

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

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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 (CBCL), and Verbal IQ (VIQ) was estimated using subtests of the WISC-III. A reaction time task and three 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.

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1. Introduction

Executive functioning (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 & Ozonoff, 1996), and has been studied intensely over recent years in relation to developmental disorders (Hughes & Graham, 2002). In particular, deficits in inhibitory control (e.g., Barkley, 1997; Sergeant, 2000) have been identified in children with attention deficit hyperactivity disorder (ADHD). Pennington and Ozonoff (1996) reviewed the studies in which EF tasks were administered to children with ADHD, and found that of 60 EF measures used, children with ADHD performed significantly worse on 40 tasks. Children with ADHD consistently scored lower on measures of motor inhibition and working memory such as the sequential memory task and the self-ordered pointing task (Pennington & Ozonoff, 1996).

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; APA, 2000) and the International Classification of Disease and Related Health Problems (ICD-10; WHO, 1992). DSM-IV 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. Around 6% of children aged 5–11 years old will have motor problems that can be diagnosed as DCD.

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, 2003). In Sweden, this overlap has been categorized as Deficits in Attention, Motor control and Perception (DAMP; Gillberg, 1992), 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. 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).

Several researchers have provided generalized neurodevelopmental explanations for this comorbidity. Kaplan et al. (1998) postulated that ADHD, DCD 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). 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.

However, a general neurodevelopmental delay does not account for the fact that symptoms of developmental disorders appear mostly as patterns of recognizable syndromes. Also, certain syndromes have a tendency to be comorbid with particular syndromes, providing evidence against a purely generalized and diffuse explanation for developmental disorders. 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). 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. First, 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). These tasks 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 Hofsten, 1994). The detection and correction of errors are associated with EF (Sergeant, 2000), as is strategic planning (Pennington & Ozonoff, 1996).

As none of the above studies controlled for comorbid attention problems, it is possible that the deficits observed in children with DCD are due to comorbid attention problems. Wilson, Maruff, and McKenzie (1997) excluded children with a diagnosis of ADHD in their research on information processing in children with DCD. They tested children with and without DCD on covert orienting in a visuospatial attention task (COVAT) and found that children with DCD could not use advance information to prepare or program motor responses. This was exacerbated by the increased processing demands of more complex responses. When attention was directed by endogenous probability cues these children also 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.

The second argument for a link between DCD and EF is within models of EF. Several information processing models linking ADHD and EF have been postulated (e.g., Barkley, 1997; Schachar, Tannock, & Logan, 1993; Sergeant & van der Meere, 1990). In most of these models, motor behavior plays a central role. In Barkley's (1997) model of ADHD, behavioral inhibition permits the effective performance of four executive abilities, which then influence the motor system in the service of goal-directed behavior. 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. Sergeant described a three-tiered information processing system incorporating the child's energetic state. 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. The third level consists of the management or EF system that reviews performance and corrects errors. 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, there is evidence to suggest that impairments in DCD can 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. 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 and Ozonoff (1996). The Go/No-Go Task (GNG; Shue & Douglas, 1992) is the seminal operationalization of response inhibition, and has been closely linked to children with attention problems (Sergeant, 2000). The second measure of EF is a measure of the ability to update working memory as the task progresses to respond correctly. The final test, the Goal Neglect Task (GNT; Duncan, Emslie, Williams, Johnson, & Freer, 1996), measures the ability to use instructions to maintain goal-directed behavior. 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.

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. In this study, inattention was measured by parent report of attention using the attention subscale of the Child Behavior Checklist (CBCL; Achenbach, 1991), which has been shown to capture the inattentive symptomatology in ADHD in a population sample (Graetz, Sawyer, Hazell, Arney, & Baghurst, 2001). 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.

2. Method

2.1. Participants

The participants were 238 children (117 boys, 121 girls) between 6.67 and 14.83 years of age. Mean age was 10.58 years (S.D. = 2.26). Participants were recruited from 42 schools in the Perth metropolitan region, which represented the distribution of academic achievement within the state of Western Australia. Children who had an estimated Verbal IQ (VIQ) below 80 were excluded from the study. Mean estimated VIQ was 102 (S.D. = 12.80, range = 80–150), and mean inattention score (CBCL: Achenbach, 1991) was 2.83 (S.D. = 3.09, range = 0–20).

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 Neurodevelopmental Index (NDI) of the McCarron Assessment of Neuromuscular Development (MAND; McCarron, 1997). Their mean NDI was 73 (S.D. = 6.66, range = 55–80). Children who scored at or above 100 (43 girls and 33 boys) were included in the control group (mean NDI = 111, S.D. = 9.64, range = 100–155). There were no significant differences between the two groups for age [$t(102) = -1.5$, $P = .14$], estimated VIQ [$t(102) = -.37$, $P = .71$] or inattention [$t(102) = -.90$, $P = .37$].

2.2. Measures and apparatus

2.2.1. Wechsler Intelligence Scale for Children (WISC-III; Wechsler, 1991)

VIQ was estimated using the Vocabulary and Information subtests of the WISC-III. 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: $r = .75$).

2.2.2. McCarron Assessment of Neuromuscular Development (MAND; McCarron, 1997)

The MAND comprises 10 tasks, 5 assessing fine motor and 5 assessing gross motor skills. The scaled scores on each of these tasks are added and age norms, provided for children aged 3.5–18 years, are used to determine the NDI with a mean of 100 and standard deviation of 15. A score below 55 is classified as a severe disability, 55–70 a moderate disability and 71–85 a mild disability. Test-retest reliabilities after a month interval over the 10 tasks range from .67 to .98 (McCarron, 1997). Tan, Parker, and Larkin (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.

2.2.3. Child Behavior Checklist (CBCL; Achenbach, 1991)

This is a standardized questionnaire designed to measure internalizing and externalizing behavior problems in children aged 4–12 years. The parent form was used, and 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 1-week test-retest reliability is .92 (Achenbach, 1991).

2.2.4. Choice reaction time task (CRT)

This was a line-length discrimination task designed to assess visual inspection time (Anderson, 1988). It requires the child to press, as quickly as possible, a blue key if two lines 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).

2.2.5. Tasks measuring executive functioning (EF)

EF was assessed with a set of three computer-administered tasks, selected because of their known relations to ADHD (Pennington & Ozonoff, 1996) or because of their clear face validity.

2.2.5.1. Go/No-Go Task (GNG). GNG was modified from the GNG 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 1-s 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, no response is required. There were two trials of the task (GNG1 and GNG2), each consisting of 120 stimuli (60 ‘go’ and 60 ‘no-go’). 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 and non-ADHD children (Pennington & Ozonoff, 1996; Shue & Douglas, 1992).

2.2.5.2. Trailmaking/Memory Updating Task. 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). Children 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. There are two trials (TMT1 and TMT2) of 120 stimulus presentations each, of which 20 presentations are the target stimulus. For each presentation, a blue key is pressed if the stimulus is the target stimulus, otherwise a red key is pressed. Scores include the mean time (MN), standard deviation (S.D.) and the number correct out of 20 (NC).

2.2.5.3. Goal Neglect Task (GNT). 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. 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. There are 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 GNT has been positively related to age and IQ (Duncan et al., 1996).

2.3. Procedure

Children in grades 2–7 in Perth primary schools were invited to participate in ‘Project KIDS,’ a large-scale, long running project in which data are collected for child-related research in school holiday periods. Older children were recruited through participating Perth high schools. All testing was carried out with 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

enrollment of the child/children was then sent to the parents with a CBCL form to complete. Testing for Project KIDS took place on the campus of the University of Western Australia, in the Child Study Center. In order to maintain the children's interest and motivation 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. Testing was conducted in three 90-min sessions. The first test session was followed by a 30-min recess, and the second by a 60-min lunch break. Testing was administered by a team of researchers conducting related studies with the data collected. The order of test administration was not uniform. For most children, testing was completed within 4.5 h, but in some cases, testing required up to 5.5 h and included additional tests to those presented here. 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.

3. Results

3.1. 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 1. 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.

Age 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 seven 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 (CRT2(var) and TM1(S.D.)), and the positive correlations revealed that the higher the inattention the greater the variability of the measures. Note that in only one case (TM1(S.D.)) was the EF measure that correlated with NDI also correlated with inattention.

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

Table 1
Pearson correlations for each of the variables (*N* = 238)

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

* *P* < .05.

** *P* < .01.

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. 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.

3.1.1. Choice reaction time task

NDI was correlated with two measures in this task, namely CRT1(rtrcr) and CRT2(rtrcr). Inattention correlated with CRT2(var). For the CRT1(rtrcr), age in step 1 [*R*² = .381; *F*(1, 236) = 145.41, *P* = .000] and NDI in step 3 [*R*²_{Change} = .020; *F*_{Change}(1, 234) = 7.674, *P* = .006] were significant predictors, whereas for CRT2(rtrcr), these were age and sex in step 1 [*R*² = .351; *F*(2, 234) = 63.224, *P* = .000], and NDI in step 3 [*R*²_{Change} = .014; *F*_{Change}(1, 232) = 4.932, *P* = .027]. For the variance measure in trial 2 (CRT(var)), only age in step 1 [*R*² = .021; *F*(1, 235) = 5.036, *P* = .026], and inattention in step 2 [*R*²_{Change} = .023; *F*_{Change}(1, 234) = 5.619, *P* = .019] were significant predictors.

3.1.2. Go/No-Go Task

Only the first GNG trial was investigated 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]. There were no significant effects for inattention [*R*²_{Change} = .016; *F*_{Change}(1, 235) = 3.872, *P* = .0502] or NDI [*F*_{Change} < 1].

Table 2

Results for the hierarchical regression analyses on the measures from the Trailmaking/Memory Task

EF variable	Step	Predictors	R^2_{Change}	F_{Change}	df	P
TM1(MN)	1	Age	.252	79.655	1, 236	.000
	2	Inattention	.010	3.285	1, 235	.071
	3	NDI	.052	17.652	1, 234	.000
TM1(S.D.)	1	Age	.317	109.363	1, 236	.000
	2	Inattention	.019	6.556	1, 235	.011
	3	NDI	.031	11.628	1, 234	.001
TM2(MN)	1	Age, sex	.368	68.547	2, 235	.000
	2	Inattention	.006	2.085	1, 234	.150
	3	NDI	.034	13.358	1, 233	.000
TM2(S.D.)	1	Age	.272	88.353	1, 236	.000
	2	Inattention	.008	2.734	1, 235	.100
	3	NDI	.014	4.684	1, 234	.031

3.1.3. Trailmaking/Memory Updating Task

Table 2 summarizes 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 TM1(S.D.) only.

3.1.4. Goal Neglect Task

In the first step, both age and VIQ were entered and were statistically significant predictors of GNT [$R^2 = .391$; $F(2, 235) = 75.346$, $P = .000$]. However, neither inattention in step 2 [$R^2_{\text{Change}} = .008$; $F_{\text{Change}}(1, 234) = 2.992$, $P = .085$], nor NDI in step 3 [$R^2_{\text{Change}} = .007$; $F_{\text{Change}}(1, 233) = 2.91$, $P = .089$] were significant.

3.2. 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(S.D.) [$F(1, 97) = 22.52$, $P = .000$], TM2(MN) [$F(1, 97) = 12.45$, $P = .001$], and TM2(S.D.) [$F(1, 97) = 6.19$, $P = .015$]. These findings are consistent with those found using hierarchical regression analysis.

4. 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), 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., 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) 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., 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, VIQ and sex were taken into account, the only EF measure that was linked to the NDI was the Trailmaking/Memory Updating Task, considered a measure of both working memory and behavioral inhibition (Rabbitt, 1997). None of the other tests designed to measure response inhibition were 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 S.D.) 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 CRT 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., Piek & Skinner, 1999) and found it to be slower for the children with movement problems. In a recent study investigating timing and force control in boys, it was found that boys with a dual diagnosis of ADHD and DCD were more dysfunctional compared with an ADHD only group in terms of their RT and peak force (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, whereas timing problems in children with DCD has been associated with cerebellar function (e.g., Lundy-Ekman, Ivry, Keele, & Woollacott, 1991). 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.

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), 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.

5. 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 EF, 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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