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Do motor coordination and sleep difficulties predict peer functioning in children and adolescents with attention-deficit and hyperactivity disorder after accounting for existing ADHD symptomology?

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Children with attention-deficit and hyperactivity disorder (ADHD) are more likely to experience peer problems compared to their non-ADHD peers, though ADHD-specific symptoms only partially explain this association. This study examined whether sleep difficulties and motor coordination problems are additional predictors of peer problems in an ADHD population. An ADHD sample of 72 participants aged 6–14 years (M = 9.86 years, SD = 1.79 years) was evaluated for an association of peer problems with measures of motor coordination, sleep difficulties as well as ADHD and comorbidity symptoms. Hierarchical multiple regression analysis (HMRA) was used to test the current study aims. Motor coordination, but not sleep difficulties, predicted additional variance in peer problems after controlling for inattention, hyperactivity/impulsivity, internalizing problems, oppositionality, and conduct problems. Poor motor coordination predicts peer problems beyond ADHD symptoms. Clinicians seeking to improve peer functioning in children with ADHD should also consider motor coordination difficulties in addition to existing treatment strategies.

Statement of contribution

What is already known

- Children with attention-deficit and hyperactivity disorder (ADHD) experience greater peer problems (i.e., making friends, being victimized, participating in play) than their typically developing peers.
- Previous studies have attributed this association between ADHD and peer problems to the symptoms of ADHD (i.e., inattention and/or hyperactivity) disrupting the typical trajectory of social development.

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- However, quantitative studies have identified that symptoms of ADHD predict only portion of the variance in a child's peer problems – highlighting that there may be other unique factors that contribute to the higher incidence of peer problems typically observed in this population.

What this study adds

- This study tested whether additional theoretically relevant factors could predict levels of peer problems in children with ADHD beyond the primary symptoms of the disorder.
- Internalizing symptomatology, conduct problems, oppositionality, motor coordination, and sleep difficulties were added to a regression model already including inattention and hyperactivity symptoms. These factors explained 51% of the variability in peer problems.
- In this sample of 72 ADHD children, the results of the final model highlighted that only motor coordination and conduct problems remained significant predictors of peer problems – highlighting two potentially important target areas for screening and intervention.

Attention-deficit/hyperactivity disorder (ADHD) is a childhood neurodevelopmental disorder with an estimated prevalence of 2–7% (Polanczyk, De Lima, Horta, Biederman, & Rohde, 2007). ADHD is characterized by age-inappropriate and persistent levels of inattention and/or hyperactivity/impulsivity, causing pervasive impairments across home, social, educational, or vocational settings and with childhood onset before the age of 12 years (American Psychological Association [APA], 2013). The impairments are often considered as arising from inattention, hyperactivity/impulsivity, and dysregulations of executive functioning that underpin the disorder (Brown, 2009).

Peer problems during childhood predict long-term negative outcomes, including educational disengagement, truancy, substance misuse, delinquency, psychopathology, and maladjustments (McQuade & Hoza, 2008; Parker & Asher, 1987; Rubin, Bukowski, & Parker, 1998). More strikingly, peer-reported social functioning predicts distal outcomes stronger than baseline IQ, grades, and peer-reported behavioural ratings (Hoza, 2007). Notably, peer relationships are unique in children's social life in that both parties involved are of similar status: Within peer friendships, children learn how to negotiate, cooperate, and resolve conflicts; and the lessons learnt through these interactions serve as enduring models and representations for later social cognitions and behaviours throughout life span (Hoza, 2007). One study found that peer problems contribute more towards long-term problems in children with ADHD rather than the immediate symptoms of the disorder (Uchida *et al.*, 2018). The high rates of peer problems among those with ADHD are therefore particularly detrimental, as these problems are a potential gateway to later maladjustments. This could be attributed to the protective effects of healthy peer functioning, whereby positive social relationships engender mutual empathy, further social skill development, as well as mutual empowerment and encouragement (Jordan, 2013). Healthy peer relationships can promote resilience in children with ADHD (Mackenzie, 2018); and protecting a child from peer victimization (Cardoos & Hinshaw, 2011) as well as internalizing and externalizing disorders (Schei *et al.*, 2015). Therefore, better understanding of potential risk factors leading to peer problems in ADHD may provide opportunities for intervention and improve life outcomes.

Peer problems in children with ADHD fall broadly into two categories: (1) the difficulties in eliciting positive interactions with peers, such as playing cooperatively, forming, and maintaining meaningful friendship; and (2) the propensity in eliciting negative reactions from peers, such as dislike, neglect, rejection, and bullying by peers (Fogleman, Leaberry, Rosen, Walerius, & Slaughter, 2018; Hoza, 2007). Notably, the Multimodal Treatment Study of Children with ADD (MTA) found 50–80% of children with

ADHD were classified as 'rejected' by their peers (Hoza, 2007). As childhood is a critical period for social development, exposure to peer problems limits opportunities to acquire fundamental skills necessary for effective social functioning in later life (Hoza, 2007). The 'Matthew effect' (Merton, 1968) describes the phenomenon of cumulative advantages or disadvantages, whereby those who are in a favourable position (e.g., social skills) accumulate more advantage over time; conversely, those who are initially in a unfavourable position become more disadvantageous over time. For example, those children who can cooperate will gain greater access to peers and also more opportunities to develop friendships and refine their social skills. In contrast, early exposure to peer problems curtails opportunities for friendship, thus prematurely forecloses further possibility for developing prosocial skills, and thereby increasing the likelihood of experiencing more peer problems over time.

ADHD core symptoms (i.e., inattention and hyperactivity/impulsivity) are frequently cited as the primary cause of peer problems in key models that seek to explain social difficulties in children with the disorder. For example, Crick and Dodge's (1994) social information processing model suggests that the onset of peer problems stems from an impairment of social processing functioning unique to children with ADHD (McQuade & Hoza, 2008). Inattentive children may fail to recognize important social cues and miss opportunities for social learning (Dodge *et al.*, 2003); in contrast, hyperactivity or impulsivity increases problematic behaviours such as intrusiveness, oppositionality, or aggression which evoke dislike and rejection from peers (Coie, Dodge, Terry, & Wright, 1991). Other models describe a similar trajectory towards social impairment in ADHD children via alterative pathways. Examples include disruptions relating to social self-control (Rosen et al., 2014), play-related difficulties (Cordier, Bundy, Hocking, & Einfeld, 2009), and disruptions to executive functioning and theory of mind (Forner *et al.*, 2017). This proliferation of models offering competing explanations to peer problems in children with ADHD highlights the absence of any single cause in favour of multiple causal pathways.

Irrespective of the theoretical perspective one may conceptualize this association, the core symptoms of ADHD cannot provide a complete explanation for the onset of peer problems (Hoza, 2007, p. 2). Intervention studies have shown that treating ADHD core symptoms with medications only partially lessens, without fully eradicating, peer problems (Abikoff *et al.*, 2004; Mrug *et al.*, 2012). The evidence therefore suggests additional risk factors at play in driving peer dysfunction beyond the ADHD core symptoms; and comorbid internalizing and externalizing pathologies present as plausible candidate risk factors.

Indeed, internalizing problems in children with ADHD are uniquely and independently associated with bullying, which lead to additional problems such as social withdrawal and loneliness (Fogleman *et al.*, 2018). Oppositionality and conduct problems increase the risks of peer victimization and social rejection (Gaub & Carlson, 1997; Humphrey, Storch, & Geffken, 2007). Studies have highlighted that these associated or 'secondary' consequences of ADHD significantly elevate the risk of peer problems. For example, oppositional behaviour predicts additional variance in parent-/teacher-reported bullying – above and beyond what was already explained by core ADHD symptoms (Wiener & Mak, 2009). However, these models continue to offer only a partial explanation: Even in studies which include both primary predictors (i.e., ADHD core symptoms) and secondary predictors (i.e., internalizing and externalizing symptoms), a substantial proportion of variance in peer problems remains unexplained, thereby suggesting the presence of other extraneous influences.

Recently, poor motor coordination has been found to be a significant risk factor for peer problems among non-ADHD children – predicting fewer friendships, lower social confidence, as well as higher rates of peer victimization and social rejection (Cairney, Rigoli, & Piek, 2013). One postulate is that the lack of age-appropriate motor skills restricts a child's ability to engage with his peers, such as through structured and unstructured play. Approximately 50% of children with ADHD also experience motor coordination problems in studies using motor assessment by standardized measures of motor proficiency (Fliers *et al.*, 2010; Goulardins, Marque, & De Oliveira, 2017; Kaiser *et al.*, 2015). As poor motor coordination is prevalent in ADHD children, routine screen for motor coordination difficulties has been recommended in ADHD clinics (Lange, 2017). Interestingly, a recent study has demonstrated this link between motor problems and peer rejection within a community sample (Goulardins *et al.*, 2015). After accounting for the ADHD core symptoms (inattention and hyperactivity/impulsivity), motor coordination independently predicted teacher-rated social functioning, underscoring motor coordination as an additional mechanism in predicting peer problems in ADHD. While Goulardins *et al.* (2015) demonstrated that motor coordination could predict variance in social problems beyond the ADHD core symptoms, the relative significance of this predictor has not yet been simultaneously tested after controlling for the associated or 'secondary' consequences of ADHD mentioned previously (i.e., internalizing problems, conduct problems, and oppositionality) – representing a gap in the current knowledge.

A number of previous studies warrant preliminary inferences of overlapping neurobiological factors that may underpin the impact of motor problems on peer functioning in children with ADHD. A systematic review by Kaiser *et al.* (2015) found that pharmacological treatment of ADHD also resulted in improved motor functioning in 28–67% of children. Such findings are subject to further experimental studies examining subsequent changes in peer functioning and may have limited utility for children already medicated for ADHD yet still displaying motor skills below age-appropriate norms.

Sleep difficulties are another common comorbidity in ADHD – up to 70% of children with ADHD experience problems with sleep (Becker, Langberg, & Byars, 2015; Cortese, Faraone, Konofal, & Lecendreux, 2009; Papadopoulos *et al.*, 2018). The consequences of sleep difficulties independent of comorbidities (e.g., ADHD) are concerning; however, the cumulative effects of sleep difficulties and ADHD symptomology can result in individuals becoming especially vulnerable to psychosocial maladjustment (Lycett *et al.*, 2016). Children and adolescents with ADHD who also experience sleep difficulties are at increased risk of disruption to their academic performance, impulse control, concentration, and social functioning relative to either ADHD or sleep difficulties in isolation (Lycett *et al.*, 2016; Wiggs, Sparrowhawk, & Barnett, 2016; Yürümez & Kılıç, 2013).

Sleep difficulties impact negatively on opportunities for positive peer interactions through increased irritability, low mood, and higher rates of daytime sleepiness; they also exacerbate symptoms of ADHD by increasing difficulties with concentration and hyperactivity/impulsivity (Vaughn, Elmore-Staton, Shin, & El-Sheikh, 2015; Wiater *et al.*, 2005). However, it is unknown whether sleep difficulties can uniquely predict peer problems after accounting for the core and secondary symptoms of ADHD, or motor coordination. It has also been suggested that sleep difficulties may interact with other predictors of peer problems (including motor problems) by exacerbating symptoms of other problems (Lycett *et al.*, 2016). For example, behavioural manifestations of sleep problems during childhood include poorer reaction times and reduced visuo-spatial accuracy (Paavonen *et al.*, 2010). This may lead to further disparity between children with existing movement difficulties and their typically developing peers in the classroom and in

the playground, increasing susceptibility to poor peer interactions. These untested and thus unknown possibilities in the ADHD population form the second knowledge gap in this conundrum.

Overall, the current literature provides support for the contention that both motor coordination and sleep difficulties are plausible putative risk factors leading to peer problems in children with ADHD. The aim of the current study was therefore to address the two aforementioned knowledge gaps; and more specifically, to explore whether motor coordination and sleep difficulties (including an interaction of the two variables) can account for any additional variance in peer problems – above and beyond what can be accounted for by ADHD core symptoms, oppositionality, conduct problems, and internalizing symptoms. We hypothesize: (1) Motor coordination and sleep difficulties will account for unique variance in peer problems, after accounting for ADHD core symptoms, oppositionality, conduct problems, and internalizing symptoms; (2) there will be a significant interaction effect between motor coordination and sleep difficulties as predictors of peer problems.

Method

Participants

The sample comprised of 72 children and adolescents aged 6–14 years, recruited from a state-wide specialist ADHD service located in *location removed for double-blind review* (M_{age} = 9.86 years, *SD* = 1.79 years). This service provides a comprehensive multidisciplinary assessment service for children with a complex presentation of ADHD. All referred children had a known diagnosis of ADHD by their own psychiatrist or paediatrician prior to referral, and were then assessed by the multidisciplinary team, which includes psychiatry, speech pathology, neuropsychology, clinical psychology, social work, and occupational therapy. Psychiatric diagnoses are re-assessed by the senior consultant child and adolescent psychiatrists of the service, based on *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5) diagnostic criteria. Exclusion criteria for the current study included other diagnosed neurodevelopmental or neurological disorders (e.g., global developmental delay or pervasive developmental disorder). All measures utilized in the current study were administered as part of routine assessment battery. There was a male preponderance (*n* = 66; 91.67%). Approximately 84% of this sample was diagnosed with the 'combined presentation' of ADHD, 15% with the 'predominantly inattentive presentation' and 1% with the 'predominantly hyperactive/impulsive presentation'.

Measures

Bruininks–Oseretsky Test of Motor Proficiency (BOT-2; Bruininks & Bruininks, 2005)

The BOT-2 is a standardized and clinician-administered assessment that measures fine and gross motor performance by 53 items, applicable for the age range between 4 and 21 years. The test provides an overall indicator of an individual's motor coordination and yields composite scores for manual control, manual coordination, body coordination, and strength and agility domains. The assessment is reported to take approximately 60 min to administer. Raw scores are converted into standard scores adjusted for age and gender norms as per the scoring procedure detailed in the BOT-2 Test Manual (Bruininks & Bruininks, 2005). Standardized scores were included in the current analysis, with higher

scores indicative of a greater degree of motor proficiency. BOT-2 has been demonstrated to have sound psychometric properties and ecological validity, as a measure useful and applicable in the real world (Bruininks & Bruininks, 2005; Tan, Parker, & Larkin, 2001; Vinçon, Green, Blank, & Jenetzky, 2017).

Conners Third Edition – Parent Version (Conners-3; Conners, 2008*)*

The Parent-Conners-3 is a standardized and validated informant-rated questionnaire that evaluates ADHD symptoms (inattention and hyperactivity/impulsivity) and related problems (i.e., learning problems, executive functioning, aggression, and peer relations). The current study utilized the parent-rated version of the measure. A parent rates his/her child's typical behaviours within the preceding month period, on a Likert scale from 0 (*not true at all/never*) to 3 (*very much true/very often or frequently*). Raw scores are standardized according to age and gender, and then converted into index scores and *t*-scores adjusted for age and gender norms. *T*-scores for the inattention, hyperactivity/impulsivity, oppositionality, conduct problems, internalizing symptoms, and peer relations subscale scores were included in the current study. The Conners-3 demonstrates excellent reliability and validity (Conners, 2008).

Sleep Disorders Scale for Children (SDSC; *Bruni* et al.*, 1996*)

The SDSC is a 26-item scale developed to evaluate sleep difficulties in children within the previous 6 months. The measure is completed by the parent of the child and takes approximately 5–10 min to complete. Item 1 measures the child's average hours of sleep, from 1 ('9–11 h') to 5 ('less than 5 h'). Item 2 measures the child's average time to fall asleep, from 1 ('less than 15 min') to 5 ('more than 60 min'). The remaining 24 items are rated on a 5-point Likert scale, from 1 ('Never') to 5 ('Always [daily]'); an example item is '*The child has nightmares that he/she does not remember the next day*'. The SDSC has demonstrated acceptable internal reliability (α = .71 to .79) for total sleep scores and good test–retest reliability (r = .71) in both typically developing and children diagnosed with sleep disorders (Bruni *et al.*, 1996). Raw scores are converted into *t*-scores derived from a normative sample (Bruni *et al.*, 1996). The SDSC has demonstrated good discriminant validity in identifying children with pre-existing sleep disorders compared to typically developing controls (Bruni *et al.*, 1996), and construct validity for the measure has been supported across several different populations. Recent evidence supports the SDSC as a valid screening tool for overall sleep difficulties in children with ADHD, though the interpretability of subscale scores is yet to be fully validated (Mancini *et al.*, 2019). Therefore, only overall sleep difficulty scores were used in the current study.

Procedure

Ethical approval to use these data for research was approved by the committee named removed for double-blind review. Parents also provided informed consent allowing the de-identified data for research analysis and publication. The Conners-3 measures were completed by parents as part of intake assessment. The BOT-2 was administered to children by a trained occupational therapist. Diagnoses of ADHD per DSM-5 diagnostic criteria (APA, 2013) were confirmed using a diagnostic interview conducted by a senior psychiatrist.

Data analysis

Analyses were completed using IBM SPSS (version 25.0). Following data checking of the relevant assumptions, a hierarchical multiple regression analysis (HMRA) was used to test both hypotheses. HMRA provides a theory-driven approach to the order in which variables are entered in a model. ADHD symptoms (inattention and hyperactivity/impulsivity) were entered as control variables on the first step of the HMRA. Oppositionality, conduct problems, and internalizing symptoms were entered as the second step. Motor coordination and sleep difficulties were entered as predictors as the third step of the HMRA. In the final step of the HMRA, the interaction effect was added to the model. In this approach, the impacts and effect size of the variables examined could be isolated incrementally over sequential steps.

Results

Prior to testing the regression model, statistical assumptions relevant to multiple regression analysis were evaluated. First, visual inspection of the relevant histograms indicated that the data were sufficiently confirming to approximate normal distribution to proceed with analyses. Second, inspection of normal probability plot against standardized residuals also indicated that the assumptions of normality, linearity, and homoscedasticity of residuals were also met. Third, Mahalanobis distance did not exceed the critical chi-square value for $df = 4$ (at $\alpha = .001$) of 18.47, indicating that multivariate outliers were not of concern. Finally, high tolerance detected for all predictors in the model indicated the absence of problematic multicollinearity in the data. The data were therefore deemed suitable for HMRA. Descriptive statistics and bivariate correlations are provided in Table 1.

The ANOVA for each step in the regression model was statistically significant, indicating that the predictor variables in combination explained significant variance in peer problems. Unstandardized (B) and standardized (β) regression coefficients and squared semi-partial correlations for each step of the regression analysis are provided in Table 2.

Step 1. The first step in the model included ADHD symptoms (inattention and hyperactivity/impulsivity), which predicted a statistically significant 17.9% of the variance in peer problems. However, inattention was the only significant predictor on this step.

Step 2. The addition of internalizing problems, conduct problems, and oppositionality significantly increased the explained variance in peer problems to 42.1%. Conduct problems and oppositionality were the only significant predictors on this step.

Step 3. The addition of motor coordination and sleep difficulties significantly increased the explained variance in peer problems to 48.1% – only conduct problems and motor coordination were significant predictors.

Step 4. The last step of the HMRA demonstrated that, in combination, the predictors could explain a significant 51% of the variance in peer problems, $R^2 = .51$, $F(8,62) = 8.08$, $p < .001$. By Cohen's (1992) conventions, a combined effect of this magnitude can be considered 'large' ($f^2 = 1.04$). In this step, the interaction term between motor coordination and peer problems was added, but was found to be at the marginal non-significant level ($p = .06$) in our sample of 72 children. Of the predictors included, only conduct problems and motor coordination were significant predictors in the final model on the unique variance of peer problems (accounting for 15 and 3%, respectively).

Table 1. Descriptive statistics and bivariate correlations for sample (N = 72)

Variable	M (SD)	% of N in clinically meaningful ranges	Range	1	2	3	4	5	6	7	8
1. Inattention[a]	80.40 (11.15)[d]	8.33% elevated (n = 6) 83.33% very elevated (n = 60)	47–100	–	.47**	.88**	.31**	.31**	−.29*	.29*	.42**
2. Hyperactivity/impulsivity[a]	82.64 (13.28) [d]	4.17% elevated (n = 3) 84.72% very elevated (n = 61)	47–114		–	.45**	.31**	.49**	−.29*	.33**	.21
3. Internalizing problems[a]	84.08 (10.19)[d]	4.17% elevated (n = 3) 88.89% very elevated (n = 64)	57–101			–	.36**	.35**	−.39**	.36**	.41**
4. Conduct problems[a]	88.93 (30.10)[d]	4.17% elevated (n = 3) 72.22% very elevated (n = 52)	43–190				–	.80**	−.15	.14	.56**
5. Oppositionality[a]	85.14 (16.26)[d]	4.17% elevated (n = 7) 77.78% very elevated (n = 56)	46–118					–	−.08	.11	.34**
6. Motor coordination[b]	40.68 (9.21)[e]	61.11% (n = 44)	28–78						–	−.21	−.33**
7. Sleep difficulties[c]	74.07 (16.95)[d]	84.72% (n = 61)	40–100							–	.01
8. Peer problems[a]	80.68 (23.32)[d]	2.78% elevated (n = 2) 69.44% very elevated (n = 50)	42–137								–

Notes. All variables are standardized according to age. Variables 1–5 and 8 were also adjusted for sex

[a]Conners (2008) suggests that a t-score of 65–69 indicates *elevated* scores, whereas t-scores of 70+ are *very elevated*. T-scores >65 warrant strong consideration for diagnoses; [b]Bruininks & Bruininks, 2005) classify children *at risk* of motor coordination difficulties on the BOT-2 if they are at or below the 15th percentile; [c]Bruni et al. (1996) have suggested a total cut-off score of 39 (i.e., a t-score of 55) in their evaluations of the SDSC; [d]t-scores are reported for these measures; [e]Standard scores are reported for this measure; *$p < .05$; **$p < .001$.

Table 2. unstandardized and standardized regression coefficients and squared semi-partial correlations for each predictor variable on each step of a hierarchical multiple regression model predicting peer problems in an ADHD sample (N = 72)

Variable	*B [LLCI, UCLI]*	β	sr^2	R^2 *Change*
Model 1 (R^2 = .18)				
Inattention	0.88 [4.36, 1.40]	.42**	.14	–
Hyperactivity/impulsivity	0.00 [−0.44, 0.44]	.00	.00	
Model 2 (R^2 = .42)				
Inattention	0.56 [−0.30, 1.42]	.27	0.01	.24***
Hyperactivity/impulsivity	0.03 [−0.40, 0.45]	.01	0.00	
Internalizing problems	0.05 [−0.88, 0.99]	.02	0.00	
Conduct problems	0.58 [0.32, 0.83]	.73*	0.19	
Oppositionality	−0.49 [−0.98, 0.00]	−.34*	0.04	
Model 3 (R^2 = .48)				
Inattention	0.61 [−0.23, 1.45]	.29	0.02	.06*
Hyperactivity/impulsivity	0.02 [−0.41, 0.45]	.01	0.00	
Internalizing problems	−0.05 [−1.01, 0.91]	−.02	0.00	
Conduct problems	0.56 [0.31, 0.80]	.71*	0.17	
Oppositionality	−0.45 [−0.93, 0.04]	−.31	0.03	
Motor coordination	−0.55 [−1.07, −0.02]	−.21*	0.04	
Sleep difficulties	−0.24 [−0.51, 0.04]	−.17	0.02	
Model 4 (R^2 = .51)				
Inattention	0.70 [−0.13, 1.53]	.34	0.02	.03
Hyperactivity/impulsivity	−0.03 [−0.45, 0.39]	−.02	0.00	
Internalizing problems	−0.16 [−1.11, 0.79]	−.07	0.00	
Conduct problems	0.53 [0.28, 0.77]	.67*	0.15	
Oppositionality	−0.39 [−0.87, 0.09]	−.27	0.02	
Motor coordination	−0.51 [−1.02, 0.00]	−.20*	0.03	
Sleep difficulties	−0.21 [−0.48, 0.06]	−.15	0.02	
Interaction	4.68 [−0.14, 9.51]	.18	0.03	

Notes. B = unstandardized coefficient; β = standardized coefficient; sr^2 = semi-partial squared correlation. Moderator variable calculated as the interaction of motor coordination and sleep difficulties. Interaction = motor coordination*peer problems.
*$p < .05$; **$p = .001$; ***$p < .001$.

Discussion

There are three key findings in this study. First, motor coordination, but not sleep difficulties, predicted peer problems – above and beyond the variance already explained by ADHD and comorbid symptoms. Second, no significant moderation effect between motor coordination and sleep difficulties was detected. Third, of the eight predictors examined in the final regression model, only motor coordination and conduct problems significantly accounted for peer problems variance. ADHD symptoms (inattention and hyperactivity/impulsivity), internalizing problems, and oppositionality did not account for additional variance in peer problems beyond those already explained by conduct problems and motor coordination. These findings provided support for the relative importance of conduct problems and motor coordination in the development of peer problems in children with ADHD.

Understanding the factors that predict peer problems in childhood and adolescence is necessary given that the quality of peer relationships during childhood and adolescence predict many important social and developmental outcomes in later life. For example, children who experience peer problems are at greater risk of delinquency, incomplete schooling, substance abuse, academic underachievement, and psychopathology in later life (Parker & Asher, 1987; Rubin, Bukowski, & Parker, 1998). Positive peer functioning in childhood is protective against such outcomes (Skrzypiec, Slee, Askell-Williams, & Lawson, 2012). The rate of peer problems experienced by children and adolescents with ADHD is up to eight times higher than their typically developing peers (Hoza, 2007; Waschbusch & Willoughby, 2008). In the current study, approximately 70% of the current ADHD sample reported either *elevated* or *very elevated* levels of peer difficulties. This high incidence rate is consistent with past research where 82% of ADHD children reported peer difficulty scores exceeding one standard deviation above the mean for typically developing children, and 60% exceeding two standard deviations above the mean (Pelham & Bender, 1982). By understanding the risk factors that predict peer problems among a paediatric ADHD population, targeted strategies to improve peer functioning (by curtailing the risk of additional complications in later life) can be developed.

Our findings provide preliminary support that poor motor coordination (frequently comorbid with ADHD) represents an additional factor in elevating the risk of peer problems in the ADHD population. Our findings are significant in the ADHD literature, as only a very limited number of studies exist that explore the role of motor coordination in relation to social functioning among children with ADHD. Goulardins *et al.* (2015) found motor coordination remained a significant predictor of social problems after controlling for ADHD symptoms in a non-clinical sample of children of whom some have ADHD traits but not the diagnosis. Our study provides preliminary suggestion that this relationship may persist even within a clinical sample of ADHD children, though more conclusive evidence could be attained in future studies that also include a control group. Our study also controlled for both primary ADHD core symptoms (as per Goulardins *et al.*, 2015) and secondary comorbid symptoms (including conduct problems, internalizing problems, and oppositionality). Results showed that motor coordination remained a significant predictor of peer problems after controlling for covariates in a clinical ADHD sample. For children with ADHD, motor coordination appears to be a better predictor of peer problems than the ADHD core symptoms (i.e., inattention and hyperactivity/impulsivity) and related comorbid symptoms (i.e., internalizing problems and oppositionality). The current findings provide preliminary suggestion that motor coordination may represent a key predictor of peer problems among children with ADHD with an effect size comparable to anti-social/conduct problems known to predict peer problems in this population. These findings also guide direction for future studies that could utilize either longitudinal methods or to include a control group in order to provide conclusive support. Our findings support the current advocacy that children with ADHD should be routinely assessed for motor coordination difficulties (Lange, 2017). Furthermore, if replicated in a larger study that includes a control group, these findings will raise important clinical implications – that targeting and treating motor coordination difficulties may engender similar or comparable therapeutic effect as treating anti-social conduct problems; and maybe better effects, given the notorious poor response of conduct problems to intervention.

Our findings are consistent with previous studies' findings of similarly sized relationships albeit in non-clinical ADHD samples (Goulardins *et al.*, 2015; Mancini, Rigoli, Roberts, Heritage, & Piek, 2017; Missiuna *et al.*, 2014; Rigoli, Piek, & Kane, 2012). In the non-ADHD samples, the more proficient an individual's motor skills, the fewer peer problems they tend to experience (Cairney, Rigoli, & Piek, 2013). Cairney *et al.* (2013) argue that motor coordination is a fundamental determinant of the quality of peer functioning in childhood that facilitates a greater number of opportunities for children to experience positive peer engagement. Examples include collaborating in the classroom or participating in both structured and unstructured group play. Cairney *et al.* (2013) also described how children with poor motor skills are less likely to participate in physical activity. Physical activity participation has well-established benefits for peer functioning. Though not directly examined the current study, the possible mediating effect of physical activity participation on the association between motor coordination and peer problems is an area worth further investigation.

Possessing age-appropriate motor coordination reduces the likelihood of negative peer experiences. Conversely, children whose motor coordination is poorer than their peers have fewer opportunities to engage positively with peers and are more likely to experience peer rejection and victimization (Campbell, Missiuna, & Vaillancourt, 2012; Livesey, Lum Mow, Toshack, & Zheng, 2011). These early exposures to peer-related difficulties further increase the risk of additional social difficulties and fewer opportunities for positive peer interactions, leading to a 'vicious cycle' and ensuing the 'Matthew effect'. Moreover, peer problems can prematurely foreclose the development of resilience, as 'relational resilience' theory stipulates that resilience resides not within an individual, but is developed within growth-fostering relationships. Peer connections provide an important source of friendships through which a child can learn and experience support and empathy as well as mutual empowerment and encouragement, enhancing functional and psychological resilience (Jordan, 2013). The early identification and management of peer problems among children with ADHD is therefore critical.

Our findings underscore the unique contribution of motor coordination in the peer functioning of children and adolescents with ADHD, even after accounting for ADHD symptoms, which are well-known antecedents of peer problems (Fogleman *et al.*, 2018; Wiener & Mak, 2009). In our findings, conduct problems was the only other significant predictor of peer problems in the final regression model. Children experiencing conduct problems display a range of undesirable social behaviours, including aggression, short-temper, and lying or cheating (Lockwood *et al.*, 2013). It is therefore unsurprising that conduct problems were detected as a strong predictor of peer problems in our study. Interestingly, the inclusion of conduct problems into the regression model also rendered ADHD core symptoms (inattention and hyperactivity/impulsivity) redundant as predictors of peer problems. One likely explanation is that ADHD core symptoms manifest within problematic behaviours (i.e., conduct problems), which in turn can increase the risk of peer problems (Coie *et al.*, 1991; Dodge *et al.*, 2003).

No bivariate association between sleep and peer problems was detected. This contrasts with previous findings which identified a relationship between sleep difficulties and quality of social interaction (Vaughn, Elmore-Staton, Shin, & El-Sheikh, 2015; Williams, Nicholson, Walker, & Berthelsen, 2016). One possible explanation is that our sample is small, with insufficient statistical power to detect this effect. Alternatively, previous findings were derived from typically developing populations. Children and adolescents with ADHD have been previously found to express unique sleep profiles (Mancini *et al.*, 2019) that may not have been adequately captured using a parent-report

questionnaire which was originally standardized in a normative population (Bruni *et al.*, 1996; Mayes *et al.*, 2008). While our study provides preliminary evidence to suggest no relationship between sleep and peer functioning in an ADHD population, further studies using a larger sample size with additional objective measures of sleep quality (i.e., actigraph or polysomnography) could capture more accurately the unique sleep profiles and difficulties in the ADHD population.

Each participant in the current study had a formal diagnosis of ADHD prior to participation in the study. Participants were sampled from a specialized ADHD service and thus engaging in treatment or intervention, meaning the current findings may not be directly applicable to those children who are not engaging in treatment. Information regarding the specific treatment schedule, including prescribed medications, for each child was not obtained as part of this study. Therefore, the possible impact of stimulant medication on sleep quality could not be assessed and is strongly recommended in future follow-up studies. Given the small sample size and cross-sectional design of this study, several limitations should be considered. While conduct problems and motor coordination were significant predictors of peer problems in the current study, it is important to recognize that 49% of the variability in peer problems remains unaccounted for. Future studies could replicate, extend, and refine our findings by using larger samples and exploring additional variables beyond those included here. Second, our study utilized a parent-rated measure to represent peer problems. Other studies suggest that peer nomination is a more valid and potent measure (Hoza, 2007). Future studies may consider replicating our findings using a peer-report measure to represent 'peer problems'. Third, the cross-sectional and correlational nature of the current study limits our scope to evaluate causal relationships by examining the effects of temporal association. While poor motor coordination is a probable cause of peer problems, a bi-directional relationship between variables cannot be ruled out. Children and adolescents who experience peer problems (i.e., bullying or social exclusion) may have fewer opportunities to refine and develop their motor proficiency through interpersonal activities such as play. Longitudinal studies could probe for the effects of different predictors during different critical developmental windows. Future research using experimental and interventional design could probe and dissect causal relationships with greater precision, for example, motor skill interventions targeting different components in our model could be evaluated for their impacts in improving peer functioning.

Conclusion

Conduct problems remained the strongest predictor of peer problems in the current study. However, motor coordination was the only other variable to significantly account for unique variance in peer problems. Motor coordination problems were a better predictor of peer problems than ADHD core symptoms (i.e., inattention and hyperactivity/impulsivity), internalizing problems, oppositionality, and sleep problems. Sleep difficulties could not predict peer problems independently, or via an interaction with motor coordination. Our study, to our knowledge, is the first to provide support of these findings in a clinical sample of children with ADHD. Clinicians seeking to improve peer functioning in children and adolescents with ADHD should measure, evaluate, and address motor coordination disorder symptoms, in addition to oppositional, conduct problems, and ADHD core symptoms.

Conflicts of interest

All authors declare no conflict of interest.

Author contributions

Vincent Oreste Mancini, Ph.D. (Clinical Psychology) (Conceptualization; Data curation; Formal analysis; Methodology; Writing – original draft; Writing – review & editing) Kathryn E. Althorpe (Methodology; Writing – original draft; Writing – review & editing) Wai Chen (Conceptualization; Data curation; Methodology; Supervision; Writing – original draft; Writing – review & editing).

Data availability statement

Research data are not shared due to ethical requirements dictated by the Western Australian Department of Health, Child and Adolescent Mental Health Service.

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