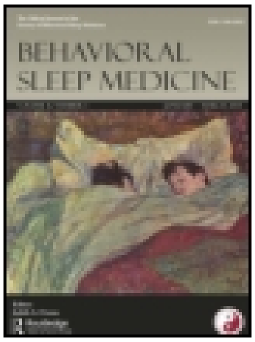

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Moderating Effect of Motor Proficiency on the Relationship Between ADHD Symptoms and Sleep Problems in Children With Attention Deficit Hyperactivity Disorder–Combined Type

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ABSTRACT

Objectives/Background: A high proportion of children with Attention Deficit Hyperactivity Disorder- Combined type (ADHD-CT) experience sleep and motor problems. This study investigated (a) whether motor proficiency moderated the relationship between ADHD symptoms and sleep problems in children with and without ADHD-CT and (b) whether this moderation differed as a function of ADHD diagnosis.

Participants: A sample of 70 primary school male children between 8–15 years were recruited; children with ADHD-CT (n = 38; mean age 10 years, 2 months [SD = 1 year, 6 months]) and a typically developing (TD) (n = 32; mean age 9 years, 6 months [SD = 1 year, 5 months]) group.

Methods: Motor proficiency was measured using the Movement Assessment Battery for Children-2nd Edition (MABC-2), ADHD symptoms were measured using the Conners' Parent Rating Scale (CPRS) and parent reported sleep problems were measured using the Children's Sleep Habits Questionnaire (CSHQ).

Results: Children who reported higher ADHD symptoms and lower motor proficiency scores reported more sleep problems. The moderation effect only held in children with a diagnosis of ADHD-CT and not in the typically developing group.

Conclusions: These findings indicate that children who experience greater severity of ADHD symptoms who also have lower motor proficiency may be at increased risk of experiencing sleep problems. These findings also illustrate the importance of considering motor proficiency when exploring risk factors for sleep problems in children with ADHD-CT as well as sleep interventions.

Attention deficit hyperactivity disorder (ADHD) is one of the most common neurodevelopmental disorders with a worldwide prevalence rate estimated at approximately 5.3% (Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007). Children with ADHD experience impairments in psychosocial functioning, putting them at increased risk of social isolation, rejection by peers, family conflict, low self-esteem, and poor academic outcomes (Faraone et al., 2015). The DSM-5 (American Psychiatric Association [APA], 2013) describes three subtypes of ADHD: predominantly Hyperactive Impulsive subtype (ADHD-HI), predominantly Inattentive subtype (ADHD-PI), and a Combined subtype

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(ADHD-CT) that includes a combination of inattentive, impulsive, and hyperactive symptoms. Individuals with ADHD show marked variation in ADHD profiles or symptoms, supporting emerging research that suggests most cases of ADHD arise from a "pool" of genetic and environmental factors (Faraone et al., 2015).

Psychiatric comorbidity is considered the "rule rather than the exception" (Gillberg, 2010, p. 1543) for children with ADHD and may include intellectual disabilities, mood disorders, disruptive behavior, anxiety disorders, tic disorders, and autism spectrum disorders (Antshel, Zhang-James & Faraone, 2013; Gillberg, 2010; Gillberg et al., 2004). ADHD children are also two to three times more likely than their typically developing peers to experience sleep problems (Corkum, Tannock, Moldofsky, Hogg-Johnson, & Humphries, 2001; Mindell & Owens, 2010). The most frequently reported sleep problems include sleep-onset delay, bedtime resistance, and night awakenings (Cortese, Faraone, Konofal, & Lecendreux, 2009; Sung, Hiscock, Sciberras, & Efron, 2008). The cause of sleep problems in ADHD is unknown; however, biological and behavioral or environmental factors have been proposed (Becker, Langberg, & Byars, 2015). A number of neural mechanisms have been identified that may contribute to insomnia in ADHD. For example, orexinergic hyperactivity as a result of disruption to the amygdala, disruption to the 5HT system that influences the regulation of the sleep-wake cycle, and a reduction in REM and NREM sleep as a result of inhibition of the amygdala (Kohyama, 2016). Behaviorally, hyperactive-impulsive symptoms have been found to be associated with higher rates of bedtime resistance (Lecendreux, Konofal, Bouvard, Falissard, & Mouren-Simeoni, 2000; Wagner & Schlarb, 2012) and inattention has been found to be associated with children having difficulties picking up on the cues associated with bedtime. Furthermore, several studies have linked increased psychopathology (e.g., greater severity of ADHD symptoms; Corkum, Moldofsky, Hogg-Johnson, Humphries, & Tannock, 1999; Mayes et al., 2009; Sung et al., 2008) and the use of psychotropic medication with greater sleep problems for children with ADHD (Gruber, Sadeh, & Raviv, 2000; Mick, Biederman, Jetton, & Faraone, 2000).

In addition to sleep problems, up to 50% of children with ADHD are reported to experience fine and gross motor difficulties on standardized measures of motor proficiency (a measure of motor performance across a range of different fine and gross motor tasks that are scored in terms of either speed or accuracy; Henderson, Sugden, & Barnett, 2007; Piek, Pitcher, & Hay, 1999). In particular, children who present with the ADHD-PI subtype have been found to experience more impairments with fine motor skills, have slower reaction times, and experience poorer online motor control during complex motor tasks compared to ADHD-CT and ADHD-HI subtypes (Kaiser, Schoemaker, Albaret, & Geuze, 2014). However, whether specific ADHD subtypes are associated with particular motor difficulties remains unknown. The exact mechanisms that underlie the association between motor difficulties and ADHD symptoms is also unclear. In line with Barkley's (1997) theory it has been proposed that motor difficulties may be attributed to the core inhibitory and attentional deficits in ADHD. Similarly, it has been proposed that the overlap in the neural mechanisms involved in both cognitive and motor processes (e.g., prefrontal cortex and cerebellum) may be disrupted during development for children with ADHD, resulting in both cognitive-attentional and motor deficits (Diamond, 2000). Studies also suggest that comorbid autism spectrum disorder (ASD) symptoms may be associated with greater motor impairment for children with ADHD (Papadopoulos et al., 2012; Reiersen, Constantino, & Todd, 2008). Furthermore, contextual and environmental factors such as ADHD children's higher engagement in physical activity has also recently been shown to be related to better motor proficiency (Hoza et al., 2015; Smith et al., 2013).

An association between sleep and motor problems in children with developmental disorders has previously been reported. In a study conducted by Barnett and Wiggs (2012), sleep problems (e.g., bedtime resistance, parasomnias, and daytime sleepiness) were shown to be highly prevalent in a sample of children aged 8–12 years (n = 32) who met diagnostic criteria for Developmental Coordination Disorder (DCD). Furthermore, a study conducted by Taylor, Schreck, and Mulick (2012) in a large sample of children with autism spectrum disorder (n = 335) reported an association between sleep disruption and motor skills measured on an adaptive behavior scale, although medication use was not accounted for in this study (Taylor et al., 2012). Despite these interesting findings, we are not aware of any research that has considered the relationship between motor proficiency and sleep in children with a primary diagnosis of ADHD.

Theoretical models of sleep problems in children with neurodevelopmental disorders propose that sleep problems are caused by a multitude of biopsychosocial risk factors (Becker et al., 2015); thus, understanding how risk factors work together is crucial to better inform our understanding of sleep problems (Hollway & Aman, 2011). In particular, a range of biological (e.g., circadian rhythm), neurological (overlap in disrupted brain circuitry), psychological (e.g., emotional function), social (e.g., peer relations), as well as contextual factors (e.g., levels of physical activity or sedentary behavior) have been proposed to work together to underpin sleep disturbance. One factor that may increase ADHD children's vulnerability to sleep problems is their motor proficiency. Motor problems in children with ADHD that have been found to be associated with disruption to underlying brain circuity (e.g., deficits in basal ganglia, cerebellum, and prefrontal cortex) may overlap with brain regions implicated in sleep (Becker et al., 2015), and thus, for children with neurodevelopmental disorders this may manifest in deficits in various domains of development and regulation. An alternative hypothesis is that better motor proficiency may be associated with greater engagement and participation in activities (Stodden et al., 2008), which has been shown to be associated with better sleep (Brand, Jossen, Holsboer-Trachsler, Pühse, & Gerber, 2015). Given the emerging association between sleep and motor problems for children with developmental disorders (Barnett & Wiggs, 2012; Taylor et al., 2012), it is pertinent to investigate if lower motor proficiency, commonly reported for children with ADHD, is associated with parent-reported sleep problems. Understanding the association between motor proficiency and sleep disturbance for children with ADHD will have implications clinically, as interventions targeting motor proficiency may be a useful adjunct to traditional sleep interventions (e.g., melatonin and behavioral sleep interventions).

The aim of this study was to investigate whether motor proficiency was a significant moderator of the relationship between ADHD symptoms and sleep disturbance in a sample of primary school-aged children with and without ADHD-CT. Secondly, we were interested in whether the moderating effect of motor proficiency differed as a function of ADHD diagnosis. Given the heterogeneity of ADHD symptom severity in clinical populations, we approached this study using both a dimensional (combined groups ADHD-CT +TD) and categorical approach (TD versus ADHD-CT).

Method

Participants

This study was approved by the Human Research Ethics Committees of Monash Health, Monash University in Melbourne, and Deakin University, Melbourne, Australia. Informed consent was obtained from parents in accordance with the Declaration of Helsinki.

The clinical cohort from this study comprised a subset of children from the "Attention Kids" research project investigating motor functioning in children with ADHD-CT. For further details in relation to sample characteristics, please see Connolly et al. (2016).

Participants were males aged between 8 and 15 years with a diagnosis of ADHD-CT made by their pediatrician (n = 38), and were recruited from Private Paediatric Clinics in Melbourne. Participants were required to meet the relevant DSM-IV or DSM-5 criteria for ADHD-CT. Diagnosis was confirmed by the citing of a diagnostic report or letter by a clinical researcher. Children with a comorbid diagnosis of ASD were not excluded from the study to ensure a representative sample of children with ADHD. Exclusion criteria included any medical, genetic, or current comorbid neurological condition. Inclusion or exclusion criteria were determined by obtaining participants' developmental, medical, and psychiatric history via parent interview.

Typically developing (TD) boys (n = 32) were recruited via advertising in the local community (e.g., sports and recreation centers) and primary school newsletters. No TD participant had any neurological, psychiatric, or psychological diagnosis, as determined through a parent interview and screening questionnaire.

Measures

Conners' Rating Scale

The Conners' Parent Rating Scale (CPRS, long form; Conners, Sitarenios, Parker, & Epstein, 1998) was administered to assess ADHD symptoms. The CPRS is a widely used screening instrument that evaluates ADHD according to the *Diagnostic and Statistical Manual of Mental Disorders*, fourth edition, text revision (DSM-IV-TR; American Psychological Association, 2000) symptom scales that consists of 80 items and contains 7 subscales (oppositional, cognitive problems, hyperactivity, anxious-shy, perfectionism, social problems, and psychosomatic). The CPRS has good reliability and validity for young people aged 6 to 18 years. Scores obtained from the CPRS are converted to *t*-scores. A *t*-score above 70 is considered to be in the clinically elevated range. For the purpose of this study, the ADHD Global index score was used. We did not apply the clinical cutoff for the Conner as we were interested in exploring ADHD symptoms dimensionally. Parents were asked to provide responses to items on the CPRS that reflected their child's behavior while off medication.

Children's Sleep Habit Questionnaire

Sleep problems were assessed using the Children's Sleep Habit Questionnaire (CSHQ), a validated 33-item measure, where higher scores are more problematic. The CSHQ distinguishes samples of children attending a sleep clinic from a community sample (Owens, Spirito, & McGuinn, 2000). Eight sleep problem domains were examined (bedtime resistance, sleep duration, parasomnias, night waking, daytime sleepiness, sleep anxiety, sleep-onset delay, and sleep disordered breathing), as well as total sleep problems and sleep duration. A cutoff total CSHQ score greater than 41 can be used to identify children with sleep disturbances with a sensitivity of .80 and a specificity of .72 (Owens et al., 2000). Parents were asked to provide responses to items on the CSHQ that reflected their child's behavior while off medication.

Motor proficiency

Motor proficiency was measured using an age-appropriate measure of motor performance: the Movement Assessment Battery for Children (MABC-2; Henderson et al., 2007). The MABC-2 has been found to have good reliability, with Pearson's coefficients of .77, .84, .75, and .80 for manual dexterity, aiming and catching, balance, and total MABC-2 score, respectively (Henderson et al., 2007). The MABC has been previously used in children with ADHD-CT (Papadopoulos, Rinehart, Bradshaw, & McGinley, 2013). It comprises a total of eight tasks grouped into three subtests: manual dexterity, aiming and catching, and balance. Age-adjusted standard scores are provided for subtest scores and total impairment scores. Higher standard scores on the MABC-2 indicate better motor proficiency. The MABC-2 was administered by a graduate student who had undergone training in the administration and scoring of the MABC-2. The MABC-2 was conducted in a standardized test setting at the Clinical Research Centre for Movement Disorders and Gait, Kingston Centre, Melbourne. Participants on medication were asked to discontinue taking their medication 72 hours prior to testing.

Data analysis

Descriptive statistics were calculated for ADHD symptoms, motor proficiency scores, and sleep problems for ADHD-CT diagnosed and TD children. Correlations between variables were conducted. To assess whether motor proficiency moderates the effect of ADHD symptoms on sleep problems, optimal least squares regression analyses using the PROCESS application in SPSS (Model

1; Hayes, 2017) was conducted. To avoid any multicollinearity issues, ADHD symptoms and motor proficiency were mean centered by the PROCESS application. For the analyses, a 95% confidence interval (CI) was used to indicate significance. To address whether the possible effect of the interaction of ADHD symptoms and motor proficiency on sleep problems differed as a function of ADHD diagnosis, the model was tested three times, first for ADHD-CT+TD, second for ADHD-CT only, and third for TD only. Finally, the Johnson Neyman (J–N) technique was applied to derive regions of significance (points of transition) of the moderation effect in the three samples (Preacher, Rucker, & Hayes, 2007).

Results

Sample characteristics

Table 1 shows the means and standard deviations for all measures for both participant groups *and Table 2 shows the correlations between the different measures/ scores applied in the study*. There was no significant difference in age between groups. Intellectual functioning for children in the ADHD-CT group fell in the average range; however, FSIQ, VCI, and PRI were significantly lower in the

Table 1. Participant's characteristics.

Mean (*SD*)	ADHD-CT group (*n* = 38)	TD group (*n* = 32)	*p*
Age in months	120.24 (19.86)	114.84 (17.77)	.239
Intellectual functioning			
FSIQ	97.05 (13.12)	113 (12.6)	.001
VCI	98.03 (14.75)	109.03 (19.52)	.002
PRI	102.66 (13.19)	112.44 (12.48)	.004
Children's Sleep Problems			
Bedtime Resistance	7.90 (2.80)	6.94 (1.92)	.010
Sleep Onset Delay	2.03 (0.75)	1.75 (.84)	.152
Sleep Duration	4.95 (1.83)	3.66 (1.07)	.001
Sleep Anxiety	5.68 (2.16)	4.88 (1.50)	.070
Night Wakings	4.16 (1.53)	3.44 (.84)	.016
Parasomnias	9.26 (2.01)	7.91 (1.30)	.002
Sleep Disordered Breathing	3.34 (0.58)	3.31 (.64)	.842
Daytime Sleepiness	12.66 (3.68)	10.03 (2.21)	.001
Total CSHQ Score	47.32 (9.25)	39.53 (5.55)	.001
ADHD symptoms			
ADHD Global Index	71.13 (12.76)	45.23 (6.42)	.001
Movement ABC-2			
Manual Dexterity	6.87 (2.45)	8.19 (2.67)	.035
Ball Skills	10.52 (3.39)	11.41 (3.06)	.263
Balance	9.29 (2.29)	11.66 (3.28)	.001
MABC-2 Total	8.40 (2.70)	9.97 (2.61)	.016

Table 2. Correlations.

ADHD + TD	Total MABC-2 Score	ADHD Global Index
Total CSHQ Score	−.328**	.550**
Total MABC-2 Score	–	–
ADHD Global Index	−.309**	–
ADHD-CT		
Total CSHQ	−.332*	.288
Total MABC-2 Score	–	–
ADHD Global Index	.288	–
TD		
Total CSHQ	−.043	.623**
Total MABC-2 Score	–	–
ADHD Global Index	−.069	–

Note. ***p* < .01, **p* < .05

Table 3. OLS regression estimating sleep problems severity from ADHD symptoms severity, motor proficiency, and their interaction (with mean centering).

Whole Sample (ADHD-CT + TD)					
	Coefficient	*SE*	*T*	*P*	*LLCULCI*
a: constant/intercept	43.1	0.87	49.67	.000	41.37–44.83
b 1: ADHD symptoms severity (*F*)	0.26	0.05	4.84	.000	.15–.36
b 2: Motor Proficiency (*M*)	−0.54	0.32	−1.69	.09	−1.17 to −.10
b 3: F X M	−0.05	0.02	−2.51	.014	−.08 to −0.01
Note. R = .62, R^2 = .39, F(3,66) = 13.98 p = .001.					
ADHD-CT Only					
a: constant/intercept	46.71	1.37	33.99	.001	43.91 to 49.51
b 1: ADHD symptoms severity (*F*)	.27	.12	2.28	.029	.03 to .51
b 2: Motor Proficiency (*M*)	−.82	.52	−1.58	.124	−1.88 to .24
b 3: F X M	−.10	.05	−2.14	.040	−.20 to −0.01
Note. R = .51, R^2 = *.26.*, F(3,33) = 4.05 = p = .02.					
ADHD-CT only, controlling for the Autism Diagnostic Observation Schedule (ADOS) overall score					
a: constant/intercept	47.30	1.83	25.89	.000	43.58–51.02
b 1: ADHD symptoms severity (*F*)	.28	.12	2.31	.027	.03–.53
b 2: Motor Proficiency (*M*)	−.91	.56	−1.64	.111	−2.05 to .22
b 3: F X M	−.10	.05	−2.14	.040	−.20 to .01
b 4: ADOS Overall Score	−.16	.33	−.50	.623	−.83 to .50
Note. R = .52, R^2 = *.27.*, F(3,33) = 3.03 = p = .03.					
Typically Developing					
a: constant/intercept	39.33	.80	49.03	.000	−37.68 to 40.97
b 1: ADHD symptoms severity (*F*)	.41	.16	2.48	.019	.07–.74
b 2: Motor Proficiency (*M*)	−.42	.46	−.93	.362	−1.35 to 0.51
b 3: F X M	−.18	.14	−1.25	.221	−.48 to 0.12
Note. R = .65, R^2 = .42, F(3,28) = 6.78, p = .001.					

ADHD-CT group compared to the TD group. For motor proficiency (MABC-2), participants in the ADHD-CT groups scored significantly lower than participants in the TD group on the manual dexterity and balance domain as well as for total MABC-2 score.

As expected, children in the ADHD-CT group on average had clinically significant levels of ADHD symptoms measured using the CPRS. Children in the ADHD-CT group on average fell in the range of experiencing clinically significant sleep problems on the CSHQ (scored > 41). The ADHD-CT group also reported significantly greater sleep problems in relation to the domains of bedtime resistance, sleep duration, night wakings, parasomnias, and daytime sleepiness compared to the TD group. There were no significant differences reported between groups in relation to sleep anxiety and sleep disordered breathing.

Moderation analysis

We examined the moderating effect of motor proficiency on the association between ADHD symptoms and sleep problems in (a) children with and without ADHD-CT, (b) in children with ADHD-CT only (both not controlling and controlling for Autism symptoms), and (c) TD children. The structure and the results of the model applied on the three samples are reported below.

ADHD symptom severity (ADHD Global Index) was the focal predictor (F), and motor proficiency was the proposed moderator (M). F, M were included as predictors in an OLS regression predicting the children's sleep problems. The following model was tested for the three different samples:

$$Children's\ Sleep\ problems = a + b1\ ADHD\ Global\ Index + b2\ Motor\ Proficiency \\ + b3(ADHD\ Global\ Index\ x\ Motor\ Proficiency)$$

Information pertinent to this model can be found in Table 3 for each of the samples tested. In the whole sample (ADHD + TD), ADHD severity and the level of motor proficiency were found to significantly interact in relation to the severity of sleep problems [$b3$ = –.05, t(66) = −2.51, p = 0.01].

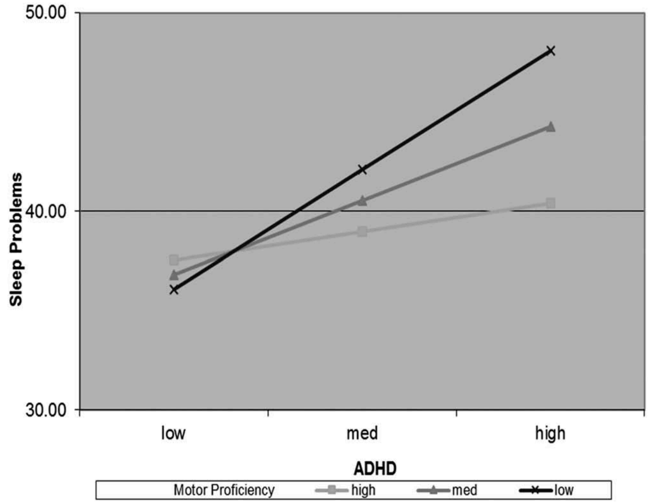

Figure 1. Whole sample (ADHD-CT+ TD) ADHD symptoms severity and sleep problems moderated by motor proficiency (without mean centering).

The coefficient for the interaction means that, as motor proficiency increases by one unit, the coefficient for ADHD symptoms on sleep problems decreases (because the coefficient is negative) by .05. In the sample diagnosed with ADHD-CT only, ADHD severity and the level of motor proficiency were found to significantly interact in regard to the severity of sleep problems ($b3 = -0.10$, $t[33] = -2.14$, $p = .04$). The coefficient for the interaction means that, as motor proficiency increases by one unit, the coefficient for ADHD symptoms on sleep problems decreases (because the coefficient is negative) by .10. Notably, the effect of the interaction of ADHD symptoms and motor proficiency accounted for 10% of the variance of sleep problems in the ADHD sample, compared to 6% for the combined sample. However, in the TD sample, ADHD severity and the level of motor proficiency were not found to significantly interact in regard to the severity of sleep problems (b3 = −0.18, t[28] = −1.25, $p = .22$). Figure 1 plots this interaction graphically using the coefficients from this model for the entire sample (ADHD-CT +TD). To control for the potential effect of autism spectrum disorder manifestations, the Autism Diagnostic Observation Schedule (ADOS) overall score, which was available for the diagnosed ADHD-CT children, was introduced as a covariate in the moderation analysis (in that context, the analysis equation changed as following: *Children's Sleep problems = a +b1 ADHD Global Index + b2 Motor Proficiency +b3 [ADHD Global Index x Motor Proficiency] +b4ADOS*). Results did not differentiate. Specifically, the effect of ADOS scores (as an analysis covariate) was insignificant (b4 = −0.16, $t[33] = -0.50$, $p = .63$) and the coefficient for the interaction between ADHD symptoms and Motor Proficiency remained practically unchanged (b3 = −0.10, $t[33] = -2.14$, $p = .04$; compared to the results before the addition of the covariate).

The Johnson Neyman Technique

The Johnson Neyman (J–N) technique was applied to derive regions of significance (points of transition) of the moderation effect in the three samples (Preacher et al., 2007). This technique allowed us to define what values (ranges of values) of *motor proficiency* produce a *statistically significant moderation effect* on sleep problems. In order to apply this method, the analysis was repeated without mean centering of the ADHD symptoms and motor proficiency. Findings revealed that in the whole sample, when the standard score of motor proficiency was 2.44 or lower, the coefficient for ADHD on sleep problems was significantly higher with a trend to increase. In the ADHD-CT sample the transition point is even lower at 0.41. Thus, a lower level of motor proficiency in the ADHD-CT sample has a higher impact on the effect of ADHD symptoms on sleep problems.

Discussion

The aim of this study was to investigate if motor proficiency moderated the association between ADHD symptoms and sleep problems in primary school-aged boys. We were also interested in whether this moderation effect differed as a function of ADHD diagnosis. Findings supported a moderation effect of motor proficiency on the relationship between ADHD symptoms and sleep disturbance for a combined sample of children with and without ADHD-CT. This effect was stronger and initiated from a lower level of motor proficiency among ADHD-CT diagnosed children. Therefore, it is suggested that, although greater ADHD symptom severity increases the risk of sleep problems, this could be buffered by better motor proficiency among children with a diagnosis of ADHD-CT.

The findings of this study are in line with proposed neurobiological and neurobehavioral hypotheses that support the overlap in brain regions implicated in ADHD, motor, and sleep disturbances (Becker et al., 2015; Diamond, 2000) that may give rise to a number of symptomatic syndromes. Indeed, clinically, these findings are in line with the ESSENCE screening model proposed by Gillberg (2010) that emphasizes the need for clinicians to screen for clusters of early symptomatic syndromes in young children, including deficits in attention, motor, activity, sleep, and behavior in order to inform early intervention (please see Gillberg, 2010, for more information on the ESSENCE model).

In addition to the neurobiological overlap in attentional, motor, and sleep psychopathology, another explanation for the moderating effect of motor proficiency may be that children with ADHD-CT may be less likely to participate in physical activity (Kambas et al., 2012) or engage in an active lifestyle. This may be because engagement in physical activity has been found to be associated with better motor proficiency, among other psychosocial outcomes (Stodden et al., 2008; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006) for children with ADHD (Hoza et al., 2015; Smith et al., 2013). There is also emerging literature of an association between increased physical activity and better sleep quality for children with neurodevelopmental disorders (Brand, Jossen, Holsboer-Trachsler, Pühse, & Gerber, 2015). Future research should take into account the impact of physical activity on the relationship between ADHD symptoms, sleep disturbance, and motor proficiency in primary school aged children.

The finding that motor performance did not buffer the effect of ADHD symptoms on sleep problems for the TD group may be related to differences in the mechanisms that underlie sleep and motor problems for children diagnosed with ADHD-CT compared to TD children. In particular, studies conducted by Kirov, Banaschewski, Uebel, Kinkelbur, and Rothenberger (2007) suggest an association between hypermotor symptoms and REM sleep patterns for children with ADHD, implying an overlap in pathophysiological mechanisms. Future research is needed to better understand how differences in biological mechanisms may relate to differential susceptibility of motor interventions for children with ADHD-CT.

A strength of this study is the administration of an objective standardized performance measure of motor proficiency, as previous studies to date have relied upon subjective questionnaire-based measures of motor problems (e.g., Developmental Coordination Disorder Questionnaire; Vineland Adaptive Behavior Scales; Barnett & Wiggs, 2012; Taylor et al., 2012). Despite this, there are a few limitations of this study. Firstly, although parents were asked to rate children's ADHD symptoms and sleep behavior while they were off medication, retrospective reporting for parents may have been difficult and led to underreporting of children's symptoms. Future studies should therefore control for medication use. Secondly, the inclusion of a structured diagnostic interview in addition to the

CPRS would have added further validity of the ADHD diagnosis. Lastly, although this study used a well-validated parent measure of children's sleep problems, the addition of a gold standard objective measure of sleep such as actigraphy to measure sleep latency as well as a clinical sleep-disorder diagnosis would have further strengthened this study.

Conclusions

This study is the first to our knowledge to investigate if motor proficiency measured using the Movement Assessment Battery for Children (MABC-2) was a significant moderator of the association between ADHD symptoms and sleep problems in children with ADHD-CT. Findings indicate that children who experience relatively higher ADHD symptoms who also experience lower motor proficiency may be at increased risk of experiencing sleep problems. These findings also illustrate the buffering effect of motor proficiency when exploring risk factors for sleep problems in ADHD-CT, justifying the need to consider motor proficiency when targeting sleep problems in primary school-aged children with ADHD-CT.

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