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# Motor Proficiency in Children with Attention Deficit Hyperactivity Disorder: Associations with Cognitive Skills and Symptom Severity

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**SUMMARY**

**Objectives:** Of children with Attention Deficit Hyperactivity Disorder (ADHD), 45-70% have motor skill problems, which can adversely affect social competence, peer relations, and academic skills. The aim of this study is to assess motor skills in school-aged children with ADHD, and to elucidate if there are any relationships between ADHD symptoms and cognitive function.

**Method:** Included in this study were 58 children (38 ADHD, 20 controls) between 8-11 years of age. Children were diagnosed with ADHD via the Schedule for Affective Disorders and Schizophrenia for School-Aged Children Present and Lifetime Version. The parents were asked to fill out the Conner's' Parent Rating Scale – Revised Short Turkish Form to determine the symptom domains and the symptom severity. The Wechsler Children's Intelligence Scale-IV was used to assess cognitive skills, and the Bruininks -Oseretsky Motor Proficiency Test was used to assess motor skills.

**Results:** Children with ADHD had impaired performance in many motor skill areas compared to the controls. Impairments in fine motor skills were correlated with problems in attention, working memory, and processing speed. In the ADHD group, age was not correlated with motor skills.

**Conclusion:** The multistage clinical evaluation of ADHD should include screening for problems in motor skills. If deficiencies are found, the child should be clinically evaluated for motor proficiency and, if necessary, should be referred for appropriate objective assessment and intervention programs.

**Keywords:** attention deficit hyperactivity disorder, motor skills, children.

## INTRODUCTION

Motor development is defined as gaining the ability to control voluntary movements via physical growth and neural maturation; it has been shown to be correlated with social and cognitive development (Fernandes et al. 2016). Recent studies have shown that progress with fine motor skills in the preschool years predicts academic success at school age, while several reviews have stressed that bilateral coordination is strongly associated with fluent intelligence and fine motor skills with visiospatial processing (Grissmer et al. 2010, van der Fels et al. 2015). In addition, several studies have shown that motor skills are associated with executive functions, mainly inhibition, working memory, planning, cognitive flexibility, and decision making, which in turn are associated with social-emotional development and academic skills (Diamond 2013, Fernandes et al. 2016). The prefrontal cortex (PFC) is the central brain region for executive functions; it is the last of the brain regions to mature, and is most prone to the effects of physical activity and physical skills (Halperin and Healey 2011). Neuroimaging studies have shown that

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the brain regions traditionally thought to be associated with motor activity (cerebellum and basal ganglia) and cognitive function (PFC) are activated simultaneously during the execution of certain cognitive or motor tasks (Budde et al. 2008, Diamond 2000).

When viewed from the perspective of psychiatric disorders, attention deficit hyperactivity disorder (ADHD) is located at the crossroads between motor skill and executive function problems. ADHD is a neurodevelopmental disorder, and is the most common psychiatric disorder in children; its main characteristic is inattention and/or a hyperactivity-impulsivity pattern, which impairs daily functioning (Faraone and Biederman 1998). Between 45-70% of children with ADHD suffer motor skill problems that adversely affect their social adaptation, peer relations, and academic skills (Barkley 1998, Harvey and Reid 1997, Kadesjo and Gillberg 1998, Kooistra et al. 2005, Rasmussen et al. 1983). ADHD is characterized by a wide range of motor skill problems, including both fine and gross motor skill problems, bilateral coordination problems, balance and gait disorders, and body control problems (Goulardins et al. 2017). Although there is currently no absolute relationship between ADHD and subtle neurological signs such as balance, movement planning/control, fine motor skills, and sensory integration, these signs are often suggestive of ADHD (Dickstein et al. 2005, Gustafsson et al. 2000). The only study to our knowledge on this subject in our country demonstrated that adolescents with ADHD had a greater prevalence of fine motor coordination problems, which were associated with social problems (Ayaz et al. 2013).

No method can objectively suggest or predict ADHD. Therefore, the diagnosis and assessment of ADHD require a multi-step clinical process consisting of gathering information from the child's family and school, a mental status examination, and rating scales completed by the physician, teacher, family, and/or child. Objective information from neuropsychological batteries may also be helpful and suggestive of ADHD (Bahçivan-Saydam et al. 2007, Greenhill et al. 2008, Prifitera and Dersh 1993, Sattler 2002, Schwean and McCrimmon 2008). Because there is nothing that can lead to a definitive diagnosis of ADHD, attempts have been made to define an ADHD profile with various neuropsychological batteries (Çelik et al. 2017). The Wechsler Intelligence Scale for Children-IV (WISC-IV) is the latest version of the Wechsler intelligence scales. Studies have suggested that working memory and processing speed scores that are significantly lower than perceptual reasoning and verbal comprehension scores may provide a profile that is predictive of ADHD; indeed, 88% of an ADHD clinical sampling met these criteria (Mayes and Calhoun 2006, Wechsler 2003). Despite the fact that a strikingly large number of studies have defined an ADHD profile with various neuropsychological batteries to aid in the diagnosis and treatment of ADHD, a markedly low number of studies have defined a motor skill profile or profiles for ADHD to aid in its diagnosis, determine the child's level of functionality, and plan treatments. Although motor skill problems are generally recognized in ADHD, we believe our current study was necessary, as no domestic study has yet examined motor skills in school age children with ADHD, and because no published studies had specifically addressed the relationship between different motor skill and cognitive skill domains of the WISC-IV in school age children with ADHD. Therefore, the current study aimed to compare the motor competencies of school children with ADHD and age- and sex-matched healthy children; it also aimed to determine possible associations between motor competence, symptom domains, symptom severity of ADHD, and cognitive function as assessed by the WISC-IV.

## METHODS

Forty of the 726 patients aged 8-11 years who presented to the Child and Adolescent Psychiatry Department between December 2015 and December 2016 and who were diagnosed with ADHD were enrolled in this study. These 40 children met the following inclusion criteria: having combined type ADHD, being right-handed, not using any psychotropic medication, having no psychiatric disorder other than ADHD, having a total WISC-IV intelligence score of 70 or more, having no history of head trauma, having no history of neurological or chronic physical disorder requiring long term follow-up, having no history or current physiotherapy of participating in any regular programmed sport activity apart from daily physical activities appropriate for his/her age at school or leisure times, and volunteering for study participation.

The control group consisted of 20 age- and sex-matched subjects who presented to the same hospital's Child and Adolescent Psychiatry Outpatient Clinic with acute physical complaints and met the following criteria: being right-handed, having no psychiatric disorder, using no psychotropic medication, having a total WISC-IV intelligence score of 70 or more, having no history of head trauma, having no history of neurological or chronic physical disorder requiring long term follow-up, having no history or current physiotherapy or history of participating in any regular programmed sport activity apart from daily physical activities appropriate for his/her age at school or leisure times, and volunteering for study participation.

Each participant was questioned about his/her medical and family history, and information about each participant's family features was obtained via psychiatric interviews and recorded to the Sociodemographic Data Form prepared by the study's authors. Confirmation and/or exclusion of psychiatric diagnosis was performed via the semi-structured interview entitled '*Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime Version (K-SADS-PL)*'**.** The K-SADS-PL was developed by Kaufman et al. (1997) to determine past and present mental disorders according to the diagnostic and statistical manual of mental disorders of children and adolescents IV (DSM-IV); its validity and reliability for the Turkish population was verified by Gökler and colleagues. The mother of each participant was requested to complete the *Conner's Parent Rating Scale – Revised Short Turkish Form (CPRS-R/S)* to determine symptom domains and symptom severity of ADHD (Conners 1997, Kaner et al. 2006). Cognitive skills were assessed by the WISC-IV, which was administered by a clinical psychologist (Chen et al. 2009). The WISC-IV determines four separate intelligence domains, including verbal comprehension, perceptual reasoning, working memory, and processing speed. The verbal comprehension domain is composed of "similarities, vocabulary, comprehension, general knowledge (additional subtest), and word finding (additional subtest)"; the perceptual reasoning domain includes "block design, picture concepts, matrix reasoning, and picture completion (additional subtest)"; the working memory domain includes "digit span, letter-number sequencing, and arithmetic (additional subtest)"; and the processing speed domain is composed of "coding, symbol search, and cancellation (additional subtest)". All standardization and normalization studies for the WISC-IV were performed by the Turkish Psychological Association (Uluç et al. 2011). In addition, all participants were administered the Edinburgh Handedness Questionnaire (Oldfield 1971), while fine and gross motor skills were evaluated using the Bruininks-Oseretsky Motor Proficiency Test (BOT) (Bruininks and Bruininks 2005, Lucas et al. 2013). The BOT is a standard test that is widely used to determine the motor skills of children aged 4.5 – 14.5 years. It is composed of 8 subtests with a total of 46 tests assessing gross and fine motor skills. The BOT was revised for persons aged 4-21 years so that it could be completed within 45-60 minutes. The BOT test has an excellent reliability (0.88-0.92) and a confidence interval of 95% (Lucas et al. 2013).

The current study was approved by the Hacettepe University Non-interventional Clinical Research Ethics Committee on 02.12.2015 (No: GO 15/693-17). All participants and their families provided written informed consent.

### Statistical Analysis

Statistical analyses were performed using the Statistical Program for Social Sciences (SPSS) v. 23.0. The normality of the distribution of continuous variables was tested with the Kolmogorov-Smirnov test. Discontinuous variables were compared with the Chi-square test ($x^2$). Continuous variables were compared with the Mann Whitney-U test in cases where parametric test assumptions were not met. The magnitude of inter-group significant differences was calculated in the form of the eta-square ($\eta^2=Z^2/n$) value. The obtained eta-square ($\eta^2$) values were interpreted according to the determination coefficient (r) ($r^2= \eta^2$), an index for the magnitude of effect. Studies have shown that when r=0.10, the magnitude of the effect is small and explains 1% of the total variance; when r=0.30, the magnitude of the effect is moderate and explains 9% of the total variance; when r=0.50, the magnitude of the effect is large and explains 25% of the total variance (Cohen 2007, Ferguson 2009, Kramer et al. 2003). As the parametric test assumptions were not met for correlation analyses, Spearman's correlation test was used. Even though no definitive range exists for the interpretation of correlation coefficients in terms of magnitude, the correlation is very weak when $0.01 \leq r \leq 0.25$; weak when $0.26 \leq r \leq 0.49$; moderate when $0.50 \leq r \leq 0.69$; high when $0.70 \leq r \leq 0.89$; and very high when $0.90 \leq r \leq 1.00$ (Kramer et al. 2003). All analyses were two-sided, and values of $p<0.05$ were considered significant.

## RESULTS

This study included a total of 60 children aged 8-11 years (40 with ADHD and 20 normal controls). Two children in the ADHD group could not complete the BOT, and were therefore excluded from the analysis. As a result, a total of 38 children with ADHD and 20 healthy children were included in the final analysis. The sociodemographic and developmental features of the ADHD and control groups are shown in Table 1. The two groups had similar age and sex distributions, and had comparable demographic, perinatal, and developmental features (Table 1). All patients were living in nuclear families, and none of them had a history of parental divorce or death. The ADHD group had a significantly greater familial rate of psychiatric disorders than the controls (Table 1). All patients were right handed and right footed

**Table 1**. Sociodemographic and developmental features in the ADHD and control groups

| | | ADHD n=38 | Control n=20 | Statistics | | |
|---|---|---|---|---|---|---|
| | | **n (%)** | **n (%)** | **$\chi^2$** | **p** | **r** |
| Gender | Female | 8 (21.1) | 7 (35) | | | |
| | Male | 30 (78.9) | 13 (65) | 1.329 | 0.250 | 0.131 |
| Sibling/s | Absent | 10 (26.4) | 4 (20) | | | |
| | Present | 28 (73.6) | 16 (80) | 0.773 | 0.379 | 0.115 |
| Incongruity | Absent | 33 (86.8) | 17 (85) | | | |
| | Present | 5 (13.2) | 3 (15) | 1.328 | 0.249 | 0.151 |
| Maternal chronic medical condition | Absent | 34 (89.4) | 18 (90) | | | |
| | Present | 4 (10.6) | 2 (10) | 0.084 | 0.771 | 0.038 |
| Paternal chronic medical condition | Absent | 32 (84.3) | 16 (80) | | | |
| | Present | 6 (15.7) | 4 (20) | 0.051 | 0.822 | 0.029 |
| Psychiatric disorder in family | Absent | 28 (73.6) | 18 (90) | | | |
| | Present | 10 (26.4) | 2 (10) | 4.005 | 0.034 | 0.263 |
| Pregnancy | Planned | 30 (78.9) | 16 (80) | | | |
| | Unplanned | 8 (21.1) | 4 (20) | 0.531 | 0.466 | 0.095 |
| Medical problems during pregnancy | Absent | 33 (86.8) | 17 (85) | | | |
| | Present | 5 (13.2) | 3 (15) | 0.299 | 0.584 | 0.071 |
| Delivery | Vaginal | 23 (60.6) | 9 (45) | | | |
| | C/S | 15 (39.4) | 11 (55) | 1.050 | 0.306 | 0.134 |
| Gestation | Term | 34 (89.4) | 17 (85) | | | |
| | Preterm | 4 (10.6) | 3 (15) | 0.335 | 0.563 | 0.076 |
| Perinatal complication | Absent | 27 (71.1) | 16 (80) | | | |
| | Present | 11 (28.9) | 4 (20) | 2.513 | 0.113 | 0.208 |
| Preschool education | Absent | 8 (21.1) | 3 (15) | | | |
| | Present | 30 (78.9) | 17 (85) | 1.763 | 0.184 | 0.174 |
| | | **Median (min-max)** | **Median (min-max)** | **Z** | **p** | **r** |
| Age (months) | | 109 (100-132) | 112 (97-132) | -0.207 | 0.836 | 0.027 |
| Maternal age (years) | | 34 (26-49) | 37 (27-47) | -1.049 | 0.294 | 0.138 |
| Paternal age (years) | | 37 (25-52 | 40 (30-48) | -0.426 | 0.670 | 0.056 |
| Maternal education (years) | | 11 (5-15) | 11 (8-17) | -1.049 | 0.294 | 0.138 |
| Paternal education (years) | | 11 (5-21) | 11 (8-17) | -1.537 | 0.124 | 0.202 |
| Number of siblings | | 1 (0-2) | 1 (0-3) | -0.851 | 0.395 | 0.112 |
| Monthly income (TL) | | 3500 (1400-12000) | 4000 (1300-15000) | -0.464 | 0.651 | 0.061 |
| Walking (months) | | 12 (9-18) | 12 (9-16) | -0.803 | 0.422 | 0.105 |
| Talking (months) | | 12 (9-24) | 12 (12-18) | -0.502 | 0.616 | 0.066 |
| Potty training (months) | | 30 (18-40) | 30 (18-36) | -0.680 | 0.567 | 0.089 |

ADHD: Attention Deficit Hyperactivity Disorder, min: minimum, max: maximum, $\chi^2$: Chi-square test, Z: Mann-Whitney U test, r: effect size

**Table 2.** Symptom severity and motor and cognitive skills in the ADHD and control groups

| | ADHD | Control | | | |
|---|---|---|---|---|---|
| | **Median (min-max)** | **Median (min-max)** | **Z** | **p** | **r** |
| **CPRS-R /S** | | | | | |
| Oppositional | 7 (2-14) | 5 (1-11) | -1.504 | 0.083 | 0.198 |
| Cognitive problems/Inattention | 10(1-17) | 3 (0-10) | -2.991 | <0.001 | 0.393 |
| Hyperactivity | 6 (2-14) | 1 (0-7) | -3.294 | <0.001 | 0.433 |
| ADHD Index | 20 (8-34) | 7.5 (1-19) | -1.918 | 0.002 | 0.252 |
| **WISC-IV** | | | | | |
| Block Design | 9 (2-15) | 8 (6-14) | -0.329 | 0.742 | 0.043 |
| Similarities | 9 (4-14) | 10 (6-13) | -0.558 | 0.577 | 0.073 |
| Digit Span | 8 (4-12) | 9 (6-13) | -0.887 | 0.375 | 0.116 |
| Picture Concepts | 9 (3-14) | 8 (6-16) | -0.874 | 0.382 | 0.115 |
| Coding | 9 (4-13) | 8 (6-15) | -0.671 | 0.502 | 0.088 |
| Vocabulary | 9 (3-13) | 10 (3-12) | -0.218 | 0.827 | 0.029 |
| Letter–Number Sequencing | 9 (5-12) | 10 (4-13) | -0.507 | 0.612 | 0.067 |
| Matrix Reasoning | 9 (5-15) | 10 (7-13) | -1.530 | 0.126 | 0.201 |
| Comprehension | 8 (4-13) | 8 (5-15) | -0.451 | 0.652 | 0.059 |
| Symbol Search | 8 (2-14) | 10 (4-14) | -2.112 | 0.034 | 0.277 |
| Verbal Comprehension Index | 90 (70-126) | 96 (76-112) | -0.079 | 0.937 | 0.010 |
| Perceptual Reasoning Index | 91 (69-126) | 96 (83-111) | -1.246 | 0.213 | 0.164 |
| Working Memory Index | 91 (71-117) | 91 (79-115) | -0.556 | 0.579 | 0.073 |
| Processing Speed Index | 89 (65-115) | 100 (74-118) | -2.082 | 0.039 | 0.273 |
| Full Scale IQ | 91 (70-121) | 97 (77-109) | -1.442 | 0.149 | 0.189 |
| **BOT** | | | | | |
| Fine motor precision | 8 (4-19) | 9 (7-13) | -1.828 | 0.068 | 0.240 |
| Fine motor integration | 8 (2-9) | 10 (5-10) | -3.816 | <0.001 | 0.501 |
| Manual Dexterity | 3 (1-7) | 3 (1-5) | -0.926 | 0.354 | 0.122 |
| Bilateral coordination | 3 (0-8) | 6 (2-7) | -2.717 | 0.007 | 0.357 |
| Balance | 6 (1-8) | 8 (5-10) | -3.444 | 0.001 | 0.452 |
| Running speed and agility | 6 (1-8) | 8 (4-9) | -3.490 | <0.001 | 0.458 |
| Upper-limb coordination | 7 (1-10) | 8 (5-12) | -1.505 | 0.132 | 0.198 |
| Strength | 6 (3-11) | 8 (6-12) | -2.548 | 0.011 | 0.335 |
| Fine Manual Control | 10 (11-17) | 22 (16-27) | -2.085 | 0.037 | 0.274 |
| Manual Coordination | 6 (0-10) | 8 (5-12) | -2.475 | 0.013 | 0.325 |
| Body Coordination | 25 (12-36) | 29 (20-34) | -2.984 | 0.003 | 0.392 |
| Total Motor Composite | 52 (36-70) | 60 (43-68) | -0.933 | 0.351 | 0.123 |

ADHD: Attention Deficit Hyperactivity Disorder, CPRS-R/S: Conner's Parent Rating Scale – Revised Short Turkish Form, WISC-IV: Wechsler Children's Intelligence Scale-IV, BOT: Bruininks -Oseretsky Motor Proficiency Test, min: minimum, max: maximum, Z: Mann-Whitney U test, r: effect size

according to the Edinburgh Handedness Questionnaire. No ADHD patient had an additional psychiatric disorder in the present state assessment.

With regards to the CPRS-R/S, both the ADHD and control group had similar oppositional subscale scores, while the ADHD group had significantly higher inattention/cognitive problems, hyperactivity, and ADHD index scores (Table 2). With regards to the WISC-IV, both groups had similar scores in the following: block design, similarities, digit span, picture concepts, coding, vocabulary, letter-number sequencing, matrix reasoning, comprehension, verbal comprehension, perceptual reasoning, working memory, and total intelligence. The children in the ADHD group had significantly lower symbol search and processing speed scores, with moderate effect sizes (Table 2). The motor proficiency results revealed that the two groups had similar manual skill, upper limb coordination, and total motor composite scores; there

**Table 3**. ADHD symptom severity and motor skill correlations in the whole sample

| | CPRS-R/S | | | |
|---|---|---|---|---|
| | Oppositional | Cognitive problems/ Inattention | Hyperactivity | ADHD Index |
| | $r_s$ | $r_s$ | $r_s$ | $r_s$ |
| BOT | | | | |
| Fine motor precision | -0.147 | -0.422** | -0.243 | -0.260 |
| Fine motor integration | -0.228 | -0.356* | -0.234 | -0.399* |
| Manual Dexterity | -0.012 | -0.252 | -0.144 | -0.147 |
| Bilateral coordination | 0.090 | -0.249 | -0.105 | 0.125 |
| Balance | -0.124 | -0.322* | -0.254 | -0.110 |
| Running speed and agility | 0.070 | 0.196 | 0.249 | 0.003 |
| Upper-limb coordination | -0.176 | -0.129 | -0.118 | -0.034 |
| Strength | 0.029 | -0.328* | -0.257 | -0.286 |
| Fine Manual Control | -0.189 | -0.426** | -0.205 | -0.334* |
| Manual Coordination | -0.200 | -0.150 | -0.192 | -0.084 |
| Body Coordination | 0.073 | -0.325* | -0.172 | 0.139 |
| Total Motor Composite | -0.066 | -0.208 | -0.045 | -0.230 |

Spearman correlation test
ADHD: Attention Deficit Hyperactivity Disorder, CPRS-R/S: Conners' Parent Rating Scale – Revised Short Turkish Form, BOT: Bruininks -Oseretsky Motor Proficiency Test
$r_s$: rho correlation coefficient
*p<0.05, **p<0.01

was a slight non-statistical difference in fine motor precision between the two groups. Fine motor integration, bilateral coordination, balance, running speed, agility, and strength scores were significantly lower in the ADHD group, as were the fine manual control, manual coordination, and body coordination scores, with moderate effect sizes (Table 2).

## The correlation between motor proficiency and ADHD symptom severity, cognitive skills, and age

ADHD symptom severity and motor skills had weak inverse correlations with inattention/cognitive problems, fine motor precision, fine motor integration, balance, strength, fine motor skill, and manual coordination. There was a very weak inverse correlation between ADHD index, fine motor integration, and fine manual control (Table 3).

The BOT and the WISC-IV scores were used to determine possible correlations between motor skills and cognitive skills (Table 4). The different domains of cognitive skills had the strongest and most frequent correlations with fine motor precision and fine motor integration, which had a positive correlation with almost all subtest and scale scores, including total intelligence score, with the exception of vocabulary, comprehension, and verbal comprehension scores (Table 4).

**Table 5**. Motor skill and age correlations in the ADHD and control groups and the whole sample

| | ADHD Age (months) | Control Age (months) | Whole Sample Age (months) |
|---|---|---|---|
| | $r_s$ | $r_s$ | $r_s$ |
| BOT | | | |
| Fine motor precision | 0.389 | 0.770** | 0.306* |
| Fine motor integration | 0.391 | 0.137 | 0.138 |
| Manual Dexterity | 0.127 | 0.312 | 0.123 |
| Bilateral coordination | 0.186 | 0.229 | 0.215 |
| Balance | 0.469 | 0.198 | 0.181 |
| Running speed and agility | 0.063 | 0.179 | 0.274 |
| Upper-limb coordination | 0.275 | 0.035 | 0.150 |
| Strength | 0.498* | 0.405* | 0.454* |
| Fine Manual Control | 0.272 | 0.638* | 0.324* |
| Manual Coordination | 0.230 | 0.035 | 0.187 |
| Body Coordination | 0.452* | 0.523* | 0.437* |
| Total Motor Composite | 0.380* | 0.538* | 0.431* |

Spearman correlation test
ADHD: attention deficit hyperactivity disorder, BOT: Bruininks -Oseretsky Motor Proficiency Test, $r_s$: rho correlation coefficient
*p<0.05, **p<0.01

**Table 4.** Motor and cognitive skill correlations in the whole sample

| BOT | WISC-IV | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Block Design | Similarities | Digit Span | Picture Concepts | Coding | Vocabulary | Letter–Number Sequencing | Matrix Reasoning | Compre-hension | Symbol Search | Verbal Compre-hension Index | Perceptual Reasoning Index | Working Memory Index | Processing Speed Index | Full Scale IQ |
| | $r_s$ | $r_s$ | $r_s$ | $r_s$ | $r_s$ | $r_s$ | $r_s$ | $r_s$ | $r_s$ | $r_s$ | $r_s$ | $r_s$ | $r_s$ | $r_s$ | $r_s$ |
| Fine motor precision | 0,569** | 0,335* | 0,311* | 0,337* | 0,286* | 0,151 | 0,332* | 0,395** | 0,193 | 0,355* | 0,251 | 0,507** | 0,386** | 0,381** | 0,528** |
| Fine motor integration | 0,256 | 0,060 | 0,123 | 0,258 | 0,188 | 0,165 | 0,462** | 0,355* | -0,179 | 0,375** | 0,077 | 0,382** | 0,357* | 0,353* | 0,349* |
| Manual Dexterity | 0,221 | 0,137 | 0,065 | 0,051 | 0,061 | 0,086 | 0,219 | 0,313* | 0,207 | 0,106 | 0,083 | 0,177 | 0,156 | 0,138 | 0,166 |
| Bilateral coordination | 0,283* | 0,312* | 0,257 | 0,158 | 0,252 | 0,087 | 0,219 | 0,338* | 0,021 | 0,283* | 0,228 | 0,324* | 0,269 | 0,312* | 0,378* |
| Balance | 0,207 | 0,099 | 0,130 | 0,081 | 0,229 | 0,230 | 0,158 | 0,439** | 0,084 | 0,248 | 0,124 | 0,305* | 0,128 | 0,292* | 0,294* |
| Running speed and agility | 0,087 | 0,036 | 0,201 | 0,356* | 0,028 | 0,168 | 0,185 | 0,163 | 0,005 | 0,246 | 0,004 | 0,286* | 0,204 | 0,202 | 0,269 |
| Upper-limb coordination | 0,086 | 0,026 | 0,009 | 0,252 | 0,007 | 0,130 | 0,005 | 0,135 | 0,161 | 0,098 | 0,021 | 0,131 | 0,115 | 0,114 | 0,186 |
| Strength | 0,061 | 0,116 | 0,307* | 0,201 | 0,081 | 0,140 | 0,043 | 0,056 | 0,154 | 0,099 | 0,012 | 0,119 | 0,158 | 0,007 | 0,106 |
| Fine Manual Control | 0,568** | 0,199 | 0,222 | 0,281* | 0,298* | 0,124 | 0,452** | 0,499** | 0,110 | 0,392** | 0,107 | 0,536** | 0,419** | 0,416** | 0,498** |
| Manual Coordination | 0,086 | 0,006 | 0,301 | 0,014 | 0,119 | 0,004 | 0,134 | 0,163 | 0,081 | 0,100 | 0,024 | 0,125 | 0,092 | 0,136 | 0,085 |
| Body Coordination | 0,210 | 0,256 | 0,218 | 0,260 | 0,025 | 0,115 | 0,195 | 0,339* | 0,072 | 0,165 | 0,125 | 0,336* | 0,215 | 0,237 | 0,323* |
| Total Motor Composite | 0,348* | 0,198 | 0,182 | 0,188 | 0,312* | 0,151 | 0,290* | 0,356* | 0,107 | 0,185 | 0,091 | 0,362** | 0,280* | 0,268 | 0,334* |

Spearman correlation test

ADHD: attention deficit hyperactivity disorder, BOT: Bruininks -Oseretsky Motor Proficiency Test, WISC-IV: Wechsler Children's Intelligence Scale-IV, $r_s$: rho correlation coefficient

*p<0.05, **p<0.01

Inverse correlations (correlation coefficient ($r_s$) > 0.40) were found between fine motor precision, block design, and perceptual reasoning scores; between balance and matrix reasoning scores; and between fine manual control, block design, letter-number sequence, reasoning, perceptual reasoning, working memory, and processing speed scores (Table 4).

Correlation analyses revealed correlations between age and strength, body coordination, and total motor composite in both the ADHD and the control groups. Fine motor precision and fine manual control had a moderately strong positive correlation with age in the control group, but not in the ADHD group (Table 5).

## DISCUSSION

This study investigated relationships between motor skills and cognitive variables among school age children with ADHD and age and gender matched healthy controls. Children with ADHD performed worse than the controls in several domains of motor skills, mainly fine motor integration, bilateral coordination, balance, running speed, and agility. Fine motor precision and fine manual control were most closely related to symptoms of inattention and almost all cognitive skills, with the exception of verbal skills. Although healthy children between 8-11 years of age had an age-related increase in fine motor precision and fine manual control, no such increase occurred in children with ADHD.

As expected, the ADHD group had significantly higher inattention/cognitive problems, hyperactivity, and total ADHD symptom severity scores than the control group. There were no differences between the two groups with respect to oppositional symptoms; this may be because we excluded children with comorbid oppositional defiant disorder. With regards to cognitive skills, the ADHD group had significantly lower symbol search and processing speed scores, with a moderate effect size. A review of studies where WISC-IV was used to evaluate ADHD shows that children with ADHD have lower subtest scores in coding, number sequencing, and symbol search, as well as lower scores in working memory and processing speed compared to children with healthy development (Biederman et al. 2004, Thaler et al. 2010). It is generally accepted that children with ADHD and normally developing children have similar total intelligence (Antshel et al. 2006). The main problem in children with ADHD is that they are unable to effectively use their intelligence capacity; this is because they have poor attention and self-control, and exhibit fewer target-oriented behaviors. In our current study, the ADHD group had lower processing speed scores and normal total intelligence scores, which are consistent with published data. However, our small sample size limited the statistical significance of other subtests and working memory. A comparison of motor skills revealed that children with ADHD had significantly lower fine motor integration, bilateral coordination, balance, running speed, agility, strength, fine manual control, manual, and body coordination scores, all with moderate effect sizes. Assessment of motor skills revealed a 20-25% variance between children with ADHD and normal controls, suggesting that the ADHD profile attempted to be determined by neuropsychological batteries may also be determined by BOT. In order to determine whether it is possible to construct an ADHD-specific profile with BOT, more detailed studies should be conducted. These studies should have larger sample sizes, wider age range, and should include other psychopathology groups, other ADHD subtypes, and other ADHD comorbidities.

After we determined that there was a correlation between motor skills and ADHD, we wanted to determine whether there was a correlation, (and if so, its magnitude) between motor skills and ADHD symptom severity. We found an inverse correlation between inattention/cognitive problems and fine motor precision, fine motor integration, balance, strength, fine manual control, and body coordination scores. These results are similar to those in the literature, which suggest that fine motor skill problems are more frequent and more severe in inattentive-type ADHD. It has been suggested that "sustained attention" is used for complex and successive tasks requiring higher skill levels; further, that sustained attention problems impair both the perception and inner representation of emotional inputs, which are regulated by target-oriented self (Barkley 1997, Doyle et al. 1995, Piek et al. 1999). In our current study, we also found several other correlations between fine motor skills and inattention symptoms, in that important markers of attention (namely coding, letter number sequencing, symbol search subtests, and working memory and processing speed scores) were positively correlated with fine motor precision, fine motor integration, and manual coordination scores. Previous studies indicate that fine motor skills are correlated with cognitive processes such as processing speed, working memory, and academic success; in addition, these studies show that fine motor precision strongly predicts school achievement in subsequent years (Dyck and Piek 2014, Kurdek and Sinclair 2001, Rigoli et al. 2012, Wassenberg et al. 2005). We believe that the correlations found in our current study between motor skills and executive functions (e.g., attention, working memory, and processing speed) are consistent with the "Hybrid Neuropsychological Model of Executive Functions" proposed by Barkley (Barkley 1997, 2006). Barkley's model defines ADHD as an inhibition disorder. Further, that model indicates that appropriate behavioral inhibition is necessary to effectively fulfill the following four executive functions used to explain ADHD: verbal working memory, non-verbal working memory, self-regulation, and planning. Barkley's model proposes that the inability to control inhibition is the common problem underlying the child's deficits in executive function. According to Barkley, a failure to inhibit motor behavior is the main deficit in ADHD. Since the neural systems responsible for execution and control of goal-directed motor behaviors are dependent on proper executive processing, motor behavior is believed to be inseparable from executive functions (Barkley 1997, 2006).

Neurobiological hypotheses are as popular as neuropsychological hypotheses for explaining the pathogenesis of ADHD pathogenesis. The hypothesis of cortical maturational delay is the most commonly accepted hypothesis for explaining ADHD neurobiology. According to that hypothesis, cortical maturation delay in ADHD predominantly occurs in the PFC, which has been emphasized as the main center of executive functions, (e.g., attention, working memory, and advanced motor control) (Shaw et al. 2007). It has been hypothesized that working memory capacity increases as the PFC matures, and this increase is accompanied by motor control development (Pascual-Leone 2000). As expected, our current study revealed an age-related increase in fine motor precision, strength, fine manual control, and body coordination scores among typically developing children aged 8-11 years. An age-related increase in fine motor skills is expected, even in this narrow age range. However, results of our study did not reveal an age-related increase in fine motor precision and fine manual control scores in children with ADHD aged 8-11 years, which supports that these children have delayed cortical maturation. Another study examined the effect of age on fine motor skills, and found that the gap between the ADHD and the control groups was progressively narrowed with age; however, it never fully closed (Meyer and Sagvolden 2006).

Although the differences between the ADHD and control groups in our current study were moderate, our small sample size reduced the generalizability of our results and prevented the effects of age quintiles and sex. Additionally, since our current study was descriptive, we did not attempt to make any statistical corrections; however, this might have produced false positive results. Nonetheless, the current study had many strengths, including the proven validity and reliability of the assessment tools, and that the ADHD group contained only non-treated patients. In the present study, we also made an attempt to minimize the potential confounders of motor competence by ensuring that none of the participants had any neurological/chronic disorder, head trauma, history of physiotherapy, or participated in a programmed sport apart from daily usual physical activities. Additionally, all cases in the ADHD group were of the combined type and were free of any other psychiatric comorbidity at current status evaluation. Lastly, considering motor development can be deeply affected by early developmental processes, the ADHD and control groups had no differences with respect to sociodemographic properties, developmental milestones, perinatal features, and hand and foot preferences. Although motor skill problems are involved in the neuropsychological and neurobiological theories of ADHD and are frequently associated with ADHD, they typically are not a part of the multi-stage clinical assessment and treatment planning in ADHD (Gillberg et al. 2003, 2004). However, motor incompetency worsens learning capabilities and daily functioning, both at school and at home, which is unfortunate, as these children already experience many academic and social difficulties. Children with ADHD who experience motor skill problems need special support, and a number of strategies need to be used by teachers, parents, and medical professionals to help them.

To date, many studies have consistently shown that physiotherapy of motor problems (especially child-centered, task-oriented approaches) improves motor competency and quality of life (Sangster et al. 2005, Schoemaker et al. 2003, Sugden and Chambers 2007, Watemberg et al. 2007, Wilson 2005). However, since most children with ADHD are not evaluated for motor problems, they are not presented with these treatment opportunities. As part of the multi-stage clinical assessment of ADHD, motor competency should be assessed, and the child should be consulted in order for the clinician to perform an objective evaluation and to put the child in the appropriate intervention programs if motor incompetency exists.

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