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Associations Between Sleep, Daytime Sleepiness and Functional Outcomes in Adolescents with ADHD

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Abstract

Objective/Background: Adolescents with attention-deficit/hyperactivity disorder (ADHD) experience greater difficulties in the domains of sleep, daytime sleepiness, and functioning compared to their peers. However, the relationship between these domains has not been fully elucidated. This study aimed to examine the relationship between sleep problems (including daytime sleepiness), ADHD severity, and functional outcomes (irritability, sluggish cognitive tempo, homework difficulties, and substance use) in a sample of adolescents with ADHD.

Patients/Methods: Eighty-two adolescents (13-17 years) and their families participated in the study. Sleep was measured by both adolescent and parent-report. Adolescent irritability and sluggish cognitive tempo were reported by both adolescents and parents, while other variables were reported by a single reporter (homework difficulties – parent; ADHD severity – parent; substance use – adolescent). Analyses controlled for demographic factors and internalising and externalising comorbidities.

Results: A weak relationship was found between adolescent-reported sleep problems and daytime sleepiness, which became non-significant in adjusted analyses (β = -.19, p =.115). In adjusted analyses, there was an association between adolescent-reported sleep problems and adolescent-reported irritability (β = -0.27, p = .025) as well as between adolescent-reported daytime sleepiness and parent-reported sluggish cognitive tempo (β = 0.28, p = .031). In adjusted analyses, parent-reported adolescent sleep problems were associated with ADHD severity (β = 0.53, p = <.001), parent-reported sluggish cognitive tempo (β = 0.63, p = <.001), both reporters of irritability (parent-report: β = 0.32, p = .004; adolescent-report: β = 0.29, p = .023), and homework problems (β = 0.37, p = .003). Parent-reported daytime sleepiness was associated with parent-reported sluggish cognitive tempo (β = 0.35, p = .005).

Conclusions: This study demonstrates the importance of a holistic assessment of adolescents with ADHD, not only focusing on symptomatology but also on sleep problems and functional outcomes. The importance of multi-informant assessment of sleep problems is also reinforced.

Associations Between Sleep, Daytime Sleepiness and Functional Outcomes in Adolescents with ADHD

Sleep problems and daytime sleepiness appear to be elevated in adolescents with attention-deficit/hyperactivity disorder (ADHD) compared to those without (Becker, Langberg, et al., 2019; Becker, 2020). Adolescence, a time characterised by major biological and environmental changes (Carskadon, 2011), is also accompanied by a shift in circadian rhythm toward "eveningness" (Colrain & Baker, 2011). This preference is at odds with environmental demands (e.g., early school start times), and can result in sleep deprivation (Crowley et al., 2018), with sleep duration typically decreasing from 8.5 to 7.5 hours per night from ages 13 to 17 (Maslowsky & Ozer, 2014). Poor sleep in adolescence has been associated with a number of negative functional outcomes, including poorer emotional regulation (Baum et al., 2014), reduced performance on school tasks (Cusick et al., 2018), and increased risk-taking behaviours (Shochat et al., 2014). Daytime sleepiness, which is also more common in adolescents with ADHD compared to those without (Becker, 2019), can contribute to similar functional detriments, including reduced educational achievement, increased anger, decreased positive emotions, and increased absenteeism (Drake et al., 2003).

'Sleep problems' is here defined as difficulty initiating, maintaining, or reinitiating sleep; or returning to wakefulness (Mindell & Owens, 2015). Daytime sleepiness is characterised by pervasive sleepiness and lack of energy during waking hours (Young, 2004). Questions remain regarding the associations between sleep problems and the manifestation of daytime sleepiness in adolescents with ADHD. One study reported that daytime sleepiness was more prevalent than specific sleep problems in adolescents with ADHD (Langberg et al., 2017), with 27.8% of the sample scoring above the clinical threshold for daytime sleepiness, and between 1.5% and 5.8% scoring above the clinical threshold for other specific sleep problems (e.g., bedtime resistance, sleep duration). Others have suggested that daytime sleepiness may be part of the ADHD phenotype, rather than being a causal result of sleep problems (Lecendreux et al., 2000). Additionally, sleep can be measured in different ways, both in terms of measures themselves (i.e., sleep rating scales vs. actigraphy), but also in terms of reporter (i.e., adolescent report vs. parent report). Past research has found inconsistency between

parent and adolescent report of sleep problems and other domains of functioning (e.g., Waters et al., 2003), highlighting the importance of a multi-informant approach to the measurement of sleep. While it is clear that both sleep problems and daytime sleepiness are prevalent in adolescents with ADHD (Becker, Langberg, et al., 2019), it is less clear how both are associated with each other, ADHD symptomatology, and functional impairments associated with ADHD.

ADHD is characterised by symptoms in the broad domains of hyperactivity, inattention, and impulsivity, and by definition needs to be accompanied by impairments in daily life (American Psychiatric Association, 2013). Functional impairments are social or occupational aspects of an individual's life that are negatively impacted by the symptomatology of the disorder. Functional domains commonly impacted in children with ADHD include educational achievement, friendships, quality of life, and overall mental health (Danckaerts et al., 2010; DuPaul & Stoner, 2014; Hoza et al., 2005; Klassen et al., 2004). These negative outcomes can continue into adulthood and can predict additional adverse outcomes such as lower educational attainment, higher rates of job termination, and greater social difficulties (Barkley et al., 2006; Ramos-Olazagasti et al., 2018). However, there is a scarcity of research into the associations between sleep difficulties and functioning in adolescents with ADHD specifically. Additionally, most studies focus on singular functional domains, which may mask interactions and shared variance between variables. More research is required to better understand potential connections between sleep problems and functional outcomes in adolescents with ADHD, which will help to understand whether improving sleep in adolescents with ADHD could lead to broader improvements in functioning. A 2016 review (Lunsford-Avery et al., 2016) only found one study that specifically examined these relationships (Langberg et al., 2013). Langberg et al. (2013) found that self-reported daytime sleepiness, but not self-reported sleep duration, was associated with both parent-reported academic impairment and teacher-rated academic competence, even when controlling for demographic variables and ADHD symptomatology. Similarly, Lucas et al. (2017) found that teacher reported daytime sleepiness was a better predictor of functioning in the classroom than sleep parameters. In terms of the relationships between sleep and daytime sleepiness,

some studies have found a relationship between these variables (e.g., Becker et al., 2019), while others have not (e.g., Lucas et al., 2017), highlighting the need for more research in this area.

More recently, Mancini et al. (2020) found that parent-reported sleep problems were not associated with parent-reported social functioning in 6-14 year olds with ADHD; however, daytime sleepiness was not evaluated in this study. This contrasts with Craig et al. (2020), who found parent-reported daytime sleepiness and sleep variability to be associated with parent-reported life skills impairment (e.g., activities of daily living, exercise etc.), and insomnia to be related to social impairment in a sample of young adolescents diagnosed with ADHD. Furthermore, studies that experimentally manipulate sleep also support the association between sleep and functioning. Restricting sleep has been shown to result in greater inattentive symptoms, poorer emotional regulation, and greater sluggish cognitive tempo (SCT) symptoms (e.g., slowed thinking, sleepiness, sluggishness, lethargy, and confusion) in adolescents with ADHD (Becker et al., 2019; Becker et al., 2020). However broader aspects of functioning such as substance use were not examined.

A diagnosis of ADHD in childhood has been shown to increase the likelihood of having ever used nicotine and illicit substances (Lee et al., 2011; Spencer et al., 2007) as well as increasing the risk of development of future substance use disorders (Lee et al., 2011; Levy et al., 2014; Spencer et al., 2007; Wilens et al., 2011). Sleep difficulties and daytime sleepiness are also associated with increased alcohol use in adolescents in the general population (Marmorstein, 2017). Assessing these relationships in a sample of adolescents with ADHD will help to further elucidate the relationships between sleep problems and substance use outcomes in adolescents with ADHD.

In summary, an emerging body of research suggests that sleep problems in adolescents with ADHD may be associated with poorer outcomes. Research to date has tended to focus on sleep problems without consideration of manifestations of daytime sleepiness, and has also tended to focus on younger adolescent samples. Furthermore, few papers have examined the associations between sleep problems and daytime sleepiness and multiple domains of functioning in adolescents with ADHD. In particular, few studies have examined mental health and related outcomes such as irritability, substance use, SCT, and ADHD severity. Additionally, academic impairments are often

seen in adolescents with ADHD, however, most of this research has focused on classroom outcomes rather than homework impairments. Examining these relationships will help to paint a more detailed clinical picture of adolescents with ADHD, which can help to inform clinical assessment and treatment pathways.

Therefore, the aims of this study are to

1) Examine the relationship between sleep problems (including sub-domains such as initiating sleep, maintaining sleep, and returning to wakefulness) and daytime sleepiness in adolescents with ADHD.
2) Examine the distinct relationships between both sleep problems and daytime sleepiness, and ADHD symptom severity, as well as functional outcomes (SCT, irritability, homework problems, and substance use).

Methods

Participants

Participants were 82 adolescents aged 13-17 years (M = 14.33, SD = 1.38). Families were recruited from April to December 2016 from an existing database of families who had expressed interest in participating in ADHD research (Lycett et al., 2014). All adolescents had been diagnosed with ADHD by their paediatrician. Families were also contacted by phone to ensure that their adolescents met the *Diagnostic and Statistical Manual of Mental Disorders* (5^{th} ed.; American Psychiatric Association, 2013) criteria for ADHD, assessed by parent-report using the ADHD Rating Scale-IV (DuPaul et al., 1998). Families were excluded if they were non-English speaking or if the adolescent had an intellectual disability or a serious medical condition.

Measures

ADHD symptom severity was measured using the parent-reported ADHD Rating Scale-IV (DuPaul et al., 1998). The total was used as were both subscales, inattention and hyperactivity/impulsivity (total: 18 items; α = .92; subscales: α = .85 - .93). Symptoms were rated off ADHD medication on a 4-point rating scale from 0 = *never or rarely* to 3 = *very often*, indicating the

frequency of symptoms over the past 6 months. Higher scores indicate more frequent ADHD symptoms.

Adolescent-reported sleep problems were measured using the Adolescent Sleep Wake Scale (ASWS; LeBourgeois et al., 2005). The total score and each of the five subscales were used (total: 28 items, α = .93; subscales: α = .84 - .87). The five subscales are: going to bed (e.g., *When it's time to go to bed, I am ready to go to bed at bedtime)*, falling asleep (e.g., *When it's time to go to sleep (lights-out), I have trouble getting to sleep)*, maintaining sleep (e.g., *During the night, I wake up more than once)*, reinitiating sleep (e.g., *After waking during the night, I have trouble getting back to sleep)*, and returning to wakefulness (e.g., *In the morning, I wake up feeling rested and alert)*. Each item was rated using a 6-point rating scale from 1 = *always* to 6 = *never*, indicating the frequency of the sleep problem over the past month, with higher scores indicating better sleep quality.

Parent-reported adolescent sleep problems were measured using the Sleep Disturbance Scale for Children (SDSC; Bruni et al., 1996). The total score was used in analyses (total: 27 items, α = .89). Each item was rated using a 5-point rating scale from 1 = *never* to 5 = *always (daily)*, indicating the frequency of the sleep problem over the past 6 months, with higher scores indicating poorer sleep quality.

Daytime Sleepiness was measured using the Epworth Sleepiness Scale (ESS; Johns, 1991). The ESS is a brief questionnaire that asks the subject to rate on the scale of 0-3 the chances that over "recent times", they, or their child, would have dozed in eight specific situations that are commonly experienced in daily life (total: 8 items, adolescent-report: α = .79, parent-report: α = .9). Items are summed to give a total score (0-24), with greater scores indicating higher levels of daytime sleepiness.

Sluggish Cognitive Tempo (SCT) was measured using the SCT module of the Child and Adolescent Behaviour Inventory (CABI) and the Child Concentration Inventory (CCI; Becker et al., 2015; Burns et al., 2018) to measure parent- and adolescent-reported SCT symptoms, respectively (CABI: α = .95; CCI: α = .90). The same 16 items are included on the CABI SCT module (0 = almost never, 5 = almost always) and CCI (0 = never, 3 = always).

Irritability was measured using the parent- and adolescent-report versions of the Affective Reactivity Index (ARI; Stringaris et al., 2012). The ARI contains six items, measuring irritable behaviour; including frequency, duration and threshold (adolescent-report: α = .88, parent-report: α = .93). Respondents rated each item using a three-point response scale (0 – 'not true' to 2 = 'certainly true'). Items are summed to give a total score (0-12), with higher scores indicative of higher levels of irritability.

Homework difficulties were assessed using the 20-item, parent-report Homework Problems Checklist (HPC; Anesko et al., 1987; α = .95). Items assess both homework engagement and homework materials management. For each item, parents rate the frequency of problem behaviours on a 4-point response scale (0 = never, 3 = very often). Items are summed to give a total score, (0-60), with higher scores indicating greater homework difficulties.

Substance Use was measured using the relevant items from the LSAC scales (Australian Institute of Family Studies (AIFS), 2005), e.g., *Have you had an alcoholic drink in the last 12 months?*. These items were self-report, and participants were asked about alcohol, cigarette, and marijuana use.

Sample characteristics included adolescent age; adolescent sex; medication use; and professionally diagnosed comorbidities (ASD, Oppositional Defiant Disorder, Conduct Disorder, depressive disorder, anxiety, OCD; parent-reported yes/no to "*Has your child ever been DIAGNOSED or TREATED for any of the following by a health professional?")*.

Procedure

The study was approved by the Deakin University Human Research Ethics Committee (2016-024). Information statements, consent forms, and surveys were mailed and/or emailed to eligible parents and adolescents using REDCap, a secure web-based data capture application (Harris et al., 2009). Adolescents received an AU$20 voucher upon completion of their survey as compensation for the time involved.

Statistical Analysis

All statistical analyses were conducted in the R environment (R Core Team, 2020), using the RStudio Integrated Development Environment. Pearson's correlation analyses were conducted to

examine the correlations between key study variables. Due to the exploratory nature of the study, and the non-independence of variables, the decision was made to not adjust for multiple comparisons. Although this may increase Type 1 error rate, we chose not to make alpha corrections as this is associated with reduced study power and increased Type 2 error rate (Ranstam, 2016). A series of separate regression analyses were then conducted to examine the relationship between adolescent-reported sleep, adolescent-reported daytime sleepiness, and each of the functional outcomes. Each analysis was run both unadjusted and adjusted (i.e. controlling for confounding variables: age, sex, medication status, and comorbidities). A series of exploratory regression analyses were also conducted to examine the relationship between parent-report adolescent sleep problems, parent-report daytime sleepiness, and each of the functional outcomes.

Results

Descriptive Characteristics

Eighty-three adolescents with ADHD and 89 parents of adolescents consented to participate in the study and completed surveys. Participants were included in the analyses if they had complete data for *both* sleep problems (ASWS) and daytime sleepiness (Epworth Daytime Sleepiness Scale) (N = 82) by adolescent report. See Table 1 for a description of the sample. The mean age of the adolescents in the sample was 14.33 years (*SD* = 1.38), and the majority were male (87.8%). Psychiatric comorbidities were common, with 42% of parents reporting their child as having an internalising disorder, and 18% reporting their child as having an externalising disorder. Sixty-eight percent of adolescents were taking ADHD medication, and 28% were taking melatonin.

Correlation Analyses

Correlational analyses were conducted to examine the relationships between key variables (e.g., sleep, daytime sleepiness, ADHD severity, irritability, SCT). The full correlation table can be found in the supplementary materials (Supplementary Figure 1). Significant but small correlations were found between adolescent-reported sleep problems and adolescent daytime sleepiness (r = -0.27, p = .015) and between adolescent reported sleep problems and adolescent-report irritability (r = -0.23,

Table 1.
Descriptive Statistics for Key Variables

Variable	
N	82
Age (M, SD)	14.33 (1.38)
Male (n, %)	72 (87.8)
ADHD Type (n, %)	
Combined	25 (31.6)
Inattentive	52 (65.8)
Hyperactive/Impulsive	2 (2.5)
ADHD Symptom Severity (M, SD)	32.00 (10.86)
Inattentive Symptoms	19.19 (5.85)
Hyperactive Symptoms	12.80 (6.36)
Comorbidities (n, %)	
Any Externalising (ODD, CD)	14 (17.9)
Any Internalising (Depression, Anxiety, OCD)	33 (42.3)
Learning	29 (38.2)
Speech	17 (22.4)
ASD	30 (38.0)
Medication - Any (n, %)	64 (82.1)
ADHD	52 (66.7)
Melatonin	22 (28.2)
Sleep Problems Total – Adolescent-report (M, SD)	4.05 (0.52)
Sleep Problems Total – Parent-report (M, SD)	54.66 (13.68)
Daytime Sleepiness Total – Adolescent-report (M, SD)	3.95 (3.78)
Daytime Sleepiness Total – Parent-report (M, SD)	3.70 (4.29)
SCT – Adolescent-report (M, SD)	19.87 (8.59)
SCT – Parent-report (M, SD)	30.53 (17.73)
Homework Problems (M, SD)	38.07 (13.08)
Any Substance use in past month (n, %)	8 (9.88)
Alcohol	7 (8.64)
Nicotine	2 (2.50)
Marijuana	1 (1.23)

p = .035). Significant correlations were also found between adolescent-reported daytime sleepiness and SCT symptoms from both adolescent- (r = 0.15, p = .022) and parent-report (r = 0.27, p = .036). Significant correlations were found between parent-reported adolescent sleep problems and parent-reported adolescent daytime sleepiness (r = 0.21, p = .031), ADHD severity (r = 0.52, p < .001), ASD (r = 0.28, p = .044), internalising comorbidities (r = 0.31, p = .002), parent and adolescent-reported Sluggish Cognitive Tempo (SCT; rs = 0.58 [p < .001] and 0.18 [p = .036], respectively), parent- and

adolescent-reported irritability (*r*s = 0.41 [$p < .001$] and 0.29 [$p = .003$], respectively), and homework problems ($r = 0.33$, $p = .024$). Significant correlations were also found between parent-report daytime sleepiness and melatonin use ($r = -0.24$, $p = .036$), as well as parent-reported SCT symptoms ($r = 0.33$, $p = .006$).

Adolescent-reported Sleep Variables

Associations Between Sleep and Daytime Sleepiness

There was a significant association between adolescent-reported sleep problems and daytime sleepiness ($\beta = -0.26$, $t = -2.28$, $p = .025$), with sleep problems accounting for 7% (adj. $R^2 = .06$) of the variance in the dependent variable, daytime sleepiness. When controlling for confounding variables known to affect sleep problems (age, sex, comorbidities, and medication), the relationship between sleep problems and daytime sleepiness was no longer significant ($\beta = -.19$, $t = -1.60$, $p = .115$). Sex was the only significant predictor in the adjusted model ($\beta = -.29$, $t = -2.54$, $p = .014$), with females experiencing greater daytime sleepiness than males. No significant associations were found between any of the ASWS subscales and daytime sleepiness (Table 2).

Associations Between Adolescent-reported Sleep Problems and Functioning

As seen in Table 3, there were significant associations between adolescent-reported sleep problems and adolescent-reported irritability; adolescent-reported daytime sleepiness and adolescent-reported SCT; adolescent-reported daytime sleepiness and parent-reported SCT; and adolescent report daytime sleepiness and substance use (any substance use in the past month). No other variables were associated with sleep problems (i.e. ADHD severity, either reporter of SCT, parent-reported irritability, homework problems, or substance use), or daytime sleepiness (i.e. ADHD severity, either reporter of irritability, or homework problems). After controlling for potential confounding variables (age, sex, comorbidities, and medication), the relationship between adolescent-reported sleep problems and adolescent-reported irritability remained significant ($\beta = -0.27$, $t = -2.29$, $p = .023$, $sr^2 = .07$), with internalising diagnosis also significant in the model ($\beta = 0.25$, $t = 2.17$, $p = .033$, $sr^2 = .06$) The relationship between daytime sleepiness and parent-report SCT also remained significant in the adjusted model ($\beta = 0.25$, $t = 2.21$, $p = .046$, $sr^2 = .05$), with ASD diagnosis also significant in the model ($\beta = .27$, $t = 2.18$, $p = .033$, sr2 = .06). However, the relationships between daytime sleepiness

and adolescent-reported SCT (β = 0.17, t = 1.29, p = .199, sr^2 = .03), and between daytime sleepiness and substance use (β = 0.18, t = 1.56, p = .125, sr^2 = .03.) were no longer significant. In the adjusted model for daytime sleepiness and substance use, age was significantly associated with substance use (β = 0.26, t = 2.39, p = .020, sr^2 = .07).

Table 2.
Association Between Sleep Problems and Daytime Sleepiness in Adolescents with ADHD

Predictor	β	β 95% CI	p	Fit
Going to bed	0.03	[-0.22, 0.28]	.803	
Falling Asleep	-0.06	[-0.35, 0.22]	.656	
Maintaining Sleep	-0.07	[-0.32, 0.19]	.601	
Reinitiating Sleep	-0.21	[-0.47, 0.05]	.108	
Returning to Wakefulness	-0.09	[-0.31, 0.14]	.436	
				R^2 = .089 95% CI[.00,.17]

Note. n = 80.

Parent-reported Sleep Variables

After finding fewer relationships than expected between sleep, daytime sleepiness, and functional outcomes, the decision was made to explore whether there was an effect of sleep reporter on the relationships being explored. A series of regression analyses, identical to the analyses already conducted for adolescent-reported sleep problems, were undertaken to explore the relationships between parent-reported adolescent sleep problems, parent-reported adolescent daytime sleepiness, and functional outcomes.

Association Between Parent-report Sleep and Daytime Sleepiness

No association was found between overall parent-reported sleep problems and adolescent-report daytime sleepiness (β = 0.20, t = 0.64, p = .087). At the subscale level (Table 4), an association was found between the "Disorders of Excessive Somnolence" subscale and adolescent-reported

Table 3.
Association Between Adolescent-reported Sleep Problems and Daytime Sleepiness and outcomes: Unadjusted analyses

	Sleep Problems				Daytime Sleepiness			
Outcome Variable	*β*	*β* 95% CI	*p*	R^2	*β*	*β* 95% CI	*p*	R^2
ADHD Severity[a]	-0.14	[-.37, 0.08]	.215	0.02	0.12	[-0.11, 0.34]	.310	0.01
SCT								
Adolescent-report[b]	-0.22	[-0.44, 0.00]	.054	0.05	0.26	[0.04, 0.48]	**.022**	0.07
Parent-report[c]	-0.16	[-0.39, 0.06]	.156	0.03	0.24	[0.02, 0.47]	**.036**	0.06
Irritability								
Adolescent-report[d]	-0.23	[-0.45, -0.02]	**.035**	0.06	0.08	[-0.15, 0.30]	.502	0.01
Parent-report[a]	-0.21	[-0.43, 0.01]	.066	0.04	0.20	[-0.02, 0.42]	.074	0.04
Homework Problems[e]	-0.03	[-0.26, 0.20]	.801	0.00	-0.03	[-0.26, 0.20]	.795	0.00
Substance Use[d]	-0.12	[-0.34, 0.11]	.304	0.01	0.32	[0.11, 0.53]	**.004**	0.10

Note.
[a]*n* = 79. [b]*n* = 78. [c]*n* = 76. [d]*n* = 81. [e]*n* = 77
Adolescent sleep problems are measured such that higher scores equate to better sleep quality.

Daytime sleepiness (β = 0.21, t = 2.01, p = .048, sr^2 = .05). An association was found between overall parent-report sleep problems and parent-report daytime sleepiness, (β = 0.24 , t = 2.20, p = .031, r^2 = 0.07) but this association attenuated when controlling for confounding variables (β = 0.23, t = 1.85, p = .068, sr^2 = .04). At the subscale level (see Table 5), Disorders of Excessive Somnolence was again the only subscale to be associated with parent-reported daytime sleepiness (β = .44, t = 4.00, p < .001, sr^2 = .16).

Associations Between Parent-reported Sleep Variables and Functional Outcomes

Parent-reported sleep problems were significantly associated with ADHD severity, parent-reported SCT symptoms, irritability (both reporters), and homework problems, but no association was found between parent-reported sleep problems and adolescent-reported SCT or substance use (Table 6). All detected associations remained significant after controlling for confounding variables (age, sex, comorbidities, medication; ADHD Severity: β = 0.54, t = 4.92, p = <.001, sr^2 = .24; Parent-Reported SCT: β = 0.64, t = 6.23, p = <.001, sr^2 = .34; Parent-Reported Irritability: β = 0.32, t = 3.02, p = .004, sr^2 = .09, Adolescent-reported Irritability: β = 0.29, t = 2.34, p = .022, sr^2 = .07; Homework Problems: β = 0.37, t = 3.11, p = .003, sr^2 = .11). The adjusted model for the relationship between parent-reported sleep problems and parent-reported irritability showed that an internalising diagnosis was also associated with parent-reported irritability (β = 0.28, t = 2.66, p = .009, sr^2 = .07), as was an externalising diagnosis (β = 0.20, t = 2.01, p = .049, sr^2 = .04). Additionally, adjusting for the relationship between sleep and homework problems revealed sex to be associated with homework problems (β = 0.26, t = 2.52, p = .020, sr^2 = .07). Analyses were also conducted using the "Disorders of Initiating and Maintaining Sleep" (DIMS) subscale only, the results of which can be found in Supplementary Table 1. Parent-report daytime sleepiness was associated parent-report SCT symptoms, as well as with substance use. The relationship between parent-report daytime sleepiness and parent-report SCT remained significant after controlling for confounding variables (β = 0.34, t = 2.75, p = .024, sr^2 = .05). The relationship between parent-report daytime sleepiness and substance use did not remain significant after controlling (β = 0.13, t = 1.06, p = .292, sr^2 = .01), however, age was significant in the model (β = 0.26, t = 2.26, p = .028, sr^2 = .06). Parent-reported daytime

sleepiness was not associated with ADHD severity, adolescent-reported SCT, either reporter of irritability, or homework problems.

Table 4.
Association Between Parent-Reported Sleep Problems and Adolescent-Reported Daytime Sleepiness – Subscales

Predictor	*β*	*β* 95% CI	*p*	Fit
Disorders of Initiating and Maintaining Sleep	0.03	[-0.28, 0.35]	.829	
Sleep Breathing Disorders	0.06	[-0.18, 0.31]	.606	
Disorders of Arousal	-0.21	[-0.48, 0.07]	.138	
Sleep-Wake Transition Disorders	0.14	[-0.16, 0.44]	.354	
Disorders of Excessive Somnolence	0.26	[0.00, 0.51]	**.048**	
Sleep Hyperhydriosis	0.00	[-0.25, 0.24]	.988	
				R^2 = .104 95% CI[.00,.18]

Table 5.
Association Between Parent-Reported Sleep Problems and Parent-Reported Daytime Sleepiness – Subscales

Predictor	*β*	*β* 95% CI	*p*	Fit
Disorders of Initiating and Maintaining Sleep	-0.23	[-0.51, 0.05]	.103	
Sleep Breathing Disorders	0.21	[-0.01, 0.43]	.056	
Disorders of Arousal	-0.16	[-0.40, 0.09]	.202	
Sleep-Wake Transition Disorders	0.23	[-0.04, 0.49]	.088	
Disorders of Excessive Somnolence	0.46	[0.23, 0.68]	**<.001**	
Sleep Hyperhydriosis	-0.01	[-0.23, 0.21]	.918	
				R^2 = .288 95% CI [.07,.39]

Table 6.
Association Between Parent-reported Sleep Problems and Daytime Sleepiness and Outcomes: Unadjusted Analyses

	Sleep Problems (parent-report)				Daytime Sleepiness (parent-report)			
Outcome Variable	*β*	*β* 95% CI	*p*	R^2	*β*	*β* 95% CI	*p*	R^2
ADHD Severity[a]	0.53	[0.31, 0.75]	< **.001**	.28	0.17	[-0.05, 0.40]	.134	.03
SCT[b]								
Adolescent-report	0.22	[-0.01, 0.46]	.065	.05	0.02	[-0.22, 0.26]	.852	.00
Parent-report	0.60	[0.40, 0.79]	< **.001**	.36	0.32	[0.09, 0.55]	**.006**	.10
Irritability[c]								
Adolescent-report	0.33	[0.11, 0.55]	**.004**	.11	0.01	[-0.22, 0.24]	.936	.00
Parent-report	0.46	[0.25, 0.67]	<**.001**	.21	0.18	[-0.05, 0.41]	.126	.03
Homework Problems[d]	0.36	[0.14, 0.58]	**.002**	.13	0.01	[-0.23, 0.24]	.948	.00
Substance Use[d]	0.03	[-0.20, 0.27]	.778	.00	0.23	[0.00, 0.46]	.046	.05

Note.
[a]*n* = 77. [b]*n* = 70. [c]*n* = 75. [d]*n* = 74.
Parent-report sleep problems are coded such that lower scores equate to poorer sleep quality.

Discussion

This study examined the associations between sleep problems, daytime sleepiness, and functional outcomes in a sample of adolescents with ADHD. There was minimal evidence of an association between adolescent-reported sleep difficulties and manifestations of daytime sleepiness, with only small associations found that were reduced to non-significance in adjusted models. Additionally, daytime sleepiness was not associated with any of the adolescent-reported sleep difficulty subscales. There was mixed evidence for the relationship between sleep difficulties and functioning in adolescents with ADHD, with findings differing depending on reporter of sleep difficulties. Parent-reported adolescent sleep was associated with almost all measured functional outcomes, whereas adolescent-reported sleep was associated with adolescent-reported irritability only. There was minimal evidence of a relationship between daytime sleepiness and functional outcomes. Adolescent-reported daytime sleepiness was associated with both reporters of SCT symptoms, whereas parent-report daytime sleepiness was associated with parent-report SCT symptoms only.

The weak relationship between sleep and daytime sleepiness is surprising. Total adolescent-report sleep problems were initially associated with daytime sleepiness, but this relationship attenuated in adjusted analyses, in which sex was the only significant predictor of daytime sleepiness, with females experiencing greater daytime sleepiness. This may indicate a differential relationship between sleep difficulties and daytime sleepiness based on sex. Some research has suggested that levels of daytime sleepiness may be influenced by pubertal stage and sex (Liu et al., 2019). Additionally, no adolescent-reported sleep subscale was associated with daytime sleepiness. This contrasts with previous research such as Becker et al. (2019) who found that restricting sleep in adolescents with ADHD led to increased daytime sleepiness, and Langberg et al. (2017), who found average time in bed on school and weekend nights to be associated with daytime sleepiness, even when accounting for factors such as comorbidities and medication use. The absence of associations in this study suggests that the link between sleep and daytime sleepiness is complex, and there are a number of possible explanations. Reliance on self-report measures of sleep may have over- or under-estimated sleep problems, as adolescents may have had trouble accurately reflecting on their sleep over the preceding month. Some research suggests that adolescents over-report their total sleep

duration (Lauderdale et al., 2008), while other studies have found that agreement between self-report and objectively reported sleep is poor for particular domains in adolescents (Zinkhan et al., 2014). However, to our knowledge, these relationships have not been tested specifically in adolescent ADHD populations. It is also possible that adolescents may struggle to reflect on their subjective experience of daytime sleepiness. Another explanation is that the sleep measure used (ASWS) did not capture the aspects of sleep most closely associated with daytime sleepiness. A sleep variable not often considered in the literature is sleep insufficiency, which is the subjective amount of sleep needed by an individual (Ebben, 2020). Some research in non-ADHD populations has found that sleep insufficiency, rather than sleep duration, is more closely related to daytime sleepiness (Hwangbo et al., 2016).

In terms of the relationships between adolescent-reported sleep, daytime sleepiness and functional outcomes, few associations were found. Associations were identified between sleep difficulties and adolescent-reported irritability, as well as between daytime sleepiness and parent-reported SCT symptoms in adjusted models. However, the variance explained by these relationships was relatively small. The results were, however, consistent with previous research such as Becker et al. (2020), who found restriction of sleep to be associated with the closely related construct of emotional regulation (parent-report), and (Langberg, Dvorsky, Becker, & Molitor, 2014), who found daytime sleepiness to be associated with SCT in a sample of college students with ADHD. Our results are also consistent with Langberg et al. (2014), who found that although daytime sleepiness and SCT were related, they are distinct constructs. The fact that sleepiness is only one facet of SCT may explain why the relationships were modest, and why a relationship was not found between parent report daytime sleepiness and adolescent report SCT. However, the general lack of relationships between adolescent-reported sleep and functional outcomes was surprising. Notably, no associations were found between either sleep problems and daytime sleepiness and substance use. One possible explanation for the absence of relationships is that the sleep variables themselves are confounding the results. It is conceivable that poor sleep, or increased daytime sleepiness, reduces the ability for adolescents to accurately perceive their behaviour or performance relative to their baseline. Some research (e.g., Van Dongen et al., 2003) has found that increased sleepiness reduces awareness of

increasing cognitive deficits, highlighting potential issues with relying on sole reporters of outcomes. Additionally, the adolescent sleep measure does not capture particular aspects of sleep such as intraindividual (i.e. night to night) variability, which some research has shown is both more prominent in adolescents with ADHD (Langberg et al., 2019) and is associated with functional outcomes (Becker et al., 2017).

Given these surprising results, the decision was made to conduct exploratory analyses to examine whether different reporters of sleep affected the relationships between sleep, daytime sleepiness, and functional outcomes. These exploratory analyses revealed a number of associations between parent-reported adolescent sleep and outcomes. Parent-reported sleep difficulties were associated with most outcomes including ADHD severity, parent-reported SCT symptoms, parent- and adolescent-reported irritability, and homework problems. These results are partially consistent with previous research linking sleep restriction in adolescence to increased inattention and SCT symptoms, and decreased emotional regulation (Becker et al., 2019; Becker et al., 2020). The relationship between sleep difficulties and homework problems contrasts with Langberg et al. (2013), who found self-reported daytime sleepiness, but not sleep difficulties, to be related to homework problems in a sample of 10-14 year olds with ADHD. The study however, assessed sleep using a single item, so it is possible that the more comprehensive assessment of sleep in the current study contributed to these differences.

One of the most interesting results illustrated by this study was the presence of associations between sleep and functioning differing depending on reporter of sleep problems. When considering adolescent-reported sleep, the only significant association identified was between sleep and irritability, however, when considering parent-reported sleep problems, several relationships were identified. One possible reason for these discrepancies is the different measurement tools used. Parents reported their adolescent's sleep using the SDSC (Bruni et al., 1996), while adolescents used the ASWS (LeBourgeois et al., 2005). The SDSC captures a number of subscales relating to diagnosable sleep problems (e.g., sleepwalking, hyperhydriosis etc.), while the ASWS focuses more on the initiation, maintenance, and cessation of sleep. It is possible that the functional variables examined are simply more strongly associated with the aspects of sleep captured by the SDSC.

However, it is also the case that as adolescents develop, they typically have increased independence, and parents may not have as accurate a picture of the functioning of their adolescent, particularly in the domain of sleep. Parents may be over- or underestimating the presence and severity of these variables, both in the domains of sleep and functional outcomes, which, in turn may be inflating the detected relationships.

This study displayed a number of strengths. The focus on a broad range of functional outcomes was a key strength of this study, as well as the consideration of multiple informants of both functioning, as well sleep difficulties and daytime sleepiness. However, there are also several important limitations to mention including the cross-sectional nature of the study. Additionally, the use of subjective sleep measures, while less invasive, reduces the accuracy of measurement and does not allow for an examination in variability in sleep problems or daytime sleepiness over time. Many of the associations detected were within-rater (e.g., parent-report sleep problems being associated with parent-reported SCT), which may indicate bias in perceptions of symptomatology rather than a true relationship. Lastly, the results should be considered cautiously in the context of the relatively small sample, particularly with variables of interest such as substance use, and the large number of comparisons. However, as discussed by Rothman (1990), adjustment for multiple comparisons can miss important findings that require further investigation. While the results should still be interpreted cautiously, novel findings can encourage further research to provide a better understanding of the findings.

Adolescents with ADHD experience greater functional impairment compared to their peers. This study provides insights into how sleep and daytime sleepiness are related to functional outcomes and suggests that initial and follow assessment of sleep problems may be warranted as part of a broader assessment of ADHD, particularly given what is already known about the links between ADHD and sleep. Additionally, adolescents with ADHD may benefit from sleep interventions to improve functional outcomes such as ADHD severity, irritability, sluggish cognitive tempo, and homework problems. However, despite a growing evidence base for interventions to improve sleep difficulties in younger children with ADHD (Hiscock et al., 2015), studies have yet to examine the

efficacy of such interventions for adolescents with ADHD. Additionally, this study demonstrates the importance of a multi-informant assessment using validated assessment measures.

This study examined the relationships between sleep difficulties, daytime sleepiness, and functional outcomes in a sample of adolescents with ADHD. Surprisingly, there was little evidence of an association between sleep problems and manifestations of daytime sleepiness. Relationships between sleep and functioning varied depending on reporter, with parent-reported sleep displaying greater associations with functional outcomes compared with adolescent-reported sleep problems. Overall adolescent-reported daytime sleepiness has minimal associations with functioning, with the exception of being associated with SCT symptoms, which may reflect decreased ability of adolescents to accurately monitor their functioning when excessively sleepy, or may simply reflect absence of these relationships.

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Highlights

Ref.: Ms. No. SLEEP-D-21-00420

- Adolescent reported sleep is not associated with adolescent reported daytime sleepiness
- Adolescent reported sleep is associated with a small number of outcomes
- Parent report sleep is associated with a range of outcomes, including ADHD severity

SLEEP-D-21-00420 - CRediT author statement

George Loram: Conceptualization, Methodology, Investigation, Formal analysis, Writing - Original Draft, Writing - Review & Editing, Visualization. **Emma Sciberras:** Conceptualisation, Methodology, Investigation, Data Curation, Resources, Writing - Review & Editing, Supervision, Project administration, Funding acquisition. **Tim Silk:** Conceptualisation, Methodology, Writing - Review & Editing, Supervision. **Mathew Ling:** Conceptualisation, Methodology, Formal analysis, Supervision, Writing - Review & Editing **Matthew Fuller-Tyszkiewicz:** Conceptualisation, Methodology, Writing - Review & Editing. **Christian Hyde:** Conceptualisation, Methodology, Writing - Review & Editing **Jane McGillivray:** Conceptualisation, Methodology, Writing - Review & Editing