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Motor coordination problems in children and adolescents with ADHD rated by parents and teachers: effects of age and gender

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Summary. *Objective*. ADHD is frequently accompanied by motor coordination problems. However, the co-occurrence of poor motor performance has received less attention in research than other coexisting problems in ADHD. The underlying mechanisms of this association remain unclear. Therefore, we investigated the prevalence of motor coordination problems in a large sample of children with ADHD, and the relationship between motor coordination problems and inattentive and hyperactive/impulsive symptoms. Furthermore, we assessed whether the association between ADHD and motor coordination problems was comparable across ages and was similar for both genders.

Method. We investigated 486 children with ADHD and 269 normal controls. Motor coordination problems were rated by parents (Developmental Coordination Disorder Questionnaire) and teachers (Groningen Motor Observation Scale).

Results. Parents and teachers reported motor coordination problems in about one third of children with ADHD. Problems of fine and gross motor skills, coordination skills and motor control were all related to inattentive rather than hyperactive/impulsive symptoms. Relative to controls, motor coordination problems in ADHD were still present in teenagers according to parents; the prevalence diminished somewhat according to teachers. Boys and girls with ADHD were comparably affected, but motor performance in controls was better in girls than in boys.

Conclusions. Motor coordination problems were reported in one third of children with ADHD and affected both boys and girls. These problems were also apparent in adolescents with ADHD. Clinicians treating children with ADHD should pay attention to co-occurring motor coordination problems because of the high prevalence and the negative impact of motor coordination problems on daily life.

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Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a persistent, heritable neurodevelopmental disorder that affects 3% to 5% of all children. It is characterized by a childhood-onset pattern of hyperactivity, inattention and impulsivity. The current classification system DSM-IV distinguishes between three subtypes: a mainly inattentive, a mainly hyperactive-impulsive and a combined subtype (American Psychiatric Association 1994). ADHD is a clinically heterogeneous condition, in which symptom overlap or co-occurrence of other conditions is the rule rather than the exception. Common comorbidities in children with ADHD include oppositional defiant and conduct disorders, mood disorders, anxiety disorders, tic disorders, autism spectrum disorders, and specific learning disorders such as dyslexia (Gillberg et al. 2004; Biederman and Faraone 2005; Rappley 2005).

Poor motor coordination or motor performance is another frequent coexisting problem in children with ADHD, though it has received less attention in research. Recent clinical and experimental evidence suggests a greater role of motor factors in ADHD than was considered before. Many children with ADHD have weak pragmatic motor skills and these may be associated with working memory performance, especially with the visual sketchpad of working memory. Structural MRI reports and neuropsychological findings like variability in timing and movement have refocused research on the role of the cerebellum in ADHD (Sergeant et al. 2006).

Clinical and epidemiological studies report that 30%–50% of children with ADHD suffer from motor coordination problems. These percentages are dependent of the type of motor assessment, referral sources and the cut-off points used (Gillberg 1998; Kadesjo and Gillberg 1998; Geuze et al. 2001; Wilson 2005). Motor coordination problems have previously been labelled ''Clumsy Child Syndrome'', ''Non-cerebral-palsy motor-perception dysfunction'', ''Minor Neurological Dysfunction'' or ''Dyspraxia of childhood'' (Miyahara and Mobs 1995; Hadders-Algra 2002; Magalhaes et al. 2006). Since 1994 the use of the term Developmental Coordination Disorder (DCD) predominates in the literature. In the Scandinavian countries the combination of ADHD and motor coordination problems has led to a special term, Deficits of Attention and Motor Perception (DAMP). DAMP in its severe form occurs in 1.2–2.0% of all 7 year olds (Gillberg 2003). Recently it was suggested to change the term DAMP into DCD-plus (Gibbs et al. 2007). The core characteristic of DCD involves a marked impairment in the performance of motor skills. This impairment has a negative impact on activities of daily life such as dressing, feeding, riding a bicycle, and/or academic achievement through poor handwriting skills. The condition is not due to medical conditions like cerebral palsy and the diagnosis should not be given to children with an IQ below 70.

It remains unclear which pathophysiological mechanisms, exactly, play a role in the origin of the co-occurrence of ADHD and motor coordination problems. Neuropsychological and neuro-imaging studies have demonstrated an underlying neurological substrate for ADHD. In ADHD dysfunction of frontosubcortical structures as well as reduced brain volumes have been established (Castellanos et al. 2002). Hypofunctional dopamine and noradrenalin systems are presumed in ADHD (Swanson et al. 2000). A dopamine-induced dysbalance of basal ganglia neurocircuitries may be an important pathophysiological component in ADHD and related movement problems (Archer and Beninger 2007). In the past it was suggested that children with ADHD have motor coordination problems as a result of their poor attention. Recent findings of inaccurate drawing in children with ADHD showed that these were not related to an attention deficit, but to a motor deficit as a separate entity from attention deficit (Miyahara et al. 2006).

Although there is robust evidence of clinically significant coexistence of ADHD and motor coordination problems, several aspects of the association between the two remain unclear.

First, data are inconsistent as to whether the association is similar for the inattentive and the hyperactive/impulsive symptoms of ADHD. It appears that mainly inattentive symptoms relate to motor coordination problems, though the relation between hyperactive/impulsive symptoms and motor coordination problems has also been reported (Kadesjo and Gillberg 1999; Piek et al. 1999). Furthermore, findings are inconsistent in how the association applies to various aspects of motor functioning (fine motor skills, gross motor skills, general coordination and control during movement). In general, most reports describe the strongest association between ADHD and fine motor problems, but some indicate a stronger relationship between ADHD and gross motor problems (Pitcher et al. 2003; Visser 2003; Tseng et al. 2004). In a genetic study into the possible shared aetiology of ADHD and DCD the inattentive subtype of ADHD was most strongly linked to control during movement (Martin et al. 2006). The inconsistencies in findings regarding the relation between inattentive and hyperactive/impulsive symptoms of ADHD and specific motor coordination problems warrant further research in this area.

Second, it is unknown whether the association of motor coordination problems and ADHD is comparable across ages. The limitations in daily life caused by poor motor performance vary with age. Four to six year old children mainly have problems with dressing, use of scissors, drawing, tying shoelaces, and riding a bicycle. Children seven to ten years old encounter difficulties in writing, dressing, swimming, constructional play, ball skills and outdoor play, while eleven to nineteen year olds have problems of clumsiness in writing, drawing, ball skills, poor table manners and tool use. It has been hypothesized that the puberty growth spurt, during which children tend to become more clumsy, would cause increased problems in children with poor motor performance (Visser 2003). This hypothesis was partly confirmed in a study, in which children with severe problems in motor performance kept motor coordination problems after the growth spurt, whereas children with mild motor difficulties did as well as control children after their rapid growth (Cantell et al. 2003). There are few data on the natural outcome and the prognostic value of motor coordination problems in children with ADHD. In a Scandinavian study 22-year-old adults with the combination of ADHD and DCD had a much poorer outcome than adults of the same age with ADHD only (Rasmussen and Gillberg 2000). The outcome in the group with the combination of ADHD and motor coordination problems was poorer with regard to social functioning and social relationships, school and work career, psychiatric problems and abuse of alcohol and drugs. All in all, these findings suggest that the association between ADHD and motor coordination problems is an important prognostic feature. The association may not be automatically comparable across ages and deserves further investigation.

A third issue concerns gender. Scientific literature on ADHD is mainly based on research in boys, since ADHD is more frequently observed in boys than in girls (Biederman et al. 2002). However, research into girls with ADHD has shown that they are as affected in their (neuro)-psychological functioning and behaviour as boys with ADHD (Seidman et al. 2005; Biederman et al. 2006). Even though girls form only a minority of children with ADHD, they should not be overlooked. So it was the third aim of our study to examine if the association of ADHD and motor coordination problems is similar for girls as it is for boys.

In sum, the present study aimed to examine the association between ADHD and motor coordination problems rated by parents and teachers in a large and well phenotyped ADHD-sample. We addressed the following questions: (1) is the association between ADHD and various aspects of motor coordination problems (fine motor problems, gross motor problems, general coordination problems, and control during movement problems) similar for the inattentive and hyperactive/impulsive symptoms, (2) is the association between ADHD and motor coordination problems comparable for children of different ages, and (3) is the association between ADHD and motor coordination problems similar for boys and girls.

Methods

Subjects

This study is part of The International Multicenter ADHD Genes study (IMAGE). IMAGE is an international collaborative study of 12 specialist centres in eight countries (Belgium, Germany, Holland, Ireland, Israel, Spain, Switzerland and United Kingdom) that aims to identify genes that increase the risk for ADHD using QTL linkage and association strategies (Kuntsi et al. 2006). Families with at least one child with the combined subtype of ADHD and at least one additional full sibling (regardless of ADHD-status) were recruited. In the Netherlands 365 families participated. Families were either invited to participate by their paediatrician or child psychiatrist, or reacted to advertisements in the Magazine or on the website of the association of Dutch Parents of children with ADHD. Data on motor functioning were collected from 337 ADHD families; these data were the focus of this study.

All children were between the ages of 5 and 19 years and were of European Caucasian descent. Participants were excluded if they had an IQ < 70, had suffered from neonatal problems leading to neurological conditions, general learning difficulties, a diagnosis of autism, or known genetic disorders, such as Down syndrome or Fragile-X-syndrome.

The control children were recruited from elementary schools and high schools in the Netherlands. Principals were contacted by mail seeking permission to ask the parents to participate. Parents who gave permission received questionnaires by mail. Both parents and teachers completed the Conners' long version. Control children had to obtain non-clinical scores on both the parent and teacher version (Conners'-N-scale: T-score ≤ 62) to rule out ADHD among them. Data on motor functioning were available from 147 control families.

Local ethics review boards in the Netherlands approved the study. Parents provided written informed consent for their children less than 12 years old; children aged 12 and older gave written informed consent themselves, in addition to their parents.

ADHD measures

The DSM-IV-based procedure used to establish an ADHD diagnosis in our sample is described fully elsewhere (Brookes et al. 2006). Briefly, screening questionnaires (parent and teacher Conners' long version rating scales (Conners 2003) and parent and teacher Strengths and Difficulties Questionnaires (Goodman 1997) were used to screen children for ADHD symptoms, and children who scored in the clinical range were subsequently invited for a complete diagnostic procedure. T-scores ≥ 63 on the Conners' ADHD-subscales (L for inattention, M for hyperactive-impulsive and N for total scores) and scores > 90th percentile on the SDQ-hyperactivity scale were considered as clinical. All children within a family scoring clinically on any of the questionnaires completed either by the parents or the teachers, were invited for a hospital visit, in which a semi-structured, standardized, investigator-based interview, the parental account of children's symptoms (PACS) (Taylor et al. 1986) was administered. The PACS covers DSM-IV symptoms of ADHD, conduct disorder, oppositional defiant disorder, anxiety, mood, and other internalizing disorders. The section on autistic behaviour traits was administered, if a clinical score (raw score ≥ 15) was obtained on the Social Communication Questionnaire (Berument et al. 1999). A standardised algorithm was applied to the PACS to derive each of the 18 DSM-IV ADHD symptoms, providing operational definitions for each behavioural symptom. These were combined with items that were scored 2 ("pretty much true") or 3 ("very much true") in the teacher-rated Conners' ADHD subscales (L, M and N) to generate the total number of hyperactive-impulsive and inattentive symptoms of the DSM-IV symptom list. Situational pervasiveness was defined as at least one symptom occurring within two or more different situations as indicated by the parents in the PACS interview, as well as the teachers' Conners' questionnaire.

Motor measures

Assessment of motor functioning was performed using the Developmental Coordination Disorder Questionnaire (DCD-Q), filled out by parents, and the 'Groningen Motoriek Observatieschaal' (Groningen Motor Observation Scale, GMO), filled out by teachers.

The DCD-Q identifies children with motor coordination problems in daily life. It is a widely accepted and in recent years frequently used questionnaire to screen for motor coordination problems. In the Netherlands it was recently translated and validated (Wilson et al. 2000; Martin et al. 2006; Schoemaker et al. 2006). The DCD-Q contains 17 items. For each item, parents are asked to compare the degree of similarity of their child with other children of the same age, and to rate this on a 5-point scale, ranging from "not at all like this child," to "extremely like this child". The total score varies from 17 to 85, with low scores representing poor performance. There are 4 subscales: fine motor control/handwriting, gross motor control/

planning, general coordination and control during movement. The internal consistency of the questionnaire is high (alpha = 0.88) (Wilson et al. 2000). Scores within the lower 10th percentile, between the 10th to the 25th percentile and above the 25th percentile of normal controls represent the presence of DCD, suspected DCD and no DCD, respectively. In this study we used the 10th percentile as the cut-off to indicate the presence of motor coordination problems.

The GMO was developed at the University of Groningen in the Netherlands and is an observation checklist to be filled out by teachers (Dellen van et al. 1990). It contains 18 items to be scored on a 4-point scale, ranging from "not at all like this child" to "like this child". The total score varies from 18 to 72. High scores on the GMO indicate poor performance. The cut-off scores to indicate the presence of DCD, suspected DCD or no DCD depend on age and gender. A score below the 15th percentile of an age- and gender-matched control group is considered suspicious for DCD, a score below the 5th percentile as presence of DCD. The 15th percentile cut-off was used as the cut-off in this study to indicate motor coordination problems. The GMO is validated for the ages 5–11, for children 12 years and older we used the 11-years cut-off points.

Data analysis

A *p*-value of < 0.05 was used to indicate statistical significance. All statistics were performed with SPSS (version 14.0; SPSS, Inc. 2005). Prorating using the mean of the list was performed in case a questionnaire (DCD-Q or GMO) had a maximum of five missing items. This was done for 32 children with ADHD (7%) and 9 control children (3%) for the DCD-Q and for 77 children with ADHD (16%) and 26 control children (10%) for the GMO.

Because of non-normality of the GMO data, we applied a Van der Waerden transformation (Van der Waerden 1950), which reduced skewness and kurtosis. A similar procedure was used on the data of the DCD-Q, so that both questionnaire scores were standardized. The GMO scores were mirrored, in addition, so that scores on all motor variables would imply the same meaning: a low score was indicative of poor motor performance, a high score of good motor performance. Pearson correlations between the different motor variables were calculated. To address the first research question, a regression analysis was conducted with Conners' inattention and hyperactive/impulsive subscales (averaged across parent and teacher) as predictors for DCD-Q and GMO total scores as well as subscale scores of the DCD-Q to investigate whether the association between ADHD and different motor coordination problems (fine motor problems, gross motor problems, general coordination problems, and control during movement problems) was similar for the inattentive and hyperactive/impulsive symptoms. Because of non-normality of the independent variable we created quartiles based on inattention and hyperactive subscales of the Conners questionnaire instead of using the continuous Conners scores. To address the second research question, an ANOVA was performed with diagnosis (2 levels: ADHD vs. control) as between subjects variable, age as covariate, and the total GMO and DCD-Q scores as dependent measures. Also, the interaction between diagnosis and age was implemented into the model, in order to investigate whether group differences would attenuate with age. Finally, an ANOVA was used with both diagnosis and gender as between subjects variables and the total scores of the DCD-Q and GMO as dependent measures. The interaction between diagnosis and gender was implemented into the model, to test whether the effect of gender on motor performance was comparable across diagnoses.

Results

A total of 486 children (375 boys, 111 girls) with ADHD (337 index patients and 149 affected siblings) were included in the study, as were 269 control children (108 boys, 161 girls, from 147 families). Table 1 shows demographics. Of the children with ADHD, 364 had DCD-Q data available, as had 267 control children. For the GMO data were available of 459 ADHD-affected participants and 247 controls. Both scales were available for 335 patients and 246 controls. Raw scores (mean ± SD) for the Conners' ADHD scales and the two motor scales, DCD-Q and GMO, are presented in Table 1 according to gender.

Motor variables, as measured by the DCD-Q and GMO, correlated significantly with each other on all subscales (as shown in Table 2). These correlations suggested that both questionnaires tapped comparable aspects of motor functioning, yet were distinct enough to be valuable as separate

Table 1. *Demographics and raw scores on ADHD rating scales and motor scales*

	ADHD ($n = 486$)				Control ($n = 269$)			
	Females		Males		Females		Males	
n	111		375		161		108	
ADHD diagnosis								
Inattentive	18.0%		5.6%					
Hyperactive-impulsive	10.8%		3.2%					
Combined	71.1%		91.2%					
Age	mean	SD	mean	SD	mean	SD	mean	SD
	11.7	3.3	11.6	3.0	11.2	3.0	11.6	2.7
ADHD								
Conners' parent	76.0	13.5	73.5	9.1	46.3	4.4	46.3	4.4
Conners' teacher	70.0	14.4	67.4	9.3	46.9	3.7	45.4	5.1
DCD-Q								
Total scores (17–85)	55.2	10.7	54.9	11.9	72.0	9.5	66.9	11.6
Subscales								
Control	16.0	4.1	17.7	5.5	24.6	5.1	23.4	5.6
Fine	9.9	2.6	9.2	3.3	17.9	2.9	15.4	3.7
Gross	12.1	3.2	12.2	3.2	15.8	2.9	14.8	3.2
Coordination	7.2	2.7	7.3	2.6	13.8	1.7	13.1	2.3
GMO								
Total scores (18–72)	28.3	10.8	33.3	12.0	20.4	5.2	23.9	10.0
Motor-affected	%		%		%		%	
DCD-Q:								
Cut off at p10	29.4		33.0		1.9		8.3	
GMO:								
Cut off at p15	29.2		34.0		7.3		9.2	
DCD-Q and GMO	16.3		17.3		0.7		3.1	

Table 2. *Correlations between motor variables*

	GMO total	DCD-Q total	DCD fine	DCD gross	DCD coord.	DCD control
GMO total	1	0.54	0.51	0.35	0.48	0.37
DCD-Q total		1	0.83	0.68	0.76	0.85
DCD fine			1	0.38	0.59	0.57
DCD gross				1	0.51	0.44
DCD coord.					1	0.43
DCD control						1

DCD-Q Developmental coordination disorder questionnaire, *GMO* Groninger motoriek obeservatielijst (mirrored). All correlations were significant $p<0.01$; *fine* fine motor control, *gross* gross motor control, *coord.* general coordination, *control* control during movement.

measures. Using established cut-off points (< 10th percentile on the DCD-Q motor scale, and < 15th percentile on the GMO), 33–34% of all boys and 29% of all girls with ADHD were affected according to one of both scales (Table 1). Eighty-six percent of children who were reported to be nonaffected by their parents were also nonaffected according to their teachers.

Association of inattentive and hyperactive/impulsive symptoms of ADHD with motor coordination problems

A significant effect of diagnosis on the total scores of the DCD-Q and GMO was observed ($F(1,581)=9.53$, $p=0.002$ and $F(1,581)=42.11$, $p<0.001$, respectively). Children with ADHD had significantly more motor coordination problems than controls. Analysis of ADHD inattention and hyperactive-impulsive subscales (averaged across Conners' parents and teachers) showed that high scores on the inattention scale were significantly predictive for all motor coordination problems assessed by the two motor scales. Hyperactive-impulsive symptoms only related to fine motor problems and coordination assessed by the DCD-Q (Table 3). Conners' total scores predicted all motor scores significantly (Total predictiveness, Table 3). Fine motor problems and problems in general coordination as measured by the DCD-Q as well as the GMO scores were predicted by Conners' total scores especially well.

Association ADHD and motor coordination problems at different ages

A significant main effect of age was found for the DCD-Q ($F(1,581)=5.66$, $p=0.02$), in which older children were reported to have less motor coordination problems than younger children. A significant interaction between diagnosis and age was present for the GMO ($F(1,581)=8.19$, $p=0.004$), but not for the DCD-Q ($F(1,581)=0.73$, $p=0.40$). For the scores on the GMO, this indicated that younger children with ADHD deviated more from controls than older children with ADHD did (see Fig. 1).

Association ADHD and motor coordination problems across gender

Gender affected motor performance rated on the GMO ($F(1,583)=30.00$, $p<0.001$), in which boys had more motor coordination problems than girls. For the DCD-Q, gender affected motor performance as well ($F(1,583)=7.44$, $p=0.007$) and there was an almost significant interaction between diagnosis and gender ($F(1,583)=3.79$, $p=0.05$), indicating that the difference between children with ADHD and controls might not be comparable for girls and boys. It appeared that normal girls had less motor coordination problems than normal boys on the DCD-Q ($F(1,245)=11.46$, $p=0.001$), whereas girls with ADHD had similar motor coordination problems as boys with ADHD ($F(1,338)=0.30$, $p=0.59$). No interaction effect was found for the GMO ($F(1,583)=0.05$, $p=0.82$) (see Fig. 2).

Table 3. *Inattention and Hyperactivity/Impulsivity as Predictors of Motor Problems*

	Inattention		Hyperactivity/impulsivity		Total predictiveness/shared variability		
	t	*p*	*t*	*p*	*F*	*p*	r^2
DCD-Q total score	−5.50		−1.66	0.10	58.98	<0.001	0.17
Subscale fine	−5.23	<0.001	−2.16	0.03	61.35	<0.001	0.19
Subscale gross	−2.33	0.02	−0.39	0.70	8.68	<0.001	0.03
Subscale coordination	−5.20	<0.001	−2.28	0.02	64.47	<0.001	0.19
Subscale control	−3.45	0.001	−0.28	0.78	16.68	<0.001	0.06
GMO total score	−7.49	<0.001	−1.19	0.23	88.63	<0.001	0.19

DCD-Q Developmental Coordination Disorder Questionnaire, *GMO* Groninger Motor Observation-scale; *Fine* fine motor control; *Gross* gross motor control; *Coordination* general coordination; *Control* control during movement.

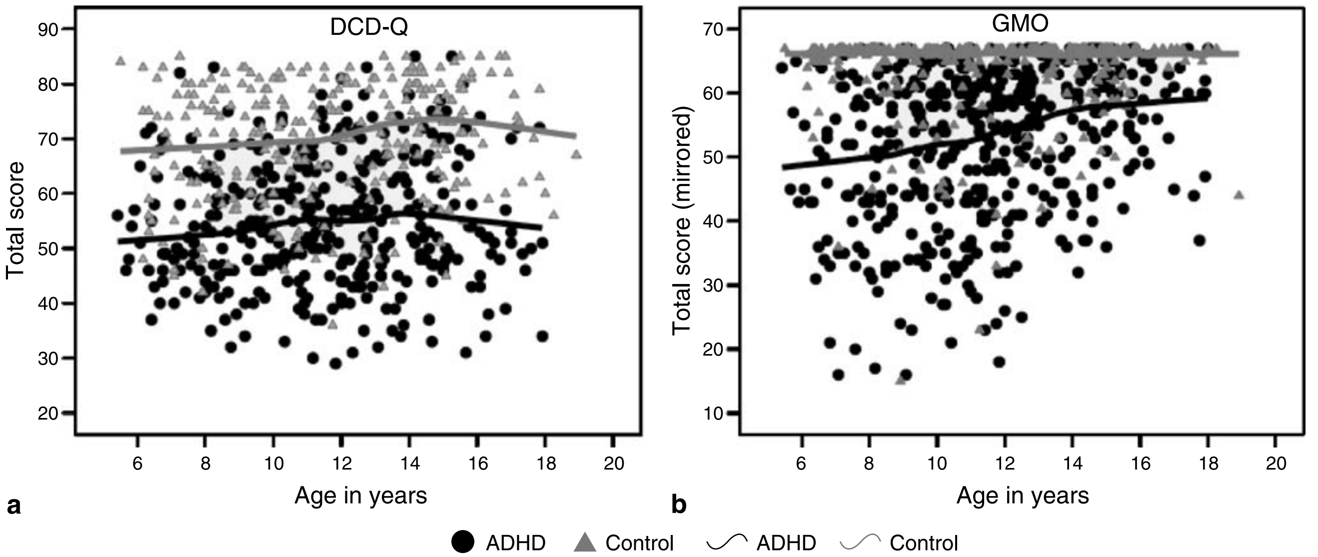

Fig. 1. Motor problems as assessed with the DCD-Q (Parents, (a)) and GMO (Teachers, (b)) in children with ADHD and controls from age 5 to 19. Total scores on both questionnaires indicate that controls perform better than ADHD-affected children at all ages. Furthermore, children with ADHD improve somewhat with age according to the teachers (*GMO*), but not according to the parents (*DCD-Q*)

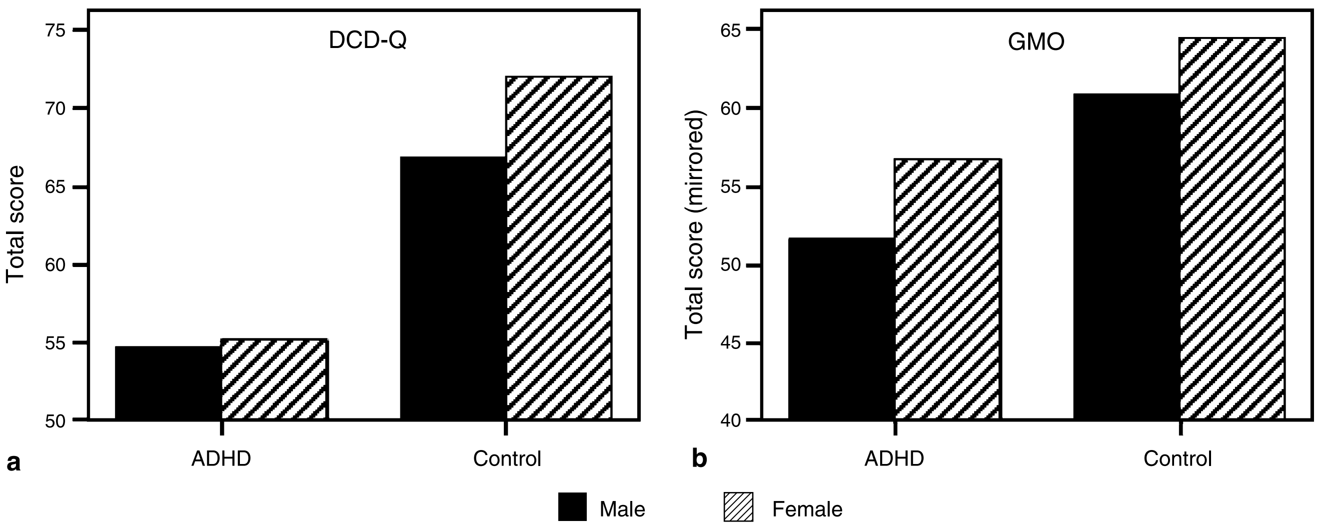

Fig. 2. Motor problems as assessed with the DCD-Q (Parents, (a)) and the GMO (Teachers, (b)) in Children with ADHD and controls across gender. Gender affects motor performance rated on the DCD-Q and GMO with boys having more motor problems than girls. On the DCD-Q, normal girls have less motor problems than normal boys, whereas girls with ADHD have similar motor problems as boys with ADHD

Discussion

The present study sought to extend our knowledge about the association of ADHD and motor coordination problems. Our results confirm previous research demonstrating a consistent relationship between ADHD and poor motor performance with high levels of motor coordination problems in ADHD. The converse is also true: others have found increased levels of ADHD in children previously diagnosed with DCD (Kadesjo and Gillberg 1999). The question is whether motor coordination problems should be called a comorbidity of ADHD, or rather are to be viewed as a co-occurrent phenomenon. In a recent article on comorbidity of tic disorders and ADHD the authors provide a comprehensive review of various possible models of comorbidity, that can be generalized to other psychiatric disorders (Banaschewski et al. 2007). In these models, comorbidity might be due to symptomatic phenocopy, in which one disorder is mistaken for the other due to overlap in the diagnostic criteria, or causes symptoms of the other. Secondly, a common etiology might lead to comorbidity with both disorders simply being alternative expressions of the biological or genetic deficit. A third possibility is that the co-occurrence of both disorders really reflects a disorder with an independent nosology. Last but not least, two disorders might show ''true'' comorbidity, meaning that one increases the risk for the other or that they share common or overlapping risk factors.

In the case of ADHD and motor coordination problems published data (Martin et al. 2006) as well as our own preliminary data (Fliers et al. in preparation) point into the direction of an overlapping etiology, with a strong shared heritability as well as unique contributors. In that case, motor coordination problems in ADHD should be viewed as a ''true'' comorbidity. However, it is too early to decide in this issue, yet.

On the level of the brain the coexistence of the disorders could reflect manifestations of a shared genetically determined disturbed dopamine pathway. The two disorders might share neural substrates and/ or functional alterations of these substrates, for example in the basal ganglia, the prefrontal cortex and their connecting loops. Also the role of lateralization and interaction between the two hemispheres has to be taken into consideration regarding ADHD and motor coordination problems (Roessner et al. 2004).

The overall percentage of children with motor coordination problems in our study (34% in boys, 29% in girls) is lower than that found in previous studies from Sweden, Canada, and Australia, that described about 50% motor affected children (Kadesjo and Gillberg 1998; Dewey et al. 2002; Pitcher et al. 2003). This may be due to sampling issues, since we excluded children with, neonatal problems leading to neurological conditions, given the context of our genetic study. Other reasons may be the use of questionnaires, only, and the fact that we used the 10th percentile as cut-off on the DCD-Q, whereas other studies have used the less strict 15th percentile.

Our first research question focused on the association between the various types of motor coordination problems and inattentive versus hyperactive/impulsive symptoms of ADHD. Scores on the Conners' scales, averaged across parents and teachers, were strong predictors of the GMO and DCD-Q total scores, as well as all DCD-Q subscales (fine motor control, gross motor control, general coordination and control during movement). Separating the effect of inattentive from hyperactive/impulsive symptoms in the regression models, inattentive rather than hyperactive/impulsive symptoms were found to be related to the DCD-Q total score and to its subscales. This finding could possibly help to end controversies of earlier studies. It supports theoretical models that emphasize deficits in information processing as the core problems underlying both ADHD and DCD (Sergeant et al. 2006). It raises the question whether the combination of ADHD-inattentive subtype plus motor coordination problems constitutes a biologically distinct subtype, as could be the case for ADHD plus Conduct Disorder (Banaschewski et al. 2003). Using stratification of ADHD according to comorbidity might help to identify biologically meaningful diagnostic subtypes or endophenotypes useful in genetic studies (Banaschewski et al. 2007).

The second question was whether the association between ADHD and motor coordination problems is comparable for children of different ages. We found a significant effect of age on the presence of motor coordination problems, with older children having less reported motor coordination problems than younger ones. This age effect was similar for ADHD and control children as observed by parents. In contrast, teacher reports using the GMO indicated that the improvement of motor coordination problems over age was stronger in children with ADHD than in controls. This discrepancy between parents and teachers may be explained by characteristics of the GMO, since this instrument does differentiate less well between average and good motor performance (Dellen van et al. 1990). Further, situational factors and informant perspectives may play a role. Overall, however, adolescents with ADHD appeared to be as severely affected with motor coordination problems as younger children with ADHD, compared to healthy controls of the same age. This indicates that deviance, rather than delay, characterizes the development of co-existing motor coordination problems over age in ADHD. This is contrary to older views but in accordance with more recent evidence of the (partial) persistence of structural brain abnormalities (Hall 1988; Castellanos et al. 2002; Shaw 2007).

The third question on effects of gender revealed that according to parents, boys and girls with ADHD were comparably affected in their motor skills. Teachers, however, indicated that boys with ADHD were more severely impaired in their motor skills than girls, which is in accordance with the literature (Gillberg and Kadesjo 2003). Girls with ADHD deviate more from control girls than boys with ADHD deviate from control boys in the view of their parents. This finding needs further attention but implies that the clinical impairment of girls with ADHD and co-occurring DCD should not be underestimated.

Strengths and possible limitations of the study

Our results should be interpreted in the context of the strengths and limitations of the study. Strengths are the large sample size, the careful approach to diagnose ADHD and the broad age range. Possible limitations are the use of questionnaire data and the absence of objective motor tests or assessments of motor functioning by experienced clinicians. Therefore we were not entitled to label our motor-affected children as suffering from ''DCD''. As yet there is no gold standard of assessment instruments to diagnose DCD, although the Movement Assessment Battery for Children (M-ABC) is the most widely used assessment to identify DCD (Polatajko and Cantin 2005). Using validated questionnaires does give a good indication of suspected DCD but does not lead to an official diagnosis of DCD. Using questionnaires however does allow investigating a much larger sample of children. The DCD-Q was recently validated in a community sample of Dutch children from 4 to 12 years old and showed the same cut off scores as the original Canadian validation study (Wilson et al. 2000; Schoemaker et al. 2006). The DCD-Q is known to be a reliable instrument to exclude motor coordination problems in a normal population (Crawford et al. 2001). Recently, the DCD-Q was also used in an ADHD population (Schoemaker et al. 2005), where it was able to detect motor coordination problems in a clinical group of ADHD children. However, an official validation of the DCD-Q in an ADHD population has not been performed to our knowledge. A study concerning this topic is underway (Fliers et al. in preparation).

Another limitation of our study is the cross-sectional design. Studying age effects should ideally be complemented by prospective longitudinal measurements of motor functioning in children with ADHD. Furthermore, since our study was designed as a sib pair study, more than one child was included in more than half of the families. The non-independency of these data did not appear to be a problem in addressing the research questions in this particular study, as it was meant to be a descriptive report of the prevalence of motor coordination problems in children with ADHD. We repeated the analyses with only one affected child per family, which gave essentially the same results, though with less power. Another possible limitation is the fact that boys were overrepresented in the ADHD group, compared to the control group. This had to do with the fact that ADHD is more frequently diagnosed in boys, and healthy girls were more willing to participate in the control group of our study than healthy boys.

Clinical implications

The high rate of motor coordination problems in children and adolescents with ADHD compared to control children has clinical consequences. Poor motor performance is highly related to low self-esteem, to higher levels of anxiety and to poor social functioning (Skinner and Piek 2001; Cummins et al. 2005). Also, recent findings describe a higher risk of obesity and vascular disease in adolescents with DCD (Cairney et al. 2005). This risk is attributable to their physically less active life style. Recently, interventions for motor coordination problems were reviewed (Wilson 2005). It seems that especially the child-centred and task-oriented methods that include cognitive components are useful therapies (Schoemaker et al. 2003; Polatajko and Cantin 2005; Niemeijer et al. 2007; Sugden 2007). Clinicians diagnosing and treating children and adolescents with ADHD should additionally assess whether motor coordination problems are present, and offer those with ADHD and co-existing motor coordination problems evidence-based interventions.

Conclusion

The present study adds to the evidence that ADHD and motor coordination problems are closely related, both in boys and girls, and both in younger and older children. The overlap of ADHD and motor coordination problems could be understood as the result of an aberrant brain development, probably affecting complex neuronal networks. Given preliminary evidence for a shared genetic background future research on this issue should be directed to finding factors that underlie both conditions, both genetic as well as environmental. A better understanding of the pathophysiology would have implications for prevention and treatment of these conditions that are so disturbing to children in daily life.

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References

American Psychiatric Association (1994) Diagnostic and statistical manual of mental disorders, 4th edn. American Psychiatric Association, Washington, DC

Archer T, Beninger RJ (2007) Movement disorders: neurodevelopment and neurobehavioural expression. J Neural Transm 114: XXXIII–XXXXLI

Banaschewski T, Brandeis D, Heinrich H, Albrecht B, Brunner E, Rothenberger A (2003) Association of ADHD and conduct disorder –

brain electrical evidence for the existence of a distinct subtype. J Child Psychol Psychiatry 44: 356–376

Banaschewski T, Neale BM, Rothenberger A, Roessner V (2007) Comorbidity of tic disorders and ADHD. Eur Child Adolesc Psychiatry 16 Suppl 1: 5–14

Berument SK, Rutter M, Lord C, Pickles A, Bailey A (1999) Autism screening questionnaire: diagnostic validity. Br J Psychiatry 175: 444–451

Biederman J, Faraone SV (2005) Attention-deficit hyperactivity disorder. Lancet 366: 237–248

Biederman J, Mick E, Faraone SV, Braaten E, Doyle A, Spencer T, et al (2002) Influence of gender on attention deficit hyperactivity disorder in children referred to a psychiatric clinic. Am J Psychiatry 159: 36–42

Biederman J, Monuteaux MC, Mick E, Spencer T, Wilens TE, Klein KL, et al (2006) Psychopathology in females with attention-deficit/hyperactivity disorder: a controlled, five-year prospective study. Biol Psychiatry 60: 1098–1105

Brookes K, Xu X, Chen W, Zhou K, Neale B, Lowe N, et al (2006) The analysis of 51 genes in DSM-IV combined type attention deficit hyperactivity disorder: association signals in DRD4, DAT1 and 16 other genes. Mol Psychiatry 11: 934–953

Cairney J, Hay JA, Faught BE, Hawes R (2005) Developmental coordination disorder and overweight and obesity in children aged 9–14 y. Int J Obes (Lond) 29: 369–372

Cantell MH, Smyth MM, Ahonen TP (2003) Two distinct pathways for developmental coordination disorder: persistence and resolution. Hum Mov Sci 22: 413–431

Castellanos FX, Lee PP, Sharp W, Jeffries NO, Greenstein DK, Clasen LS, et al (2002) Developmental trajectories of brain volume abnormalities in children and adolescents with attention-deficit/hyperactivity disorder. JAMA 288: 1740–1748

Conners CK (2003) Conners' rating scales-revised: technical manual, 6th edn. MHS

Crawford SG, Wilson BN, Dewey D (2001) Identifying developmental coordination disorder: consistency between tests. Phys Occup Ther Pediatr 20: 29–50

Cummins A, Piek JP, Dyck MJ (2005) Motor coordination, empathy, and social behaviour in school-aged children. Dev Med Child Neurol 47: 437–442

Dellen van T, Vaessen W, Schoemaker MM (1990) Clumsiness: definition and selection of subjects. In: Kalverboer AF (ed) Developmental biopsychology; experimental and observational studies in children at risk. University of Michigan Press, Ann Arbor, MI

Dewey D, Kaplan BJ, Crawford SG, Wilson BN (2002) Developmental coordination disorder: associated problems in attention, learning, and psychosocial adjustment. Hum Mov Sci 21: 905–918

Geuze RH, Jongmans M, Schoemaker M, Smits-Engelsman B (2001) Developmental coordination disorder. Hum Mov Sci 20: 1–5

Gibbs J, Appleton J, Appleton R (2007) Dyspraxia or developmental coordination disorder? Unravelling the enigma. Arch Dis Child 92: 534–539

Gillberg C (1998) Hyperactivity, inattention and motor control problems: prevalence, comorbidity and background factors. Folia Phoniatr Logop 50: 107–117

Gillberg C (2003) Deficits in attention, motor control, and perception: a brief review. Arch Dis Child 88: 904–910

Gillberg C, Gillberg IC, Rasmussen P, Kadesjo B, Soderstrom H, Rastam M, et al (2004) Co-existing disorders in ADHD – implications for diagnosis and intervention. Eur Child Adolesc Psychiatry 13 Suppl 1: I80–I92

Gillberg C, Kadesjo B (2003) Why bother about clumsiness? The implications of having developmental coordination disorder (DCD). Neural Plast 10: 59–68

Goodman R (1997) The strengths and difficulties questionnaire: a research note. J Child Psychol Psychiatry 38: 581–586

Hadders-Algra M (2002) Two distinct forms of minor neurological dysfunction: perspectives emerging from a review of data of the groningen perinatal project. Dev Med Child Neuro 44: 561–571

Hall DM (1988) Clumsy children. Br Med J (Clin Res Ed) 296: 375–376

Kadesjo B, Gillberg C (1998) Attention deficits and clumsiness in Swedish 7-year-old children. Dev Med Child Neurol 40: 796–804

Kadesjo B, Gillberg C (1999) Developmental coordination disorder in Swedish 7-year-old children. J Am Acad Child Adolesc Psychiatry 38: 820–828

Kuntsi J, Neale BM, Chen W, Faraone SV, Asherson P (2006) The IMAGE project: methodological issues for the molecular genetic analysis of ADHD. Behav Brain Funct 2: 27

Magalhaes LC, Missiuna C, Wong S (2006) Terminology used in research reports of developmental coordination disorder. Dev Med Child Neurol 48: 937–941

Martin NC, Piek JP, Hay D (2006) DCD and ADHD: a genetic study of their shared aetiology. Hum Mov Sci 25: 110–124

Miyahara M, Mobs I (1995) Developmental dyspraxia and developmental coordination disorder. Neuropsychol Rev 5: 245–268

Miyahara M, Piek J, Barrett N (2006) Accuracy of drawing in a dual-task and resistance-to-distraction study: motor or attention deficit? Hum Mov Sci 25: 100–109

Niemeijer AS, Smits-Engelsman BC, Schoemaker MM (2007) Neuromotor task training for children with developmental coordination disorder: a controlled trial. Dev Med Child Neurol 49: 406–411

Piek JP, Pitcher TM, Hay DA (1999) Motor coordination and kinaesthesis in boys with attention deficit-hyperactivity disorder. Dev Med Child Neurol 41: 159–165

Pitcher TM, Piek JP, Hay DA (2003) Fine and gross motor ability in males with ADHD. Dev Med Child Neurol 45: 525–535

Polatajko HJ, Cantin N (2005) Developmental coordination disorder (dyspraxia): an overview of the state of the art. Semin Pediatr Neurol 12: 250–258

Rappley MD (2005) Clinical practice. Attention deficit-hyperactivity disorder. N Engl J Med 352: 165–173

Rasmussen P, Gillberg C (2000) Natural outcome of ADHD with developmental coordination disorder at age 22 years: a controlled, longitudinal, community-based study. J Am Acad Child Adolesc Psychiatry 39: 1424–1431

Roessner V, Banaschewski T, Uebel H, Becker A, Rothenberger A (2004) Neuronal network models of ADHD – lateralization with respect to interhemispheric connectivity reconsidered. Eur Child Adolesc Psychiatry 13 Suppl 1: I71–I79

Schoemaker MM, Flapper B, Verheij NP, Wilson BN, Reinders-Messelink HA, de KA (2006) Evaluation of the developmental coordination disorder questionnaire as a screening instrument. Dev Med Child Neurol 48: 668–673

Schoemaker MM, Ketelaars CE, van ZM, Minderaa RB, Mulder T (2005) Deficits in motor control processes involved in production of graphic movements of children with attention-deficit-hyperactivity disorder. Dev Med Child Neurol 47: 390–395

Schoemaker MM, Niemeijer AS, Reynders K, Smits-Engelsman BC (2003) Effectiveness of neuromotor task training for children with developmental coordination disorder: a pilot study. Neural Plast 10: 155–163

Seidman LJ, Biederman J, Monuteaux MC, Valera E, Doyle AE, Faraone SV (2005) Impact of gender and age on executive functioning: do girls and boys with and without attention deficit hyperactivity disorder differ neuropsychologically in preteen and teenage years? Dev Neuropsychol 27: 79–105

Sergeant JA, Piek JP, Oosterlaan J (2006) ADHD and DCD: a relationship in need of research. Hum Mov Sci 25: 76–89

Shaw P, Gornick M, Lerch J, Addington A, Seal J, Greenstein D et al. (2007) Polymorphisms of the dopamine D4 receptor, clinical outcome, and

cortical structure in attention-deficit/hyperactivity disorder. Arch Gen Psychiatry 64: 921–931
Skinner RA, Piek JP (2001) Psychosocial implications of poor motor coordination in children and adolescents. Hum Mov Sci 20: 73–94
Sugden D (2007) Current approaches to intervention in children with developmental coordination disorder. Dev Med Child Neurol 49: 467–471
Swanson JM, Flodman P, Kennedy J, Spence MA, Moyzis R, Schuck S et al. (2000) Dopamine genes and ADHD. Neurosci Biobehav Rev 24: 21–25
Taylor E, Schachar R, Thorley G, Wieselberg M (1986) Conduct disorder and hyperactivity: I. Separation of hyperactivity and antisocial conduct in British child psychiatric patients. Br J Psychiatry 149: 760–767
Tseng MH, Henderson A, Chow SM, Yao G (2004) Relationship between motor proficiency, attention, impulse, and activity in children with ADHD. Dev Med Child Neurol 46: 381–388
Van der Waerden BL (1950) Birationale Transformation von Iinearen Scharen auf algebraischen Mannigfaltigkeiten. Math Z 51: 502–524
Visser J (2003) Developmental coordination disorder: a review of research on subtypes and comorbidities. Hum Mov Sci 22: 479–493
Wilson BN, Kaplan BJ, Crawford SG, Campbell A, Dewey D (2000) Reliability and validity of a parent questionnaire on childhood motor skills. Am J Occup Ther 54: 484–493
Wilson PH (2005) Practitioner review: approaches to assessment and treatment of children with DCD: an evaluative review. J Child Psychol Psychiatry 46: 806–823