosis in which little importance is given to ADHD-PI.

The present study found a strong association between attention and motor coordination. This is consistent with the literature describing comorbidity between children with movement problems such as DCD and attentional problems (e.g., McGee et al., 1985; Piek et al., 1999), and implies a similar etiology. The primary issue investigated in this study was whether poor performance on EF tasks found in children with ADHD was also associated with poor motor performance. Although weak, several significant relationships were identified between motor ability and the EF tasks. Once other variables such as age, Verbal IQ and sex were taken into account, the only EF measure that was linked to the NDI was the trailmaking/memory updating task which is considered a measure of both working memory and behavioral inhibition (Rabbitt, 1997). None of the other tests designed to measure response inhibition were found to be influenced by motor ability. These findings were further supported by the group analysis that compared children with mild to moderate DCD to a control sample. The differences in the two samples were clearly present for these comparisons.

It is important to note that only the timing measures (mean and sd) were influenced by motor ability, as the measure for the number of correct responses did not relate to motor performance. The other measure that was influenced by motor ability was the choice reaction time for the correct responses which were negatively correlated with the NDI score. Again, this was supported by the comparison of the DCD group with the control group. This supports other studies that have examined the RT (both simple and choice) in children with DCD (e.g.,

Henderson et al., 1992; Piek & Skinner, 1999; Schellekens et al., 1983; Smyth, 1991) and found it to be slower for the children with movement problems. In a recent study investigating timing and force control in boys with ADHD who did or did not have comorbid DCD, it was found that boys with the dual diagnosis were more dysfunctional in terms of their reaction time (RT) and the peak force that they could generate in the task (Pitcher, Piek & Barrett, 2002), although increased variability in performance was a problem for both groups. Difficulty in force control has been linked in the past to basal ganglia damage (Ivry, Keele & Diener, 1988; Lundy-Ekman, Ivry, Keele & Woollacott, 1991), whereas timing problems in children with DCD has been associated with cerebellar function (e.g., Lundy-Ekman et al., 1992). Bradshaw (2001) describes the role of the cerebellum and basal ganglia as responsible for the “more automatic aspects of behavior” (p. 14). Therefore, motor dysfunction, rather than ADHD symptomatology, appeared to be responsible for deficits in force output and initial reaction time. This supports Sergeant’s (2000) view that the first level of cognitive processing involving encoding, central processing and response organization may not be affected in ADHD, but will impact on motor organization.

Furthermore, if one considers the argument that longer RTs may be linked to the need for additional read-out time and/or short term memory capacity (e.g., Anson, 1982; Franks & Van Donkelaar, 1990), it is not surprising that there is also a relationship between motor ability and the EF task that investigates working memory. What is clear from these findings is that the primary EF tasks that investigate response inhibition are not related to movement ability.

Another important finding from this study was that there was little overlap (one correlation only) in the significant correlations found between the EF measures for motor ability and inattention. This suggests that there is not a common etiology between the two disorders. The variables most affected by motor ability were those that are thought to measure what

Sergeant (2000) refers to as the first level of the cognitive-energetic model, namely ‘encoding, search, decision and motor organization’ (p. 8). This model also distinguishes the task demands of effort, arousal and activation on the second level from the third and final level which contains executive functions such as response inhibition and error detection and correction. This model suggests that inattention may be a factor of the second level, and hence, we would not expect a relationship with the EF measures. That is, our study supports this three-tiered approach to understanding information processing and how it relates to ADHD.

Finally, it may be useful to speculate on how these results can be interpreted in terms of brain functioning. Clearly the link between movement and timing confirms past research that attributes this relationship to cerebellar functioning. Furthermore, the basal ganglia has been linked to the activation component of the cognitive-energetic model (Sergeant, 2000), although attentional processes are also associated with frontal and parietal lobes (Bradshaw, 2001). The prefrontal cortex has strong links to executive functioning tasks that involve response inhibition (Pennington and Ozmun, 1996), and have been most commonly associated with impulsivity (Bradshaw) which was not considered in the current study.

### Conclusions

Information processing deficits have been linked to children with DCD for nearly two decades. We have found in the current study that these do not appear to be linked to deficits in executive functioning, but may involve timing deficits related to the cerebellum. Furthermore, inattention also appears to be weakly linked to difficulties in EF. The EF deficits implicated in previous studies in children with DCD may have occurred as a result of comorbid ADHD symptomatology, probably hyperactivity/impulsivity, or children with DCD may have had



information processing deficits other than impaired EF which impacted on the measurement of the EF tasks. Hence, the results of previous studies exploring information processing in DCD that did not control for comorbid ADHD symptomatology should be viewed with caution. Furthermore, given the high comorbidity of ADHD and DCD and that differential etiologies are suggested, future research exploring DCD and ADHD should control for the presence of comorbid and possibly confounding symptomatology.

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Table 1: Sample description

Age category (years)	No. of Girls	No. of Boys	Total
6.00	3	3	6
7.00	17	15	32
8.00	12	19	31
9.00	17	15	32
10.00	15	14	29
11.00	14	15	29
12.00	19	13	32
13.00	17	14	31
14.00	7	9	16
Total	121	117	238



Table 2: Mean, standard deviation and range for age, NDI, VIQ and inattention score for the DCD and Control groups and total sample.

		Age (years)	NDI	VIQ	Inattention Score
DCD (n=28)	Mean	9.87	73	103	3.43
	SD	1.97	6.66	13.37	3.17
	Range	6.91-12.91	55-80	81-136	0-13
Control (n=76)	Mean	9.29	111	102	2.77
	SD	1.66	9.64	13.26	3.31
	Range	6.67-12.91	100-155	81-150	0-20
Total (N=238)	Mean	10.58	98	102	2.83
	SD	2.26	16.19	12.80	3.09
	Range	6.67-14.83	55-155	80-150	0-20

Table 3. Pearson correlations for each of the variables. (N=238)

	<b>NDI</b>	<b>Inattention</b>	<b>Age</b>	<b>Sex</b>	<b>Est VIQ</b>
<b>Inattention</b>	-.193**	—	—	—	—
<b>Age</b>	.039	-.010	—	—	—
<b>Sex</b>	.026	.067	-.037	—	—
<b>Est VIQ</b>	.054	-.078	.085	.175**	—
<b>CRT1(rt)</b>	-.072	-.028	-.291**	.001	-.106
<b>CRT1 (var)</b>	.011	.008	-.201**	.007	-.055
<b>CRT1 (rtcr)</b>	-.158*	-.013	-.617**	.013	.003
<b>CRT2 (rt)</b>	-.115	.080	-.378**	-.043	-.133*
<b>CRT2 (var)</b>	-.068	.153*	-.145*	-.077	-.109
<b>CRT2 (rtcr)</b>	-.131*	.002	-.580**	.141*	-.072
<b>GNG1</b>	-.033	.127*	-.138*	.006	.111
<b>GNG2</b>	-.022	.112	-.204**	-.082	.047
<b>TM1 (mn)</b>	-.262**	.106	-.502**	-.088	-.047
<b>TM1 (nc)</b>	.084	.018	.329**	-.050	-.084
<b>TM1 (sd)</b>	-.222**	.142*	-.563**	-.024	-.091
<b>TM2 (mn)</b>	-.222**	.070	-.588**	-.127*	-.096
<b>TM2 (nc)</b>	.046	-.046	.182**	-.129*	.025
<b>TM2 (sd)</b>	-.155*	.096	-.522**	-.047	-.109
<b>GNT</b>	.134*	-.107	.599**	.042	.228**

\* =  $p < .05$ ; \*\* =  $p < .01$

Table 4: Results for the Hierarchical Regression analyses for the Choice Reaction Time task.

<b>EF variable</b>		<b>Predictors</b>	<b>R Square</b> <small>Change</small>	<b>F</b> <small>Change</small>	<b>df</b>	<b>P</b>
<b>CRT1 (rtcr)</b>	Step 1	Age	.381	145.41	1,236	.000
	Step 2	Inattention	.000	.134	1,235	.715
	Step 3	NDI	.020	7.674	1,234	.006
<b>CRT2 (rtcr)</b>	Step 1	Age; Sex	.351	63.224	2,234	.000
	Step 2	Inattention	.000	.047	1,233	.829
	Step 3	NDI	.014	4.932	1,232	.027
<b>CRT2 (var)</b>	Step1	Age	.021	5.036	1,235	.026
	Step 2	Inattention	.023	5.619	1,234	.019
	Step 3	NDI	.001	.289	1,233	.591

Table 5: Results for the Hierarchical Regression analyses on the measures from the Trailmaking/Memory task.

<b>EF variable</b>		<b>Predictors</b>	<b>R Square</b> <small>Change</small>	<b>F</b> <small>Change</small>	<b>df</b>	<b>p</b>
<b>TM1 (mn)</b>	Step 1	Age	.252	79.655	1,236	.000
	Step 2	Inattention	.010	3.285	1,235	.071
	Step 3	NDI	.052	17.652	1,234	.000
<b>TM1 (sd)</b>	Step 1	Age	.317	109.363	1,236	.000
	Step 2	Inattention	.019	6.556	1,235	.011
	Step 3	NDI	.031	11.628	1,234	.001
<b>TM2 (mn)</b>	Step1	Age; Sex	.368	68.547	2,235	.000
	Step 2	Inattention	.006	2.085	1,234	.150
	Step 3	NDI	.034	13.358	1,233	.000
<b>TM2 (sd)</b>	Step 1	Age	.272	88.353	1,236	.000
	Step 2	Inattention	.008	2.734	1,235	.100
	Step 3	NDI	.014	4.684	1,234	.031