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Sleep-disordered breathing and daytime sleepiness predict children's reading ability

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Background. Sleep problems are common in children and are known to detrimentally affect language and cognitive abilities, as well as academic achievement.

Aims. We aimed to investigate effects of sleep on oral word and non-word reading in a large, cross-sectional sample of children.

Sample. Of 428 children who attended a public psychological science event, 339 children aged 4–14 years (mean 8;10 ± 2;2) took part.

Methods. Parents completed two sleep questionnaires (Children's Sleep Habits Questionnaire and Sleep-Disordered Breathing Questionnaire) whilst children completed the Test of Word Reading Efficiency.

Results. Hierarchical multiple linear regression assessed whether parentally reported sleep problems were able to predict word and non-word oral reading speeds as measures of sight word reading and phonemic decoding efficiency, respectively. Children with parent-reported increased sleep-disordered breathing, daytime sleepiness, and shorter sleep latency had poorer performance on the reading task for both words and non-words, as well as the total combined score. The models explained 6–7% of the variance in reading scores.

Conclusions. This study illustrates associations between sleep and word and non-word reading. The small but significant effect is clinically meaningful, especially since adverse factors affecting children's reading ability are cumulative. Thus, for children with multiple risk factors for poor reading ability, sleep problems may be another avenue for treatment. Since reading ability is a strong predictor of later academic success and life outcomes, our study provides important evidence to suggest that children with sleep problems should also be screened for literacy difficulties, and children with literacy difficulties be screened for sleep problems.

Sleep problems in childhood are known to have a detrimental effect on cognitive abilities, behavioural regulation, and academic achievement. Few studies have focused specifically

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on reading ability, which underpins general academic attainment and supports children's access to the curriculum. Here, we combine objective measures with parent report to explore the association between sleep problems and word reading fluency in a large sample of school-aged children.

Sleep

Sleep problems in children are relatively common, thought to affect around one-third of otherwise healthy children (Owens, Spirito, McGuinn, & Nobile, 2000). These span behavioural problems such as struggles at bedtime, to clinically significant problems like sleep-disordered breathing. Sleep-disordered breathing ranges from primary snoring to severe obstructive sleep apnoea syndrome. Primary snoring does not affect oxygenation or sleep architecture and is estimated to affect 7.45% of children (Lumeng & Chervin, 2008). In contrast, obstructive sleep apnoea syndrome is a condition where the upper airway becomes occluded and causes difficulty breathing during sleep, which can lead to oxygen desaturation, hypercarbia, and increased night waking. This affects 1–4% of children (Lumeng & Chervin, 2008). In addition, whilst not a sleep disorder itself, excessive daytime sleepiness can be an indication of sleep problems and/or insufficient sleep.

Sleep and academic ability

Sleep problems and sleep curtailment are associated with increased sleepiness during the day. To investigate the effects of daytime sleepiness, sleep quality, and sleep duration on school performance, Dewald, Meijer, Oort, Kerkhof, and Bogels (2010) conducted a meta-analysis of 50 studies with over 36,000 healthy typically developing children and adolescent participants. After controlling for age and gender differences, the strongest association with school performance was for daytime sleepiness ($r = -.13$), followed by sleep quality ($r = .10$), then sleep duration ($r = .07$), representing small effect sizes. These variables did not significantly correlate with one another, indicating independent associates with school performance. Effects were moderated by age, with the youngest children experiencing the strongest effects, suggesting their reduced resilience to the effects of sleep problems. This vulnerability means that early childhood sleep problems are likely associated with early low academic achievement, with cascading consequences, which could hinder later life chances. School performance was more strongly correlated with subjective rather than objective measures of sleepiness. This could reflect individual differences in amount of sleep needed, which are not captured by objective measures. Likewise, other studies have found that excessive daytime sleepiness is significantly associated with poorer academic performance (Drake et al., 2003; Ludwig et al., 2019).

Other types of sleep problems have also been associated with poorer academic abilities. For example, Gruber et al. (2014) report that higher sleep efficiency (i.e., the quality of sleep) is associated with children obtaining better grades in maths, English language, and French as a second language. In contrast, sleep duration did not affect academic performance, likely because there is great individual variability in children's sleep needs and resistance to sleep deprivation that cannot be measured or controlled for.

A meta-analysis of 16 studies on sleep-disordered breathing and academic performance indicated that sleep-disordered breathing was associated with poorer performance in core academic domains of maths, science, and language arts, but not general school performance (Galland et al., 2015). Although effect sizes were not large (Cohen's d

ranging from $-.29$ to $-.33$), there is a clear association here between sleep and academic performance. Of particular interest to the current study, there was an association between sleep-disordered breathing and poorer ability in language arts (including spelling, reading, reading comprehension, and first language studies), with an effect size of $-.31$ indicating a small to medium effect. Only two studies used validated measures of language arts (Bourke et al., 2011; Giordani et al., 2008), with most studies on school performance relying on parent- or school-reported subject grades or ratings. Notably, these two studies did not find a significant difference between control and clinical groups for word reading, and did not investigate non-word reading.

The mechanism by which sleep affects academic attainment could be due to the known influence of sleep on cognitive functions such as attention, working memory, and executive functions, which underlie more general skills such as mathematic and language abilities. For example, in a large study of 118 children, O'Brien et al. (2004) combined objective sleep and cognitive assessment with parent report. They found that children with primary snoring experienced poorer overall cognitive ability as well as specific difficulties in areas of oral language, visuospatial ability, attention, behavioural and social problems, and anxiety, relative to non-snorers. Similarly, a literature review of 33 articles on sleep-disordered breathing reported poorer memory, immediate recall, visuo-spatial skills, attention and vigilance, and more behavioural problems in children with sleep-disordered breathing relative to those without. Cognitive improvements were seen following treatment by adenotonsillectomy (Mitchell & Kelly, 2006). In addition, there are likely moderators of the association between sleep and academic ability, including ethnicity, socioeconomic status, and effortful control: the ability to control inhibition, plan, and detect errors through efficient executive attention. For example, Diaz et al. (2017) showed that sleep disruption was associated with lower academic ability for children with low levels of effortful control. In a study on cognitive performance, Buckhalt, El-Sheikh, and Keller (2007) reported that African American children and children from low socioeconomic backgrounds were more severely affected by sleep disruption relative to European American Children and children from higher socioeconomic backgrounds.

Sleep and reading

Despite clear evidence that sleep is associated with cognitive and behavioural problems, research focusing on specific academic skills such as reading ability is under-represented in the literature. This is important since, at school entry, maths and reading, followed by attention, are the strongest predictors of later academic success (Duncan et al., 2007). Soon after children learn to read, they are expected to be able to read to learn; thus, reading mediates children's ability to access the curriculum. As a result, low literacy increases the likelihood of poor educational outcomes (McLaughlin, Speirs, & Shenassa, 2014; Ricketts, Sperring, & Nation, 2014). This has long-term implications by limiting future employment options (McLaughlin et al., 2014; OECD, 2013).

Associations between sleep and academic reading ability have been demonstrated previously. For example, in a longitudinal study of 98 Israeli children, Ravid, Afek, Suraiya, Shahar, and Pillar (2009) illustrated that sleep influenced early reading development. Increased reading at age 6–7 was associated with increased sleep quality and fewer night wakings as measured by actigraphy, as well as parent report of reduced sleep-disordered breathing, periodic leg movements, parasomnias and daytime sleepiness at age 5–6. Mathematics and writing ability at age 6–7 were also associated with poorer sleep at age 5–6,

with children with the worst sleep failing their first year of school. The conclusions drawn from this study are limited because reading attainment was assessed on a three-point scale (failure, good, very good) by combining test scores and teacher ratings, rather than through direct measurement. Nonetheless, this study demonstrates preliminary evidence for the long-term and substantial effects that sleep may have on academic ability, even in children who are not seeking clinical help for sleep problems (Ravid et al., 2009).

In another study, Buckhalt, El-Sheikh, Keller, and Kelly (2009) demonstrated promising preliminary evidence of both concurrent and longitudinal relationships between sleep and academic achievement in American children in Grade 3 ($n = 166$) and Grade 5 ($N = 132$). Longitudinal analyses indicated that, after controlling for child age, gender, race, parent education, and income, reading achievement was associated independently with lower daytime sleepiness, as well as lower sleep activity and greater total sleep minutes as measured by actigraphy (Buckhalt et al., 2009). In addition, cross-sectional analyses indicated that subjective reports of poor sleep and lower sleep efficiency were associated with poorer academic achievement, including reading achievement, at both time points; and this association was stronger for children from lower SES backgrounds (Buckhalt et al., 2009). Unfortunately, however, there was a great deal of achievement data missing in these analyses (e.g., 50% of African American children's achievement data was missing in Grade 5).

These previous studies have explored the association between sleep and reading attainment generally, measured in reading comprehension tasks. To understand how sleep influences reading attainment, we need to consider its influence on the components of reading more carefully. For example, there are good theoretical reasons why sleep problems may have impact on particular aspects of word reading achievement. Fluent oral word reading is a crucial component of reading attainment, which depends upon not only knowledge about the links between spoken and written language (phonemic decoding), oral vocabulary, and language knowledge, but also broader cognitive skills such as executive function (Bredmore, Vardy, Cunningham, Kwok, & Carroll, 2019). The cognitive skills that have been shown to associate with sleep problems underpin the reading process – for example executive function (Beebe & Gozal, 2002). The language skills that underpin the ability to read individual words have also been found to be affected by sleep problems. For example, O'Brien et al. (2004) found that, relative to non-snorers, children with primary snoring had lower phonological processing (effect size .38), speeded naming (effect size .15) as well as poorer broader language skills such as comprehension of instructions (effect size .14). Dual route models of word reading (Coltheart, 2006; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001) propose that words are initially read through phonemic decoding, which relies upon phonological processing. Once words have been encountered many times, the direct route enables more automatized sight word reading. This offers a hypothesis for a causal link between sleep problems and reading attainment; if sleep difficulties lead to limited phonological skills, this would lead to limited phonemic decoding, and limited word reading in turn.

Current study

Whilst many studies report the association between sleep problems and poorer cognitive functioning across a variety of domains, little research focuses specifically on reading ability and those which do have measured reading comprehension. To our knowledge, no previous studies have investigated sleep and word and non-word reading. This study utilizes a large cross-sectional sample of children, objectively measured on a standardized word

reading test, with parent report of sleep problems. Importantly, we assessed both sight word reading and phonemic decoding to explore whether sleep differentially affects these routes to word reading. We hypothesize that increased sleep problems, as reported by parents, will be associated with poorer sight word reading and phonemic decoding ability.

Method

Participants

Children were recruited through local schools and centres such as swimming pools, libraries, museums, and cafés in Coventry, UK. Flyers and posters were distributed and displayed locally, and a digital flyer was used on social media. The study was advertised as an activity session for children aged 6–12 years, called ‘Coventry Young Researchers’. Siblings outside of the advertised age range were permitted to attend with their family. Parents registered online for their child to attend a morning or afternoon session at Coventry University to take part in several research experiments and psychological science-based activities, crafts, and games. Sessions were free to attend, and all children received a certificate and a gift (a book or t-shirt) for taking part. The Coventry Young Researchers event ran for five days in August in 2015, 2016, and 2017. Over the three years, a total of 428 children attended the event, 339 of whom are included in the present sample. There were 179 males, 160 females, with a mean age of 8;10 years ($\pm 2;2$ years). On arrival, children were sequentially allocated to take part in experiments and were free to decline taking part; thus, not all children completed the reading task and/or sleep questionnaires. Children were excluded from analyses if parents reported special educational needs ($n = 33$), first language not English (14), or an uncorrected visual (3) or hearing (3) impairment. These data were collected online at sign-up. See Table 1 for final details of included participants.

Measures

Children’s Sleep Habits Questionnaire (CSHQ)

The CSHQ is a 33-item, parent-report questionnaire covering symptoms of common sleep problems in school-aged children such as sleepwalking, bed wetting, snoring, and sleeping too little or too much (Owens, Spirito, & McGuinn, 2000). Parents respond to whether each item has occurred often (5–7 nights per week), sometimes (2–4 nights per week), or rarely (0–1 night per week) during the past week. Items are scored from one to three such that higher scores indicate increased problems. The questionnaire yields scores for eight subscales: Bedtime Resistance, Sleep Onset Delay, Sleep Duration, Sleep Anxiety, Night Waking, Parasomnias, Sleep Disordered Breathing and Daytime Sleepiness, as well as a total sleep disturbance score. A total of 41 or above signifies significant sleep problems with a sensitivity of .80 and specificity of .72 (Owens et al., 2000). In addition, the questionnaire asks whether the parent considers each sleep characteristic to be a problem, and groups problems into four categories: Sleep Behaviour, Night Waking, Morning waking, and Daytime Sleepiness. The CSHQ has shown satisfactory test–retest reliability for both normal and clinical populations (Owens et al., 2000a, 2000b).

Sleep-Disordered Breathing Questionnaire (SDBQ)

The SDBQ was based on that used by Montgomery-Downs, O’Brien, Holbrook, and Gozal (2004), which was adapted from Carroll, McColley, Marcus, Curtis, and Loughlin (1995)

Table 1. Participant details including measures completed

Year	Full sample			Sleep questionnaire complete			TOWRE complete			Both measures complete		
	n	Age (M ± SD)	Age range	Male/female	n	Age (M ± SD)	Age range	Male/female	n	Age (M ± SD)	Age range	Male/female
2015	117	8;11 ± 2;0	5;1–14;2	59/58	112	8;11 ± 2;1	5;1–14;2	58/54	97	9;0 ± 2;2	5;1–14;2	48/49
2016	82	9;4 ± 2;0	4;3–13;0	45/37	81	9;5 ± 2;0	4;3–13;0	44/37	78	9;7 ± 1;10	6;2–13;0	43/35
2017	140	8;6 ± 2;3	4;1–13;4	75/65	95	8;3 ± 2;4	4;1–13;4	52/43	119	9;1 ± 1;11	5;1–13;4	67/52
Total	339	8;10 ± 2;2	4;1–14;2	179/160	288	8;10 ± 2;2	4;1–14;2	154/134	294	9;2 ± 1;11	5;1–14;2	158/136
									243	9;2 ± 1;11	5;1–14;2	133/110

and Gozal (1998). The questionnaire contains three sections: Family and Health History, Sleep Disordered Breathing, and Daytime Sleepiness. In this case, the Family and Health History section was not included. Parents responded to 18 questions on Sleep Disordered Breathing and Daytime Sleepiness using a five-point scale, where characteristics were rated for frequency of occurrence from never (never in the past six months) to almost always (more than four times a week). Items include frequency of snoring, struggling to breathe during sleep, parental concerns about child's sleep, and falling asleep in school or whilst watching television. Items are scored from 0 (Never) to 4 (Almost Always) or reverse scored where necessary. Higher scores of the summed items indicate increased problems. The SDBQ has shown satisfactory predictive value for sleep-disordered breathing relative to polysomnography (Montgomery-Downs et al., 2004).

Test of Word Reading Efficiency (TOWRE)

The TOWRE includes two measures, Sight Word Efficiency and Phonemic Decoding Efficiency (Torgesen, Wagner, & Rashotte, 1999). Both tasks were administered and scored according to the manual. All participants received the same list of items and began at the same starting point. Sight Word Efficiency is a measure of oral word reading fluency; the ability to quickly and accurately read individual words from a list. Raw scores indicate the number of words read correctly in 45 s. Phonemic Decoding Efficiency is a measure of oral non-word reading fluency; the ability to quickly and accurately decode the pronunciation of novel words. Raw scores reflect the number of non-words correctly decoded in 45 s. The combined raw score and individual raw scores on these two component subtests are used in all analyses. Scaled (standard) scores are presented to describe the population and range of ability. Standard scores are provided for the range 6–25 years, based on an age-based distribution with a mean of 100 and a *SD* of 15. Excellent reliability and validity have been well documented across the age range, for both subtests and overall scores using a wide range of metrics (e.g. internal consistency $>.8$, inter-rater reliability $.99$, concurrent criterion validity $>.8$ as reported in the manual – Torgesen et al., 1999).

Procedures

Ethical approval for the Coventry Young Researchers event, including all experiments and activities, was granted by Coventry University Research Ethics Committee.

Parents provided consent online at the time of booking and again on arrival at the event. Children gave their verbal assent and were assured that they did not have to complete any activity if they did not want to, and they could stop an activity at any time. On arrival, they were sequentially allocated to take part in a series of experiments and free-flow activities, which included the TOWRE. Experiments lasted a maximum of 20 min with at least 10 min break between each one. Parents were provided with the sleep questionnaires and were asked to complete them during the session.

Results

Analyses

Data were analysed using IBM SPSS version 25. They were screened for outliers using Cook's distance scores >1 , and standardized residuals >3 . Only one outlier with a standardized residual >3 was found. Inclusion of this participant did not alter the significance of results; thus, she was not removed.

For each standardized score on the TOWRE, *t*-tests were used to compare children scoring above versus below the threshold for clinical sleep problems, defined as having a total score of 41 or above on the CSHQ.

Hierarchical multiple linear regression models were used to investigate the association between sleep and reading ability. Potential confounders of age and sex were investigated for each variable of interest using Pearson's correlations and *t*-tests, respectively. Increased age was associated with better sleep across several subscales (Bedtime Resistance, Sleep Anxiety, Night Wakings, Parasomnias, SDBQ Daytime Sleepiness; see Table 2) and higher scores on both TOWRE scales; thus, age was controlled in the first block of each model. Sex was not a significant confounder except that girls experienced higher scores than boys on the CSHQ Daytime Sleepiness subscale (which was not included in the final model); thus, sex was not controlled in the model. Predictor variables were scores for each subscale on the CSHQ and SDBQ, excluding the total scores. To avoid multicollinearity, the CSHQ subscales Daytime Sleepiness and Sleep Disordered Breathing were not included due to measuring the same constructs as the SDBQ. Pearson's correlation coefficients were examined for associations between all other subscales; all were below .69 (Sleep Anxiety and Bedtime Resistance: $r(284) = .69, p < .001$) (see Table 2). Variance inflation factors (VIFs) and tolerance were also acceptable. All predictors were entered in the second block of the model using forced entry. The dependent variables were raw scores on the TOWRE for total score, and individually for Sight Word Efficiency and Phonemic Decoding Efficiency. Raw scores were used, rather than standardized scores, as age was already controlled in the model. The assumption of independent errors was assessed using the Durbin–Watson statistic and was found to be violated for the Sight Word Efficiency model; this was corrected using 1,000 bootstrap samples and, for consistency, this was applied to all models. This did not change the direction or significance of findings. Due to missing data of 1.52% on the CSHQ and 1.23% on the SDBQ and to avoid excluding participants, we smoothed missing data by computing missing items using the participant's average score of completed items for the relevant scale. To assess the impact of this procedure on our findings, we conducted comparative analyses using a strict threshold of excluding all participants with any missing data point ($n = 68$).

Power analysis indicated that our sample size of 243 for the regression models was above the recommended sample of 220 to detect a small-medium effect in R^2 change with 90% power.

Descriptive data on measures

Mean (*M*), standard deviation (*SD*), and range of scores for each measure were calculated and are reported in Table 3.

Of note, 116/278 children (42%) scored a total of 41 or above on the CSHQ, the recommended cut-off score for significant sleep problems. Of parents who responded to the questions on whether they considered each sleep characteristic to be a problem, 79/245 (32%) reported at least one sleep problem, 43 (18%) reported three or more problems, 23 (9%) reported five or more problems, and 8 (3%) reported ten or more problems. The most commonly reported problems were with sleep behaviour, reported by 22% of parents, which include a broad range of behaviours around bedtime and falling asleep, as well as during sleep such as sleep disordered breathing, nightmares, and bruxism (grinding teeth). Night waking problems were reported by 21% of parents, morning waking problems by 6%, and daytime sleepiness problems by 11%.

Table 2. Pearson's correlations between age and all subscales on the Children's Sleep Habits Questionnaire (CSHQ) and Sleep-Disordered Breathing Questionnaire (SDBQ)

	CSHQ		SDBQ				TOWRE raw scores			TOWRE standard scores				
	r	p	Age in months	Bedtime resistance	Sleep onset delay	Sleep duration	Sleep anxiety	Night wakings	Parasomnias	Sleep disordered breathing	Daytime sleepiness	Sight Word Efficiency	Phonemic Decoding Efficiency	Total raw score
CSHQ	r													
	p													
Bedtime resistance														
r														
p														
n														
Sleep onset delay														
r														
p														
n														
Sleep duration														
r														
p														
n														
Sleep anxiety														
r														
p														
n														
Night wakings														
r														
p														
n														
Parasomnias														
r														
p														
n														
Sleep-disordered breathing														
r														
p														
n														
Daytime sleepiness														
r														
p														
n														
SDBQ														
r														
p														
n														
Sleep-disordered breathing														
r														
p														
n														
SDBQ daytime sleepiness														
r														
p														
n														
TOWRE														
r														
p														
n														
Sight word efficiency														
r														
p														
n														
Raw score														
r														
p														
n														

Continued

Table 2. (Continued)

	CSHQ		SDBQ					TOWRE raw scores			TOWRE standard scores					
	r	p	Sleep onset delay	Sleep duration	Sleep anxiety	Night wakings	Parasomnias	Sleep disordered breathing	Daytime sleepiness	Step-disordered breathing	Daytime sleepiness	Sight Word Efficiency	Phonemic Decoding Efficiency	Total raw score	Sight Word Efficiency	Phonemic Decoding Efficiency
Phonemic decoding efficiency raw score	.598**	<.001	-.181**	.162*	-.027	-.113	-.175**	-.169**	-.129*	.010	-.225**	-.264**	.858**	<.001	<.001	<.001
	n	293	242	240	240	.079	.006	.008	.047	.878	<.001	<.001	<.001	<.001	<.001	<.001
Total raw score	.663**	<.001	-.214**	.156*	-.002	-.146*	-.177**	-.183**	-.155*	.241	.235	.234	.294	.234	.294	.294
	p	<.001	.001	.016	.971	.024	.006	.004	.017	-.003	<.001	<.001	<.001	<.001	<.001	<.001
Sight word efficiency standard score	-.329**	<.001	-.034	.033	-.170**	-.038	-.055	-.075	-.148*	.241	.235	.234	.294	.234	.294	.294
	p	<.001	.595	.611	.009	.558	.392	.250	.024	.189	.025	.001	.391**	.338**	.381**	.381**
Phonemic decoding efficiency standard score	-.138*	.019	-.037	.093	-.170**	-.008	-.120	-.083	-.109	.239	.233	.232	.292	.292	.292	.292
	p	<.001	.573	.154	.009	.898	.063	.202	.094	-.039	-.141*	-.234**	.391**	.651**	.528**	.762**
Total standard score	-.253**	<.001	-.038	.059	-.174**	-.028	-.092	-.077	-.131**	.239	.233	.232	.292	.292	.292	.292
	p	<.001	.557	.363	.007	.665	.155	.235	.045	-.078	-.157*	-.251**	.397**	.501**	.461**	.924**
	n	291	240	238	238	240	240	240	235	.230	.233	.232	.292	.292	.292	.291

*p = < .05; **p = < .01; ***p = < .001.

Table 3. Participant scores on CSHQ, SDBQ, and TOWRE scales

	<i>n</i>	<i>M</i>	<i>SD</i>	Range
CSHQ				
Bedtime resistance	286	6.85	1.61	6–18
Sleep onset delay	284	1.70	0.81	1–3
Sleep duration	284	3.72	1.15	3–9
Sleep anxiety	286	4.83	1.35	4–11
Night wakings	286	3.50	0.98	3–8
Parasomnias	286	8.36	1.52	7–16
Sleep-disordered breathing	281	3.25	0.62	3–7
Daytime sleepiness	285	10.95	2.46	8–21
Total	286	40.75	5.32	24–64
SDBQ				
Sleep-disordered breathing	276	4.03	3.40	0–21
Daytime sleepiness	275	3.61	2.39	0–9
TOWRE				
Sight word efficiency raw	295	67.53	15.29	21–104
Phonemic decoding efficiency raw	294	39.26	12.63	8–63
Total raw	294	106.71	26.90	30–167
Sight word efficiency standard	292	112.27	13.23	57–145
Phonemic decoding efficiency standard	292	114.97	13.27	73–145
Total standard	292	115.61	14.46	65–149

Association between sleep and reading

T-tests showed no significant difference in standardized Sight Word Efficiency, $t(229) = -.51$, $p = .612$, Phonemic Decoding Efficiency, $t(229) = -.11$, $p = .914$, or TOWRE Total score, $t(229) = -.47$, $p = .643$, between children scoring above versus below the CSHQ threshold for significant sleep problems.

Regression models showed that children's improved performance on the TOWRE was predicted by increased Age, Sleep-Disordered Breathing, Daytime Sleepiness and shorter Sleep Onset Delay (see Table 4). Further investigation of TOWRE raw scores for Sight Word Efficiency and Phonemic Decoding Efficiency individually showed the same pattern of results, indicating that improved performance on both scales was predicted by increased Age, Sleep-Disordered Breathing, Daytime Sleepiness and shorter Sleep Onset Delay (see Tables 5 and 6). Excluding all participants with missing data ($n = 68$) showed the same pattern of results on all TOWRE outcomes, including specific predictors within the model, after controlling for age, Total $\Delta F(8,151) = 5.93$, $p < .001$, $\Delta R^2 = .13$, $\Delta R^2_{\text{Adjusted}} = .13$; Sight Word Efficiency $\Delta F(8,152) = 5.53$, $p < .001$, $\Delta R^2 = .11$, $\Delta R^2_{\text{Adjusted}} = .11$; Phonemic Decoding Efficiency $\Delta F(8,151) = 5.07$, $p < .001$, $\Delta R^2 = .13$, $\Delta R^2_{\text{Adjusted}} = .11$.

Discussion

This study showed a clear association between parent-reported sleep problems and children's oral word and non-word reading fluency. Specifically, after controlling for age, increased daytime sleepiness and sleep-disordered breathing with shorter sleep onset delay significantly predicted poorer performance on sight word and phonemic decoding efficiencies similarly, as well as overall TOWRE score. Our models were able to explain 6–

Table 4. Hierarchical multiple linear regression of predictors of TOWRE total raw score

Block	Predictors	Overall model			Change statistics		
		B	SE B	β	ΔR^2	ΔF	Adjusted ΔR^2
1	Constant	23.35	6.63		.41	159.63***	.41
	Age	0.75	0.06	.64***			
2	Constant	43.01	12.77		.09	4.78***	.07
	Age	0.69	0.06	.59***			
	Bedtime resistance	-1.42	1.42	-.07			
	Sleep onset delay	5.44	1.76	.16**			
	Sleep duration	-1.68	1.22	-.07			
	Sleep anxiety	0.40	1.39	.02			
	Night wakings	-1.06	1.62	-.04			
	Parasomnias	0.84	1.03	.05			
	Sleep-disordered breathing	-1.20	0.44	-.15**			
	Daytime sleepiness	-1.88	0.58	-.16**			

Note. * $p < .05$; ** $p < .01$; *** $p < .001$.

7% of the variance in scores for the subtests and total score on the TOWRE. When participants with missing data were excluded, our models explained 11–13% of the variance in scores. Whilst the direction and significance of effects were not affected, our procedure shows that removing the noise in the data (i.e. the smoothed missing values) strengthened the effect.

Whilst the proportion of variance in oral reading fluency explained by sleep problems was relatively small, this is a significant and meaningful effect, given that the causes of low literacy are probabilistic and cumulative (Carroll, Solity, & Shapiro, 2016; Pennington, 2006). For children with multiple risk factors for low literacy, such as phonological, language, and broader cognitive difficulties, the addition of sleep problems could accumulate to a substantial literacy impairment and warrants further investigation. Future

Table 5. Hierarchical multiple linear regression of predictors of TOWRE Sight Word Efficiency

Block	Predictors	Overall model			Change statistics		
		B	SE B	β	ΔR^2	ΔF	Adjusted ΔR^2
1	Constant	17.56	3.68		.45	187.11***	.45
	Age	0.45	0.03	.67***			
2	Constant	27.95	7.15		.08	4.37***	.06
	Age	0.42	0.03	.62			
	Bedtime resistance	-0.78	0.79	-.07			
	Sleep onset delay	2.53	0.99	.13*			
	Sleep duration	-0.64	0.68	-.05			
	Sleep anxiety	-0.08	0.78	-.01			
	Night wakings	-0.38	0.91	-.02			
	Parasomnias	0.59	0.58	.06			
	Sleep-disordered breathing	-0.71	0.24	-.16**			
	Daytime sleepiness	-1.03	0.32	-.16**			

Note. * $p < .05$; ** $p < .01$; *** $p < .001$.

Table 6. Hierarchical multiple linear regression of predictors of TOWRE Phonemic Decoding Efficiency

Block	Predictors	Overall model			Change statistics		
		B	SE B	β	ΔR^2	ΔF	Adjusted ΔR^2
1	Constant	5.61	3.30		.31	103.99***	.31
	Age	0.30	0.03	.56***			
2	Constant	14.71	6.43		.09	4.20***	.07
	Age	0.28	0.03	.51***			
	Bedtime resistance	-0.54	0.72	-.06			
	Sleep onset delay	2.88	0.89	.19**			
	Sleep duration	-1.06	0.61	-.10			
	Sleep anxiety	0.41	0.70	.05			
	Night wakings	-0.70	0.82	-.05			
	Parasomnias	0.24	0.52	.03			
	Sleep-disordered breathing	-0.50	0.22	-.14*			
	Daytime sleepiness	-0.85	0.29	-.16**			

Note. * $p < .05$; ** $p < .01$; *** $p < .001$.

research should explore this further by examining the prevalence of sleep problems within populations with low literacy. Meanwhile, cognitive skills such as working memory are difficult to train (Melby-Lervåg & Hulme, 2013), whereas sleep problems can be treated. Our small- to medium-effect sizes are comparable to those reported by Dewald et al. (2010) and Galland et al. (2015) for the association between sleep and academic performance, which incorporated reading amongst other subjects.

Treating sleep problems leads to improvements in cognitive ability, though with some residual effects (Biggs et al., 2014; Gozal, 1998). Thus, it is possible that treating sleep problems, in particular sleep-disordered breathing and daytime sleepiness, could be a potential avenue to increase children's reading ability and downstream consequences. Excess weight can contribute to sleep-disordered breathing for some children; thus, weight loss should be encouraged for children who are overweight or obese (Carter, Hathaway, & Lettieri, 2014). A course of intranasal corticosteroids (anti-inflammatory medication) and/or oral montelukast (a drug used for control of asthma, allergies, and wheezing) show efficacy for treating mild to moderate sleep-disordered breathing (Kaditis et al., 2016). Obstructive sleep apnoea syndrome is most commonly treated by adenotonsillectomy, which is effective in significantly reducing symptoms for around 80% of children (Marcus et al., 2013); whilst for severe treatment-resistant sleep apnoea, nocturnal ventilation is effective (Kaditis et al., 2016). Daytime sleepiness may be concurrent with sleep-disordered breathing or with another sleep disorder requiring treatment; however, usually it occurs as a result of insufficient sleep due to late bedtimes. Use of portable media devices (e.g. tablet computers and mobile phones) is prevalent in children and is known to detrimentally affect sleep quality, duration, and daytime sleepiness; thus, a reduction in evening device use could help to alleviate daytime sleepiness problems (Carter, Rees, Hale, Bhattacharjee, & Paradkar, 2016). Likewise, many sleep problems and sleep curtailment in children can be managed simply through improved sleep hygiene, behavioural techniques, and/or earlier bedtimes (Carter et al., 2014). In this study, shorter Sleep Onset Delay was associated with poorer word reading; however, this subscale is based on only one reverse-scored question (child falls asleep within 20 min). Short sleep latency is generally associated with increased tiredness; thus,

it is not surprising that both Sleep Onset Delay and Daytime Sleepiness together were predictors of performance.

Limitations and future directions

Further research should explore the association between sleep problems and specific processes that underpin reading more broadly. This will enable us to understand the causal pathways that mediate the association between sleep and reading. This study considered word-level reading only. Word-level reading is a core component of reading comprehension, but in order to understand longer passages of text, readers depend upon their broader language and cognitive skills, such as executive function and reasoning abilities (Breadmore et al., 2019). Since we know that these broader cognitive skills are related to sleep (Beebe & Gozal, 2002), we might anticipate that sleep problems associate even more closely with reading comprehension. Indeed, Giordani et al. (2008) found that obstructive sleep apnoea was significantly associated with children's poorer spelling and reading comprehension but not word reading compared to children without sleep apnoea.

This study is cross-sectional and correlational, with data collected from three cohorts over three consecutive years. Further longitudinal research should follow the development of a single cohort to discover whether improving sleep and reducing daytime sleepiness to optimum levels could lead to improvements in children's reading ability. Even so, previous research has shown that low academic performing children with sleep-related gas exchange abnormalities significantly improved their overall academic achievement following adenotonsillectomy, relative to children who received no treatment (Gozal, 1998). The study did not distinguish reading ability from overall academic achievement; however, it is likely that treatment for sleep-disordered breathing could affect reading ability. By middle childhood, reading forms the basis of much academic learning, and literacy skill significantly contributes to overall academic ability (Duncan et al., 2007). Hence, this might even be the mechanism through which improvements in sleep lead to improvements in academic achievement. Given that even mild sleep-disordered breathing such as primary snoring has an effect on children's neurocognitive abilities, we question whether all children with sleep-disordered breathing require some form of treatment, either clinically or via additional support in the classroom. We question what happens to children who do not receive treatment, and whether these children can recover from adversity.

Much previous research has focused on clinical samples (Bourke et al., 2011; Giordani et al., 2008). This study benefits from taking a cross-sectional approach of a large sample of children. However, the study was limited by not collecting background data on participants, such as ethnicity, socioeconomic status, or parent education, which have previously been found to moderate the association between sleep and academic ability (e.g., Buckhalt et al., 2007, 2009). Whilst these data would help to provide a thorough description of the sample and aid interpretation of the results, we feel that our large sample was representative of the general population.

The study was also limited by using parent report of sleep, rather than objective measures. Whilst objective measures, such as actigraphy or polysomnography, undoubtedly provide more robust measures of the precise characteristics of sleep, parent report does provide a wealth of information on children's sleep habits and behaviours over time which cannot be gathered from objective measures. Some questions arise over the accuracy of parent report for behaviours that occur during the night such as sleep apnoea, nightmares, and night waking, but parents are relatively accurate when reporting on

daytime and bedtime behaviours (McDowall, Galland, Campbell, & Elder, 2017). Of note, sleep problems were reported in 42% of our sample, which was higher than expected based on previous research and norms of the CSHQ (Owens et al., 2000) yet is in line with more recent work. For example, a recent Australian study reported sleep problems occurring in 53% of children (Fletcher et al., 2018). The increase in sleep problems may reflect increases in technology use (e.g. mobile phones and tablets), which detrimentally affect sleep but are not captured by the CSHQ (Carter et al., 2016). Given that *t*-tests showed no significant reading effects for children scoring above the CSHQ threshold for significant sleep problems, a more precise scale for daytime sleepiness and SDB must be used. Children with high scores for daytime sleepiness and SDB in particular should be identified and monitored as sleep may be impacting their reading ability.

Conclusion

This study addresses a gap in the research literature by exploring associations between parent-reported sleep problems and objectively measured word reading and phonemic decoding abilities in school-aged children. The study provides clear evidence that sleep-disordered breathing and daytime sleepiness are associated with poorer reading ability. Further research should consider whether interventions aimed at improving children's reading ability should also focus on children's night-time sleep. Treatment for sleep-disordered breathing and increasing sleep time to reduce daytime sleepiness are possible targets for intervention, which could have significant effects on reading ability. Since reading ability is strongly linked to later academic success, early intervention for sleep problems could have far-reaching implications for children's life outcomes. We recommend that children be screened for sleep problems to identify those whose reading may be affected by their sleep.

Conflicts of interest

All authors declare no conflict of interest.

Author contribution

Anna Joyce: Conceptualization (equal); Data curation (equal); Formal analysis (AJ); Investigation (equal); Methodology (equal); Project administration (equal); Resources (equal); Writing – original draft (AJ); Writing – review & editing (equal). **Helen L. Breadmore:** Conceptualization (equal); Data curation (equal); Investigation (equal); Methodology (equal); Project administration (equal); Resources (equal); Supervision (HB); Writing – review & editing (equal).

Data availability statement

Data are available on request from the authors.

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