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ORIGINAL ARTICLE

Motor development of children with attention deficit hyperactivity disorder

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Objective: To compare both global and specific domains of motor development of children with attention deficit hyperactivity disorder (ADHD) with that of typically developing children.
Methods: Two hundred children (50 children with clinical diagnoses of ADHD, according to the DSM-IV-TR and 150 typically developing controls), aged 5 to 10 years, participated in this cross-sectional study. The Motor Development Scale was used to assess fine and global motricity, balance, body schema, and spatial and temporal organization.
Results: Between-group testing revealed statistically significant differences between the ADHD and control groups for all domains. The results also revealed a deficit of nearly two years in the motor development of children with ADHD compared with the normative sample.
Conclusion: The current study shows that ADHD is associated with a delay in motor development when compared to typically developing children. The results also suggested particular difficulties in certain motor areas for those with ADHD. These results may point to plausible mechanisms underlying the relationship between ADHD and motor difficulties.

Keywords: Attention deficit hyperactivity disorder; child psychiatry; interdisciplinary relations; behavioral neurology; rehabilitation

Introduction

Attention deficit hyperactivity disorder (ADHD) is a highly comorbid and heterogeneous condition characterized by inattention, impulsivity, and hyperactivity.[1] Research has reported ADHD prevalence estimates of approximately 5.9-7.1% in children and adolescents with a male to female ratio of approximately 3:1 in population samples and up to 10:1 in clinical samples.[1] Whereas research has also reported various etiological factors contributing to ADHD, there is general consensus that ADHD may be classified as a neurodevelopmental disorder. In fact, the recently released DSM-5 has included it as part of this class of disorders.[2] The DSM-5 also notes an important relationship between ADHD and motor difficulties; however, it states that although mild motor delays often co-occur with ADHD, these are not specific to the disorder.[2] Furthermore, it is noted that any marked motor delays or "clumsiness" found in those with ADHD should be diagnosed separately. Further research in this area is needed as the basis of the relationship between ADHD and motor delay remains poorly understood.[3,4] In addition, motor problems may have a severe impact on children's daily lives and occur in 30-50% of those with ADHD.[3,4]

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Previous research has investigated specific motor difficulties (e.g., fine or gross motor ability) in ADHD[4] as well as the relationship between the cardinal symptoms of ADHD and motor performance.[5,6] Other studies have examined motor development in children with ADHD, namely an assessment of motor ability involving many facets of a child's performance, such as balance, fine and gross motor skills, and cognitive aspects related to the motor act (e.g., temporal and spatial organization).[7-9] Findings have revealed a wide range of motor problems in ADHD, including excessive overflow movements, poor timing, force control and greater variability in motor outcomes, poor balancing, difficulties in both learning and performing a variety of motor skills, and deficits in fine motor skills.[4] Pitcher et al.[4] also demonstrated that children with ADHD had significantly poorer fine and gross motor ability when compared with control children with typical development. Furthermore, children with ADHD have also scored significantly lower on tasks demanding upper limb and eye-hand coordination and visual-motor integration compared with controls.[10]

Tseng et al.[5] investigated the relationship between motor performance, attention, impulse control, and hyperactivity in children with ADHD, and found that attention and impulse control were important predictors of both fine and gross motor skills in children with ADHD.[5] Kroes et al.[6] examined whether quantitative and/or qualitative aspects of motor performance in 5- and 6-year-old children could predict ADHD, and found that two of the four qualitative domains (Dynamic Balance and

Diadochokinesis and Manual Dexterity) as well as the total qualitative score at 5 and 6 years of age predicted ADHD diagnosis one year later.

Although research linking ADHD with motor skills has increased, few studies have examined the extent of the delay in motor development in children with ADHD. In their study, Goulardins et al.[8] identified a delay of over one year between the motor age and chronological age of children with ADHD. The authors suggested that the cortical maturation delay in the prefrontal areas demonstrated by Shaw et al.[11] might partially explain these findings. The delay in reaching peak of cortical thickness for those with ADHD was most prominent in prefrontal regions linked to the ability to inhibit unwanted thoughts and responses, executive control of attention, evaluation of rewards of action, working memory, and the motor control necessary and appropriate for an expected action.[11]

The understanding of ADHD must consider the context of what is developmentally appropriate and consider the age-related changes in the neurobiology of patients at different ages. However, despite the clinical complexity of this disorder, it is possible to identify different cognitive, motor, and emotional processes that might, if altered, influence ADHD symptomatology.[12] Therefore, investigations into delayed motor development in children with ADHD may provide important information about these children's wellbeing, monitor developmental alterations, identify delays, and verify the effectiveness of intervention strategies. In addition, identifying whether there is global delay or impact on specific aspects of motor development is crucial in understanding the basis of these delays as well as highlighting particular strengths and weaknesses of these individuals.[13]

It is important to note the impact on quality of life for children with ADHD regardless of motor problems, since ADHD is a biopsychosocial disorder. However, there is strong evidence for a poorer prognosis in those individuals with both ADHD and motor problems, including poorer psychosocial and emotional functioning (i.e., higher levels of depressive symptomatology).[14] Furthermore, a positive relationship has been found between quality of life and motor development in children with ADHD; therefore, it is plausible that improving motor performance may ultimately develop skills, prevent children from acting impulsively on their feelings, and improve their self-concept and self-esteem.[7]

The current study intended to further examine the extent of the relationship between motor coordination and ADHD in children from Brazil, and identify the types of motor skills that are impacted. Thereby, the objective was to compare both global and specific domains of motor development in children with ADHD and typically developing children.

Methods

Procedures

This was a cross-sectional study, approved by the Ethics Committee of the Universidade do Sul de Santa Catarina (UNISUL) (n. 07.374.4.01.III) and the State Secretary of Education of Santa Catarina, Brazil. An invitation to participate in this study was sent to ten public schools within the Tubarão area, Santa Catarina, Brazil. Parental consent forms were obtained for all participants included in this study.

Participants

A total of 1,666 children from ten public schools in Brazil were involved in this study. Of these, 200 children, aged between 5 and 10 years, completed the entire testing and were divided into two groups: a group of 50 children with clinical diagnoses of ADHD (five girls and 45 boys; mean age: 8 years and 11 months) and a control group of 150 typically developing children (20 girls and 130 boys, mean age 8 years and 8 months). Because of the gender differences related to ADHD diagnosis,[1] the male:female ratio was purposely maintained in the control group in order to ensure the homogeneity of the samples.

The exclusion criteria for both groups were intellectual disability, autism, physical conditions (i.e., visual, hearing, heart, rheumatic, orthopedic), neurological disorder, and regular use of medication. No children were receiving medication for ADHD symptomatology. This information was obtained through a parent-rated psychosocial questionnaire, which includes questions about pregnancy, childbirth, motor development, previous diagnosis, socioeconomic conditions, and child behavior.

The initial screening process of the ADHD group consisted of providing teachers with an information guide describing ADHD symptoms. Next, the teachers identified 200 children as potential subjects. Subsequently, the teachers and parents of these nominated children were asked to complete the Swanson, Nolan, and Pelham-IV (SNAP-IV) Rating Scale. Those children who presented with six inattentive subtype symptoms and/or six hyperactive/impulsive symptoms, according to both parents and teachers, were then referred for formal assessment. A multidisciplinary team and a specialist medical doctor carried out further assessment, and ADHD was diagnosed according to DSM-IV-TR criteria.[15] The DSM-IV-TR was used in the current study as data collection occurred prior to the publication of the DSM-5. However, this does not affect the characteristics of the groups because ADHD diagnostic criteria for children and adolescents have not changed. The comorbidities that commonly occur with ADHD, such as developmental coordination disorder (DCD), learning disorders, mood disorders, oppositional defiant disorder, and conduct disorder were not screened, and therefore were not excluded from the current study.

One hundred and twenty children were assessed by the multidisciplinary team. Of these, 50 were diagnosed with ADHD, and the remaining 70 were excluded from the study. Once the ADHD diagnosis was confirmed by the multidisciplinary team, all children were further assessed by the main researcher. Following data collection, the children were referred to be treated by a multidisciplinary team at the Mother and Child Outpatient Clinic, School of Medicine, UNISUL, Brazil.

The control group comprised 150 typically developing children selected by their teachers for having an average school performance and no significant problems related to inattention or hyperactivity/impulsivity. Furthermore, any child with a previous diagnosis of ADHD according to the parent-rated psychosocial questionnaire was excluded from the control group.

Measures

The SNAP-IV – Teacher and Parent Rating Scale is a behavior rating scale, including nine items of inattention and nine hyperactivity/impulsivity items, based on DSM-IV-TR criteria.[15] The Brazilian reduced version of the SNAP-IV (18 items) was used in the current study. The scale allows parents and teachers to rate each symptom on a four-point scale from 0 (not at all) to 3 (very much). A clinical cutoff of six inattentive subtype items and/or six hyperactive/impulsive items was used in this study, according to DSM-IV-TR criteria.[16] The SNAP-IV scale is widely used to assess ADHD symptoms. It has been used in many treatment studies, including the Multimodal Treatment Study for ADHD, and has shown acceptable internal consistency.[17]

The Motor Development Scale (MDS)[13] was designed to assess the following domains: fine and global motricity, balance, body schema, spatial and temporal organization, and the level of motor development in 2- to 11-year-old children.[13] It includes specific tasks for each age, with the complexity of tasks increasing with age. Examinees proceed to tasks at the previous or next developmental age depending on task success. Fine motricity assesses fine motor and visuomotor skills and was based on the performance of tasks such as tying a knot, drawing trail, threading, throwing a small ball at a target, and touching the finger tips with the thumb. The global motricity domain involves gross motor as well as dynamic balance tasks including jumping on one foot and walking on a straight line. Balance includes static balance tasks of standing on tiptoe, standing on one foot with eyes open and closed, and stork balance. Body schema includes tasks such as imitation of gestures and graphic speed. Spatial organization comprises laterality tasks (self and others' body perspective) as well as constructing a rectangle from two triangles. Temporal organization includes tasks such as repeating verbal phrases and reproducing visual or auditory stimuli. The MDS provides values for motor ages for each domain (sum of tests results, expressed in months), for general motor age (mean of all motor ages), and for motor quotients (motor age for each domain or general motor age divided by chronological age and multiplied by 100). Positive ages or negative ages are determined by the difference between chronological age and general motor age. Motor ages demonstrate the extent of the delay in relation to the chronological age for the general and specific domains. The MDS motor quotients classify levels of motor development, ranging from very low (equal to or below 69 points), lower (70-79 points), normal low (80-89 points), normal medium (90-109 points), normal high (110-119 points), high (120-129 points), and very high (equal to or up to 130 points). According to the MDS, normal low, lower, and very low correspond to mild, moderate, and severe risk for delayed motor development, respectively.[13] The MDS has shown to be a reliable and valid instrument to assess motor development in the Brazilian population.[13] The MDS was individually administered to the ADHD and the control children in a single, 40-minute session.

Statistical analysis

Tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk) revealed non-normal distributions for most of the motor variables in both groups. Therefore, the Mann-Whitney Test (*U* statistic) was used to compare the difference between groups. All statistical analyses were performed using the SPSS version 20. Significance level was set at $p < 0.05$.

Results

As expected, more males than females[1] were diagnosed with ADHD, with a male to female ratio of 9:1. However, gender ratios between the ADHD and control groups did not differ (p = 0.54). In addition, there was no statistically significant difference for chronological age between groups (p = 0.11).

The difference between chronological age and general motor age revealed only negative ages for both groups. The descriptive analysis of the distribution of the motor ages between groups is shown in Table 1. When compared with the normative sample from the MDS, the results revealed a negative age of 23.4 months for the ADHD group and 7.8 months for the control group, suggesting that both the ADHD and control groups have lower than average motor scores.

Table 1 Distribution of motor ages between groups

	Control group		ADHD group	
	Mean ± SD	Negative ages*	Mean ± SD	Negative ages*
Fine motricity	103.5±20.7	-0.8	86.5±18.1	-20.5
Global motricity	100.8±14.1	-3.5	93.2±20.4	-13.8
Balance	98.8±22.4	-5.5	79.8±23.7	-27.2
Body scheme	96.8±19.7	-7.5	90.9±21.2	-16.1
Spatial organization	93.4±18.8	-10.9	77.5±14.1	-29.5
Temporal organization	85.6±21.4	-18.7	73.4±12.5	-33.6

ADHD = attention deficit hyperactivity disorder; SD = standard deviation.
* Difference between motor ages and chronological ages, in months.

Table 2 Distribution in percentage of children for each motor quotient

Classification	Control group	ADHD group
Normal high	6.7	0
Normal medium	59.3	6.0
Normal low	26.7	42.0
Lower	7.3	40.0
Very low	0	12.0

ADHD = attention deficit hyperactivity disorder.

The percentage of children in each motor quotient classification can be found in Table 2. More than half (52%) of the children with ADHD were classified as below normal motor development (lower and very low), in contrast, only 7.3% of the control group had lower motor development.

Table 3 describes the MDS results for the control and ADHD groups, respectively: mean, standard deviation (SD), median, minimum and maximum values for general motor age, general motor quotient, motor quotients, their MDS classification on each motor skill, the comparison between groups, and the effect size. The general motor quotient classified the motor development of children with ADHD as lower (78.4) and normal medium (93.3) for the control children. Statistically significant differences were found between the groups in all motor quotients and in general motor age.

Discussion

The present study compared the motor development of ADHD and typically developing children, and revealed a mean deficit in motor development of 23.4 months for the ADHD group. Furthermore, the general motor quotient on the MDS classified the level of motor development of the control group as normal medium (i.e., not at risk) and lower (i.e., moderate risk for delayed motor development) for children with ADHD. Thus, the motor profile revealed that children with ADHD demonstrate difficulties in motor performance when compared with typically developing children, which is in line with other research.[3,8,9]

Below-normal motor development (lower and very low) was observed in 52% of the children with ADHD, which is close to the range reported in other studies. Clinical and epidemiological studies have reported that 30-50% of children with ADHD suffer from motor coordination problems.[3,4,8] It has been noted that the type of motor assessment, referral sources, and the cutoff points used may explain the differences between studies.[3,4,8]

Although there is strong evidence for the clinically significant coexistence of ADHD and motor coordination problems, several aspects regarding the association remain unclear.[3] Most studies in the area have examined the relationship between DCD and ADHD,[3,18] a comorbidity with significant impact. However, little has been investigated regarding these motor problems as an integral symptom of ADHD.[7] Other research findings have classified the level of motor development of children with ADHD as normal (normal low), although they have

Table 3 Distribution of mean, standard deviation, median, minimum and maximum for general motor age and motor quotients and the Motor Development Scale (MDS) classification of both groups

	Control group				ADHD group					
	Mean ± SD	Median	Min-max	Classification	Mean ± SD	Median	Min-max	Classification	p-value	r
General motor age (months)	96.5±13.3	96.0	58-126		83.6±14.7	85.5	54-106		< 0.01	0.35
General motor quotient	93.3±9.7	92.5	72-118	Normal medium	78.4±8.0	78.0	62-97	Low	< 0.01	0.58
Motor quotients										
Fine motricity	99.8±15.8	101.0	66-145	Normal medium	81.1±12.0	82.0	60-108	Normal low	< 0.01	0.48
Global motricity	98.2±15.7	100.0	40-143	Normal medium	87.0±13.5	88.0	52-119	Normal low	< 0.01	0.34
Balance	94.9±17.6	92.5	49-143	Normal medium	73.8±15.2	72.0	47-107	Lower	< 0.01	0.47
Body scheme	93.3±13.0	91.0	65-135	Normal medium	84.9±12.5	84.8	60-112	Normal low	< 0.01	0.26
Spatial organization	91.1±20.3	91.0	50-161	Normal low	73.6±13.3	75.0	46-102	Lower	< 0.01	0.39
Temporal organization	83.3±20.1	77.0	50-152	Normal medium	69.8±12.6	69.5	47.6-95	Very low	< 0.01	0.29

ADHD = attention deficit hyperactivity disorder; Min-max = minimum-maximum; SD = standard deviation.
p-values were determined by Mann-Whitney (*U* statistic).

demonstrated poorer performance when compared with typically developing children.[7-9] It is possible that the motor problems in ADHD may be partly explained by neurological abnormalities found in structures related to motor control, such as the cerebellum and basal ganglia.[8] Morphometric and neuroimaging studies have been performed to identify abnormalities in brain regions for individuals with ADHD and have demonstrated reductions in volumes: total brain, prefrontal cortex, caudate nucleus, globus pallidus, anterior cingulate, and cerebellum, especially in the vermis and inferior posterior lobe.[19] Furthermore, Shaw et al.[11] found a delay in the maturation of cortical thickness in these children compared with healthy controls, especially in prefrontal regions linked to the ability to inhibit unwanted thoughts and answers, executive control of attention, evaluation of rewards action, motor control and precision appropriate to the expected action, and working memory. Recent findings have suggested an existence of common neurophysiological substrates underlying both motor and attention problems.[20]

The present study also revealed statistically significant differences between the groups for most motor quotients assessed: fine and global motricity, balance, body schema, and spatial and temporal organization. Motor quotients for each domain demonstrated that typically developing children performed within the normal medium range, except for spatial organization. Conversely, children with ADHD were at risk for delayed development in all domains, especially for balance, spatial and temporal organizations.

Previous researches have shown that children with ADHD have balance problems,[6,21] suggesting difficulties in keeping the trunk in an erect position using the proximal stabilizing muscles of the column.[21] It is plausible that abnormalities in the cerebellum may explain the association between ADHD and balance as research has implicated the cerebellum in both balance difficulties and ADHD.[8] Although Buderath et al.[22] observed minor balance and stepping disorders in individuals with ADHD, these motor deficits were compatible with mild cerebellar dysfunction. Also, problems in executive functions commonly found in ADHD, such as attention, mental calculation, orientation, and memory, interact with postural control and are associated with balance functions.[23] It is important to highlight the significant association between the children's static/dynamic balance ability and socialization behaviors in ADHD, even though this relationship still requires further research so that the underlying causes or mediating factors can be determined.[24]

Children with ADHD also performed in the low classification ranges for spatial and temporal organization, which is in line with a previous study by Poeta et al.[9] The spatial organization tasks involve processes of localization, orientation, visual-spatial recognition, perception of distance, and speed.[8] ADHD is associated with anomalous laterality and these individuals are not only characterized by a shift in handedness, but may be better described as exhibiting a more general condition of lateralization.[25] Hale et al.[26] concluded that ADHD individuals demonstrated greater right hemisphere and reduced left hemisphere contribution, and these hemispheric differences were due to management or use of available cognitive resources rather than inherent capacity. Roessner et al.[27] argued that attention should also be paid to the left-right aspects of functional and structural brain anomalies in ADHD, especially in regard to co-existing problems.

In the present study, temporal organization was the most impacted domain in children with ADHD, and is related to concepts of order, duration, frequency, and rhythm, which involves processes of perception and memory of succession, processing, storage and rememorization.[13] This concept is typically modified by the involvement of executive functions. Klimkeit et al.[28] suggested that ADHD is characterized by slow motor preparation (but not motor execution) and deficits in selective attention, vigilance, and executive functions. The very low motor quotient for temporal organization found for the ADHD group may be explained by the poorer performance on tasks involving executive functions for both children with ADHD and motor impairment.

Although children with ADHD demonstrated difficulties in fine and global motricity, and body scheme, these domains were classified as normal low range. Fine motor skills and body scheme involve visuomotor and fine motor skill tasks. Previous studies have indicated that poor fine motor ability is not a result of the ADHD symptomatology, but rather of the comorbid motor impairments.[4,18] Children with ADHD and without DCD have demonstrated "proper" fine motor fluency and flexibility, but have shown fine motor difficulties when comorbid with DCD.[18] Nevertheless, inattention has been associated with poorer fine motor skill,[5,29,30] and unsmooth movement performance has shown to be significantly related to the severity of core ADHD symptoms.[18] Children with ADHD without DCD have also scored significantly lower on tasks demanding upper limb and eye-hand coordination and visual-motor integration compared with controls.[10]

Global motricity and dynamic balance tasks were considered to be at a mild risk for delayed motor development for the ADHD group, which is in line with Piek et al.[29] who demonstrated that children with both inattention and hyperactivity are at risk for difficulties with gross motor skills. Emck et al.[31] also reported that gross motor performance is affected in children with psychiatric disorders, including ADHD. They found a developmental delay of approximately 3 years for both locomotion and object control, indicating that the psychiatric group performed significantly worse than typically developing children.[28] Goulardins et al.[8] suggested that the impairment of fine and global motricity may be related to the prefrontal cortex abnormalities found in ADHD, which causes deficits in organization, working memory, and planning and attention. In addition, a dysfunction in the cerebellum – thalamus – prefrontal circuit may cause deficits in executive function, inhibition, and motor control.[19]

The strength of our study lays in the use of a test of motor ability that has been standardized in Brazil. The motor tests most commonly used around the world, such as Bruininks-Oseretsky Test of Motor Proficiency (second edition)[32] and the McCarron Assessment of

Neuromuscular Development,[33] have not been translated and culturally adapted to Brazilian Portuguese. The MDS is a useful tool for the systematic assessment of global and specific domains of motor development. Nevertheless, future research is needed for the translation, cultural adaptation, and validation of the MDS in other countries because cross-cultural studies not only identify differences between individuals and cultures, but also help us understand their common characteristics.

The traditional subtypes of ADHD (predominantly inattentive, predominantly hyperactive-impulsive, and combined)[15] were not analyzed in this paper because they have been downgraded to presentations, according to the new DSM-5 classification.[2] Previous studies have reported a general decline in hyperactivity-impulsivity symptoms across development and a general increase in inattentive symptoms,[34] which indicates that the presentation of ADHD differs according to age of diagnosis. A developmental change in the presentation of motor functioning may also occur in ADHD.

The current study has some limitations, including the non-exclusion and identification of comorbidities that commonly occur with ADHD, such as DCD, learning disorders, mood disorders, oppositional defiant disorder, and conduct disorder. However, although ADHD is a heterogeneous condition, this study revealed that only 6% of the sample were classified with normal medium motor development. This study highlights an important relationship between ADHD and motor development. Future studies should be designed to control for comorbidities when investigating the motor problems related to ADHD. It is also important to note, however, that controlling for comorbidity in clinical samples is difficult, as 60% of ADHD cases have shown to have comorbid psychiatric diagnoses. Comparing the pattern of comorbidities might also provide useful information regarding differential responses to treatment.

The current findings support previous studies by Fliers et al.[3] and Pitcher et al.,[4] highlighting the need for further research in the area. Motor problems in children with ADHD remain a neglected area of clinical attention. Understanding and identifying delay in motor development is necessary to develop intervention strategies that may improve the quality of life of individuals with ADHD. This is crucial considering that the severity of ADHD symptoms and treatment in childhood have shown to be significant predictors for the persistence of clinical symptoms into adulthood.

Individuals with ADHD may fall, bump into objects, or knock things over. However, Williams et al.[35] have recommended that the motor impairment in ADHD should not be dismissed as a by-product of inattention. The previous version of the DSM-IV-TR considered that motor problems were usually caused by distractibility and impulsiveness rather than by motor impairment.[15] The DSM-5 states that mild delays in motor development are not specific to ADHD but often co-occur.[2] The increased motor activity that may occur in ADHD must be distinguished from repetitive motor behavior and bouts of multiple tics, which marks other neurodevelopmental disorders.

Also, careful observation across different contexts is required to ascertain if a lack of motor competence is attributable to distractibility and impulsiveness rather than to DCD.[2] Therefore, this study highlights the need for a multidisciplinary team in the assessment and treatment of these individuals, including physical and occupational therapists. All health specialists treating children with ADHD should be attentive to the high frequency of co-occurring motor problems,[3] because children who have both ADHD and motor impairment are particularly at heightened risk of psychological distress.[36]

Our results provide support for an overlap between motor difficulties and ADHD, which has important practical implications. Furthermore, the current study also points to the possibility of executive function as a mechanism underlying the relationship between motor development and ADHD and suggests possible brain deficits related to the motor difficulties of these children. The findings also suggest that, when investigating the relationship between ADHD and motor development, it is important to consider the different processes that are required when performing specific motor tasks, including motor and cognitive aspects. This may clarify the conflicting findings from previous studies and lead to a better understanding of the nature of the relationship between ADHD and motor problems.

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Disclosure

The authors report no conflicts of interest.

References

1 Willcutt EG. The prevalence of DSM-IV attention-deficit/hyperactivity disorder: a meta-analytic review. Neurotherapeutics. 2012;9:490-9.
2 American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5). Arlington: American Psychiatric Publishing; 2013.
3 Fliers EA, Franke B, Lambregts-Rommelse NN, Altink ME, Buschgens CJ, Nijhuisvan der Sanden MW, et al. Undertreatment of Motor Problems in Children with ADHD. Child Adolesc Ment Health. 2009;15:85-90.
4 Pitcher TM, Piek JP, Hay DA. Fine and gross motor ability in males with ADHD. Dev Med Child Neurol. 2003;45:525-35.
5 Tseng MH, Henderson A, Chow SM, Yao G. Relationship between motor proficiency, attention, impulse, and activity in children with ADHD. Dev Med Child Neurol. 2004;46:381-8.
6 Kroes M, Kessels AG, Kalff AC, Feron FJ, Vissers YL, Jolles J, et al. Quality of movement as predictor of ADHD: results from a prospective population study in 5- and 6-year-old children. Dev Med Child Neurol. 2002;44:753-60.
7 Goulardins JB, Marques JC, Casella EB. Quality of life and psychomotor profile of children with attention deficit hyperactivity disorder (ADHD). Arq Neuropsiquiatr. 2011;69:630-5.
8 Goulardins JB, Marques JC, Casella EB, Nascimento RO, Oliveira JA. Motor profile of children with attention deficit hyperactivity disorder, combined type. Res Dev Disabil. 2013;34:40-5.
9 Poeta LS, Rosa-Neto F. [Motor assessment in school-aged children with indicators of the attention deficit/hyperactivity disorder]. Rev Neurol. 2007;44:146-9.

10 Shen IH, Lee TY, Chen CL. Handwriting performance and underlying factors in children with Attention Deficit Hyperactivity Disorder. Res Dev Disabil. 2012;33:1301-9.
11 Shaw P, Eckstrand K, Sharp W, Blumenthal J, Lerch JP, Greenstein D, et al. Attention-deficit/hyperactivity disorder is characterized by a delay in cortical maturation. Proc Natl Acad Sci U S A. 2007;104: 19649-54.
12 Bush G. Attention-deficit/hyperactivity disorder and attention networks. Neuropsychopharmacology. 2010;35:278-300.
13 Rosa Neto F. Manual de avaliação motora. Porto Alegre: Artmed; 2002.
14 Rasmussen P, Gillberg C. Natural outcome of ADHD with developmental coordination disorder at age 22 years: a controlled, longitudinal, community-based study. J Am Acad Child Adolesc Psychiatry. 2000;39:1424-31.
15 American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, Text Revision (DSM-IV-TR). Arlington: American Psychiatric Publishing; 2000.
16 Swanson JM, Kraemer HC, Hinshaw SP, Arnold LE, Conners CK, Abikoff HB, et al. Clinical relevance of the primary findings of the MTA: success rates based on severity of ADHD and ODD symptoms at the end of treatment. J Am Acad Child Adolesc Psychiatry. 2001;40:168-79.
17 Bussing R, Fernandez M, Harwood M, Wei Hou, Garvan CW, Eyberg SM, et al. Parent and teacher SNAP-IV ratings of attention deficit hyperactivity disorder symptoms: psychometric properties and normative ratings from a school district sample. Assessment. 2008;15:317-28.
18 Lee IC, Chen YJ, Tsai CL. Kinematic performance of fine motor control in attention-deficit/hyperactivity disorder: the effects of comorbid developmental coordination disorder and core symptoms. Pediatr Int. 2013;55:24-9.
19 Valera EM, Faraone SV, Murray KE, Seidman LJ. Meta-analysis of structural imaging findings in attention-deficit/hyperactivity disorder. Biol Psychiatry. 2007;61:1361-9.
20 McLeod KR, Langevin LM, Goodyear BG, Dewey D. Functional connectivity of neural motor networks is disrupted in children with developmental coordination disorder and attention-deficit/hyperactivity disorder. Neuroimage Clin. 2014;4:566-75.
21 Stray LL, Stray T, Iversen S, Ruud A, Ellertsen B, Tonnessen FE. The Motor Function Neurological Assessment (MFNU) as an indicator of motor function problems in boys with ADHD. Behav Brain Funct. 2009;5:22.
22 Buderath P, Gartner K, Frings M, Christiansen H, Schoch B, Konczak J, et al. Postural and gait performance in children with attention deficit/hyperactivity disorder. Gait Posture. 2009;29:249-54.
23 Jacobs JV, Horak FB. Cortical control of postural responses. J Neural Transm. 2007;114:1339-48.
24 Wang HY, Huang TH, Lo SK. Motor ability and adaptive function in children with attention deficit hyperactivity disorder. Kaohsiung J Med Sci. 2011;27:446-52.
25 Reid HM, Norvilitis JM. Evidence for anomalous lateralization across domain in ADHD children as well as adults identified with the Wender Utah rating scale. J Psychiatr Res. 2000;34:311-6.
26 Hale TS, Zaidel E, McGough JJ, Phillips JM, McCracken JT. Atypical brain laterality in adults with ADHD during dichotic listening for emotional intonation and words. Neuropsychologia. 2006;44: 896-904.
27 Roessner V, Banaschewski T, Uebel H, Becker A, Rothenberger A. Neuronal network models of ADHD -- lateralization with respect to interhemispheric connectivity reconsidered. Eur Child Adolesc Psychiatry. 2004;13:I71-9.
28 Klimkeit EI, Mattingley JB, Sheppard DM, Lee P, Bradshaw JL. Motor preparation, motor execution, attention, and executive functions in attention deficit/hyperactivity disorder (ADHD). Child Neuropsychol. 2005;11:153-73.
29 Piek JP, Pitcher TM, Hay DA. Motor coordination and kinaesthesis in boys with attention deficit-hyperactivity disorder. Dev Med Child Neurol. 1999;41:159-65.
30 Noda W, Ito H, Fujita C, Ohnishi M, Takayanagi N, Someki F, et al. Examining the relationships between attention deficit/hyperactivity disorder and developmental coordination disorder symptoms, and writing performance in Japanese second grade students. Res Dev Disabil. 2013;34:2909-16.
31 Emck C, Bosscher RJ, Van Wieringen PC, Doreleijers T, Beek PJ. Gross motor performance and physical fitness in children with psychiatric disorders. Dev Med Child Neurol. 2011;53:150-5.
32 Bruininks RH. Bruininks-Oseretsky test of motor proficiency: Examiner's Manual. Circle Pines: American Guidance Service; 1997.
33 McCarron LT. MAND: McCarron assessment of neuromuscular development, fine and gross motor abilities. Dallas: Common Market Press; 1997.
34 Larsson H, Dilshad R, Lichtenstein P, Barker ED. Developmental trajectories of DSM-IV symptoms of attention-deficit/hyperactivity disorder: genetic effects, family risk and associated psychopathology. J Child Psychol Psychiatry. 2011;52:954-63.
35 Williams J, Omizzolo C, Galea MP, Vance A. Motor imagery skills of children with Attention Deficit Hyperactivity Disorder and Developmental Coordination Disorder. Hum Mov Sci. 2013;32: 121-35.
36 Missiuna C, Cairney J, Pollock N, Campbell W, Russell DJ, Macdonald K, et al. Psychological distress in children with developmental coordination disorder and attention-deficit hyperactivity disorder. Res Dev Disabil. 2014;35:1198-207.