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Sleep behaviour in children with language disorder

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Abstract: Sleep and language are intimately linked over childhood, yet objective measurements of sleep behaviour have never been compared between children with developmental disorders of language and their language-typical peers. The aim of this two-study series was to assess an emergent hypothesis that children with poor structural language development may also exhibit poor sleep. In Study 1, 196 parents of 4-10 year-old children completed the Children's Sleep Habits Questionnaire and the Children's Communication Checklist-2, including the parents of 61 children with reported language disorder. Parent-reported sleep behaviour and language ability showed a positive correlation, with children who scored more highly on the language measure showing better sleep behaviour. Interestingly, parental estimates of sleep duration showed an unexpected reverse pattern, with children who scored lower on the language measure being reported to go to bed earlier and sleep for longer than their peers. In Study 2, a subsample of 20 4-to-6 year-old children with language disorder and 20 language-typical age-matched peers contributed objective, actigraphy-derived estimates of sleep duration, efficiency and onset latency. Mirroring parental estimates in Study 1, actigraphy data showed the language disordered group slept for longer and more efficiently than their language-typical peers. We consider that parental perception of poor sleep behaviour in children with language difficulties may result from a history of poor sleep and/or from observed difficulties in sleep parameters that are not possible to assess with actigraphy. The data suggest that subjective reports of sleep behaviour and objective estimates of children's sleep be thought of as complementary.

Keywords: Sleep; Language Disorder; Actigraphy; CCC-2; CSHQ

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Introduction

A developmental relationship between sleep and the emergence of linguistic skill in typically developing children has been repeatedly demonstrated. Observationally, unfragmented night-time sleep is positively associated with language performance in pre-school (Lam et al., 2011; Touchette et al., 2007; Quach et al., 2009), and school-age children (Buckhalt et al., 2009). Experimentally, daytime naps enhance new word learning in pre-school children (see Axelsson, Williams & Horst, 2016; Hubach et al., 2009; Kurdziel et al., 2013), and such behavioural gains are positively correlated with expressive vocabulary skill (Horváth et al., 2015). In school-aged children, sleep, compared to equivalent time awake, has been found to support the consolidation of declarative word learning and lexical integration (Henderson et al., 2012) and benefit the learning of word-pair associations (Backhaus et al., 2008).

Decades of work with adults has built a picture of the neural mechanisms by which sleep promotes the consolidation of new memories, including linguistic material, through a process of hippocampal re-activation (see Paller et al., 2021 for a recent review). While equivalent work on the mechanisms on memory consolidation during sleep is still to emerge in children, behavioural research converges on the importance of sleep for the acquisition of language. Despite this, children's behavioural sleep habits, such as duration and efficiency, have never been objectively measured in those with language disorder.

Sleep in Language Disorder

The term *language disorder* refers to a neurodevelopmental disorder characterised by a deficit in the acquisition of language over childhood at any level of language description and in both receptive and expressive modalities. This definition covers idiopathic developmental language disorder (DLD), but extends more broadly to include any children who may not meet the criteria for DLD but 'who are likely to have language problems enduring into middle childhood and beyond' (Bishop et al., 2017; p.1070).

Describing behavioural sleep habits in the language disordered population is of considerable theoretical and clinical interest. Data from electroencephalography recording suggest that around half of children with DLD show atypical electrophysiological activity such as epileptiform discharges during sleep (Dlouha et al., 2020; Echenne et al., 1992; Fabbro et al., 2000; Overvliet et al., 2011; Picard et al., 1998). Initial behavioural evidence also exists to suggest that sleep may not support language learning in individuals with DLD to the same extent or in the same way as in typically developing peers, with adults who have language disorder showing reduced overnight consolidation of new phonemic learning (Earle et al., 2017). A description of sleep behaviour in children with language disorders is currently a missing link in understanding the association between sleep and language development. By 'sleep behaviour' here we mean habitual patterns of behaviour, cognition and emotion which occur during and proximate to sleep. Measurements of sleep behaviours includes subjective estimates, as well as objectively measured sleep parameters such as duration and timing of sleep activity.

Botting and Baraka recently explored subjectively measured sleep habits of 3-18 year old children with language disorders or typical development, using parent report (Botting & Baraka, 2017). Children with language disorders were reported to experience longer sleep-onset latencies (the time it takes to fall asleep after lights out) than their typically developing peers, and were more likely to wake early. Across the sample, sleep-onset latency was found to correlate with both syntax and semantic/pragmatic ability as measured by the Children's Communication Checklist (CCC; Bishop, 1998). One other study using parent-report found that children with clinically meaningful delays in receptive vocabulary at 60 months showed less mature sleep patterns (i.e., less consolidated night-time sleep) at 6 and 18 months of age compared to children with typical language development or transient delays (Dionne et al., 2011)[1].

Sleep in Autism

The work of Botting and Baraka represents an important step forward in understanding the sleep behaviours of children with language disorders. However, nearly a third of the language disordered participants in this study also had an autism spectrum condition. This is an important limitation as children with autism are already known to show extended sleep-onset latency according to parental report (see Díaz-Román et al., 2018 for a review). Indeed links between sleep difficulties and autism have been fairly consistently demonstrated. According to parent report, sleep problems co-occur with early autism symptoms and worsen over development (Verhoeff et al., 2018), with children who have autism going to bed later and getting up earlier than their peers from around 30 months of age (Humphreys et al., 2014). Over the pre-school years, sleep problems as defined by the Children's Sleep Habits Questionnaire (CSHQ; Owens et al., 2000) are more than twice as common in children with a diagnosis of autism, with group differences emerging on every subscale of the questionnaire (Reynold et al., 2019). Actigraphy data from pre-schoolers with autism and general developmental delay have also shown greater night-to-night variability in sleep measures for both groups compared to typically developing peers (Anders et al., 2011). Overall, sleep difficulties in this group are seen in objectively recorded global measures such as total sleep time (Elrod et al., 2015) but are more consistently observed in subjective, parent-reported measures (Díaz-Román et al., 2018).

The Current Study

The current paper aims to describe basic sleep behaviour in relation to language development over childhood. The extant literature is suggestive of a link between impoverished sleep behaviour and the disordered development of structural language; however this is currently based on subjective parent-report. The nature of objectively measured sleep behaviour in children with clinically significant language deficits is yet to be described. Furthermore, it is not yet clear whether an association between

[1] While this study considered a linguistic domain relevant to clinical language disorders (receptive vocabulary), diagnoses were not reported.

sleep problems and language disorder can be explained by the inclusion of children with autism in previous studies of language disorder (Marini et al., 2020; Williams et al., 2008). We therefore focused on the relationship between sleep in early-mid childhood (primary school age) and the acquisition of oral language independent of social communication skills over two studies. Study 1 employed parent-report to consider subjective relationships between language ability and sleep behaviour, while Study 2 employed actigraphic recording to look at the duration and efficiency of children's sleep along with objectively measured language ability.

Study 1 utilised two questionnaires to replicate and extend the work of Botting and Baraka (2017). The aim of Study 1 was to describe basic, parent-reported sleep behaviour and estimates of sleep quantity (as described by the Children's Sleep Habits Questionnaire) in relation to language development (as described by parent report and the Children's Communication Checklist-2) in primary-school aged children without autism. We hypothesised that children whose parents reported better language ability would also have fewer parent-reported sleep problems.

Study 1

Method

Measures

Parents were asked to fill out two well-established questionnaires, the CSHQ (Owens et al., 2000), and the Children's Communication Checklist-2 (CCC-2; Bishop, 2003), along with their child's age, sex, and a description of any developmental disorders and/or diagnoses. The study was granted ethical approval from the Department of Psychology's Departmental Ethics Committee at the University of York.

The CCC-2 is a 70 item parent-rated questionnaire, which asks respondents to quantify their children's strengths and weaknesses in communication on a scale of 0 ("less than once a week") to 3 ("every day"). The questionnaire is split into 10 sub-scales, which generate a General Communication Composite (hereafter referred to as CCC General) and a Social Interaction Deviance Composite (hereafter referred to as CCC Social). The CCC General describes structural language ability and is composed of the subscales: A-Discourse, B-Syntax, C-Semantics, D-Coherence, E-Inadequate initiation, F-Stereotyped language, G-Use of context and H-Non-verbal communication. The CCC Social describes whether or not pragmatic aspects of communication are in line with a child's general communication skill and is calculated by subtracting the age-normed scores for the grammatical/semantic sub-scales (A + B + C + D) from the age-normed scores for the pragmatic sub-scales (E + H +I-Social relations + J-Interests), a score of 0 suggests that structural language and social language are exactly in line. A score below 55 on the CCC General, in conjunction with a CCC Social score of 9 or more is consistent with a profile characteristic of DLD. A CCC General score below 55 with a negative CCC Social score is suggestive of autism, as is a CCC Social score of -15 or below with any CCC General score.

The CSHQ is a 33 item sleep screening instrument which asks parents about their child's sleep habits over the last week (or the most recent typical week). The CSHQ is concerned with sleep behaviour, that is, behavioural habits, emotions and cognitions about sleep, night-time activity including sleep-walking (an example of a parasomnia), as well as medical aspects such as sleep-disordered breathing as indicated by snoring. Scores are given for eight subscales plus a total score (CSHQ Total), with high scores indicating more difficulty in that domain. The subscales are as follows: Bedtime Resistance; Sleep Onset Delay; Sleep Duration; Sleep Anxiety; Night Wakings; Parasomnias; Sleep Disordered Breathing; and Daytime Sleepiness. Each item is scored on a scale of 1-3, such that the minimum score is 33 and the maximum 99; the clinical threshold for concern on the CSHQ is a total (sum) score of 41. Parents are also asked to estimate their child's 'bed time', 'waking time' and their 'usual amount of sleep each day'. Test-retest reliability for subscales ranges from r= .62-.79, while sensitivity for distinguishing between clinical and control groups is .80, and specificity .72. In addition to these two published questionnaires, parents were asked to fill out a descriptive Sleep History questionnaire devised by the research team to give an overall impression of how parents viewed their child's sleep. This questionnaire is available in Supplementary Materials.

Participants

In total, 273 datasets were available for analysis. 242 datasets were collected from parents completing the questionnaires online; these parents were recruited through social media, parent groups, schools and the University of York newsletter. A link to the questionnaire was sent out with a brief description of the aims of the study which mentioned the team's interest in all children, particularly those with developmental disorders of language. An additional 31 datasets were included from a previous study in the lab (Fletcher et al., 2019; Knowland et al., 2019), to which participants were recruited either as typically developing controls, or on the basis of parental concerns about language development (n = 9). Methods of recruitment were the same in this latter case, but parents completed the questionnaires on paper.

Thirty datasets were removed as parents reported that their child had a diagnosis or suspected diagnosis of autism (to address whether any differences in sleep behaviours are apparent in language disorder independent of autism); a further 14 were removed because parents did not complete the CSHQ. As the CSHQ was developed to assess the sleep behaviour of 4-to-10 year old children (Owens et al., 2000), and the CCC-2 was developed to assess the language profiles of 4-to-16 year olds (Bishop, 2003), children outside the age range of the CSHQ were removed from the analysis. This process left 196 participants whose parents reported no developmental concerns (n=135) or whose parents described a developmental language difficulty but no other biomedical condition (n=61).

If parents reported that their child had a difficulty with language development they were asked to describe it and to provide any diagnoses their child had been given. Sixty one parents described their child as having a difficulty with language development that extended beyond pronunciation. Although a smaller number (n=38) used the term DLD or similar, we included all 61 children in a Language Disordered (LD) group as language disorder of unknown origin is understood to extend beyond the group of children who meet criteria for a diagnosis of DLD (see Norbury et al., 2016).

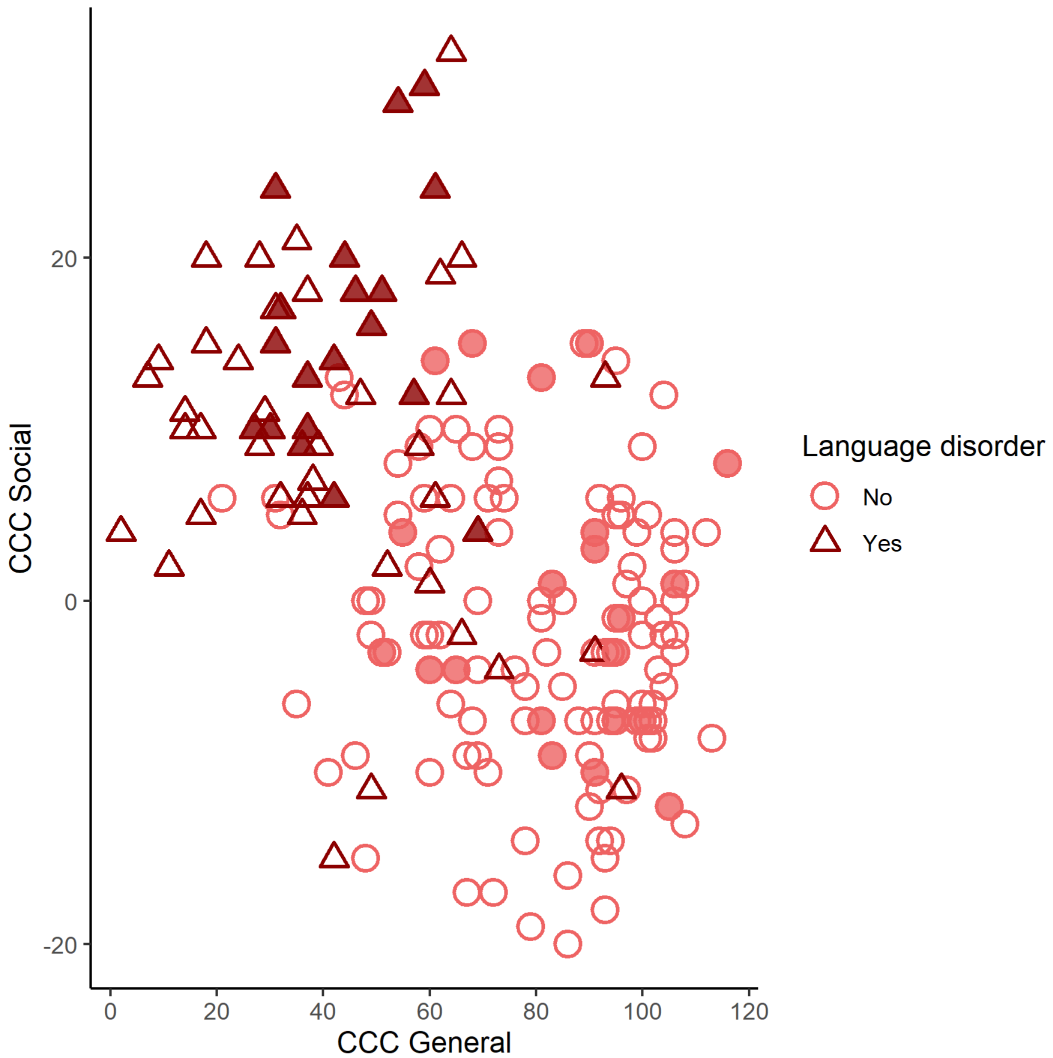

Figure 1. ***Scores on the CCC General (CCC-2 GCC subscale) and CCC Social (CCC-2 SIDC subscale). A CCC Social score of 0 suggests that social and pragmatic skills are exactly in line with general language skill, while scores above this indicate better social and pragmatic skill compared to language. 188 participants in Study 1 are shown who either did or did not have a Language Disorder according to parent report. (Those participants represented by filled shapes also participated in Study 2.)***

Of the sample of children in the LD group, 38 were male and 23 female, with an average age of 80.44 months (6 years, 8 months; *SD* = 23.58 months); while in the comparison group (Typically Developing; TD), 76 were male and 59 female, with an average age of 86.09 months (7 years, 2 months; *SD* = 23.58 months). CSHQ profiles for the whole sample are given in Table 1. The Language Disordered group scored significantly lower on CCC General (group mean = 42.11 (*SD* = 21.26), compared to the TD group (group mean = 81.51, *SD* = 20.72; $t(104.2)=11.770$, $p<0.001$), but had higher scores on the CCC Social as this measure is relative to language ability (LD group mean = 10.98, *SD* = 9.52; TD group mean = -1.43, *SD* = 8.24; $t(94.2) = -8.547$, $p<0.001$). The relationship between CCC General and CCC Social is illustrated in Figure 1 for each group.

Table 1. ***CSHQ profiles for the sample N = 196. SDB = Sleep Disordered Breathing.***

CSHQ subscale	# of items	Mean	*SD*	Min	Max	Skew	Kurtosis
Bedtime resistance	6	7.76	2.49	2	16	1.31	1.16
Sleep onset delay	1	1.62	0.76	1	3	0.76	-0.86
Sleep duration	3	4.10	1.52	2	9	1.26	0.64
Sleep anxiety	4	5.63	1.89	2	12	1.18	0.81
Night wakings	3	4.06	1.48	2	9	1.44	1.39
Parasomnias	7	8.80	1.73	7	15	0.85	0.17
SDB	3	3.39	0.85	2	8	2.75	9.79
Daytime sleepiness	8	11.01	2.51	8	18	0.82	-0.06
Total	33	45.78	8.10	33	73	0.75	-0.17

Results

Exploratory Analyses

Analysis of the questionnaire data was undertaken in an exploratory manner to allow a focused, pre-registered analysis of the objective, actigraphy data in Study 2. Correlations were assessed between CCC General and each of the CSHQ subscales (see Table 2). High scores on the CSHQ subscales indicate poor sleep, while high scores on the CCC-2 indicate better language ability. The negative correlations evident in Table 2 therefore suggest that those with better language have better sleep habits.

Table 2. *Correlations between each subscale of the CSHQ and the general language score from the CCC-2 (CCC General). Italic font indicates those p-values that do not survive Bonferroni-Holm correction. 188 parents completed both the CCC-2 and the CSHQ. SDB = Sleep Disordered Breathing. *p<0.05, **p<0.01, ***p<0.001.*

			CCC General		*CCC Social*	
		df	*r*	*p*	*r*	*p*
CSHQ subscale	Bedtime resistance	186	-0.10	0.194	0.06	0.400
	Sleep onset delay	186	-0.12	0.111	-0.04	0.580
	Sleep duration	186	-0.25	<0.001***	0.10	0.174
	Sleep anxiety	186	-0.23	0.002**	0.08	0.270
	Night wakings	186	-0.22	0.003**	0.21	0.004**
	Parasomnias	186	-0.26	<0.001***	-0.03	0.725
	SDB	186	-0.16	*0.031**	0.15	*0.037**
	Daytime sleepiness	186	-0.16	*0.024**	0.02	0.772
	Total	186	-0.34	<0.001***	0.09	0.220

Having established sample-wide associations between CSHQ and CCC General, a weighted regression was run to predict CSHQ Total score from a binary measure of whether children were reported by their parent as being language disordered or not. Five predictors were controlled for in the model, as they might be expected to explain variance in the dependent measure independently of the main predictor of interest. The continuous predictor Age (in months), and the binary predictor Sex were included, along with binary predictors describing whether or not parents reported a difficulty with Attention, Literacy and/or Social interaction, each of which has been associated with sleep differences in children (Carotenuto et al., 2016; Díaz-Román et al., 2018; Mehta et al., 2019 respectively). Parents had an opportunity to report these issues either in response to whether their child had a developmental disorder such as dyslexia or ADHD (‘*Does your child have a diagnosis, or possible diagnosis, of any other developmental disorders?*’), or when they described a language disorder (‘*Please describe your child's language difficulties and what their diagnosis is, if they have one.* ‘). Of these five predictors, Age (B = -0.02, z = -2.83, p = 0.005), Literacy (B = 2.90, z = 3.99, p <0.001) and Social interaction (B = 3.02, z = 2.58, p = 0.010) were predictive of Language Disordered group membership. These five predictors were used to calculate propensity scores for membership of the Language Disordered group.

Table 3 shows the details of a linear regression model predicting CSHQ Total by LD group membership, Literacy, Social skills, Attention, Age and Sex weighted by propensity score. The weighted model controls for differences between the LD and TD groups with respect to those factors included in the propensity score. After weighting, the groups are matched with respect to these factors, allowing an analysis of the effect of LD group membership only.

The model significantly predicted CSHQ Total; F (11.2, 189) = 3.213, p = 0.005, with membership of the Language Disordered group being the sole independently significant predictor. An unweighted model was also run as is presented alongside the weighted model in Supplementary Materials (Table SM1). Notably, membership of the Language Disordered group remains a significant predictor in the unweighted model. The relationship between language skill and CSHQ Total score is illustrated in Figure 2, which shows CSHQ Total for the LD and TD groups. Despite some visual indication of bimodality in the LD scores, both groups show unimodal distributions according to Hartigan's Dip Test (for TD $D = 0.037$, $p = 0.120$ and for LD $D = 0.519$, $p = 0.246$).

Table 3. *Weighted regression model predicting CSHQ Total scores. ***p<0.001.*

	B	Lower 95% CI	Upper 95% CI	*t*	*p*
Intercept	44.96	40.03	49.88	17.879	<0.001***
LD group	3.21	0.98	5.44	2.820	0.005***
Age	-0.04	-0.08	0.01	-1.530	0.128
Sex	2.05	-0.24	4.34	1.756	0.081
Attention	8.90	-0.21	18.01	1.915	0.057
Literacy	2.93	-1.30	7.15	1.359	0.176
Social	6.72	-1.22	14.66	1.659	0.099

The CSHQ asks parents for their child's 'bed time', 'waking time' and their 'usual amount of sleep each day'. Given that bed times, wake times and sleep duration change as children get older (see Acebo et al., 2005; Iglowstein et al., 2003), we ran partial correlations to assess relationships with CCC General, taking Age (in months) into account. Controlling for Age, significant partial correlations emerged between CCC General and 'bed time' ($r_{partial}$ (174) = 0.18, p = 0.020), as well as 'usual amount of sleep' ($r_{partial}$ (160) = -0.20, p = 0.013), but not with 'waking time' ($r_{partial}$ (162) = 0.13, p = 0.100). So as general language ability increased, bed time got later in this sample, and sleep amount was reduced, suggesting that children with poorer language got *more* sleep than their peers rather than less. This result was unexpected in the context of the rest of the CSHQ showing the opposite pattern of association with language skill.

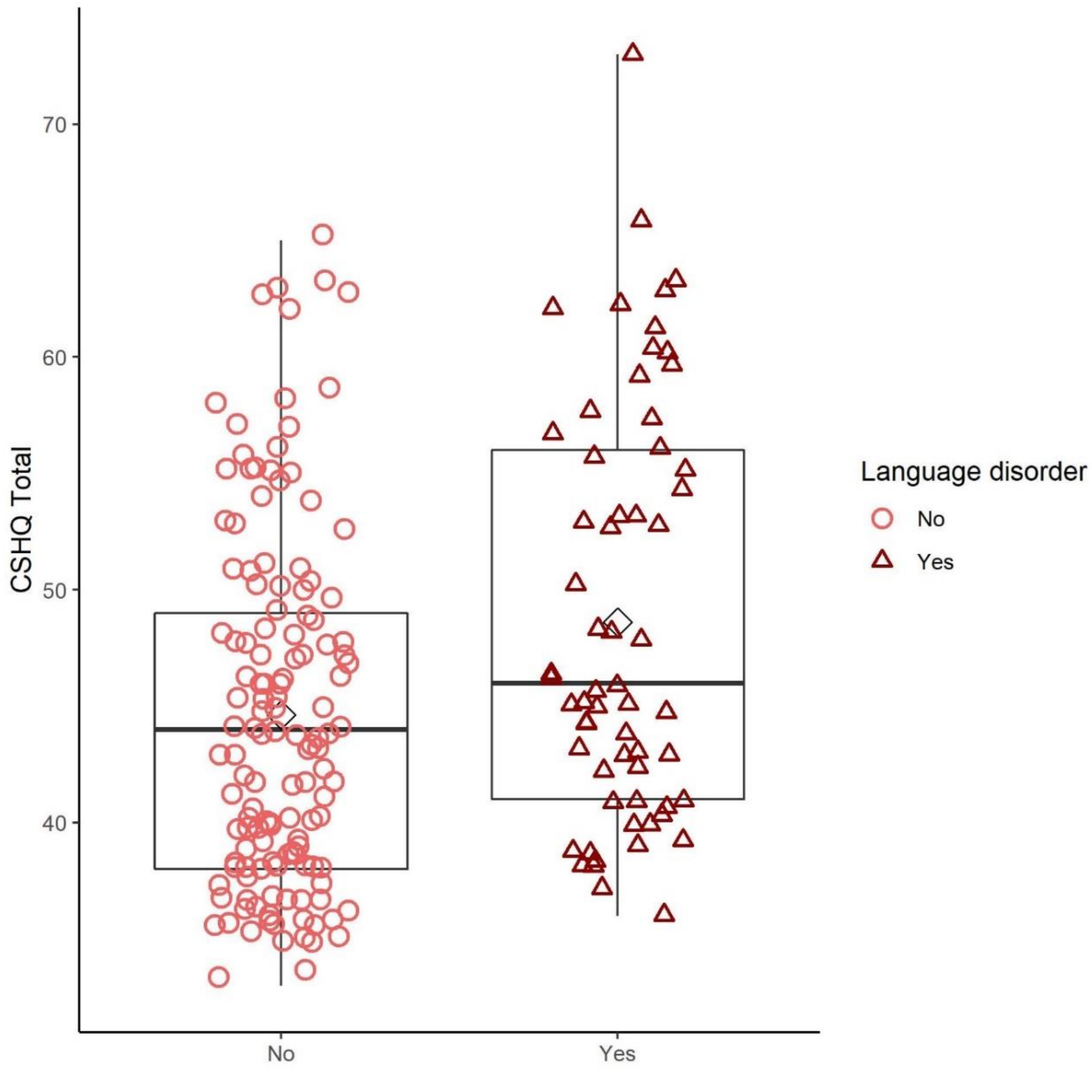

Figure 2. ***Box plot of CSHQ Total by membership of the Language disordered group.***

Discussion

Study 1 aimed to describe parent-reported sleep behaviour in primary-school aged children as a function of parent-reported language ability. We saw an association between better general language ability as described by the CCC-2 and better scores in the following domains of sleep behaviour as described by the CSHQ: Sleep Duration, Sleep Anxiety, Night Wakings, and Parasomnias (Sleep Disordered Breathing and Daytime Sleepiness were also associated with language ability but did not survive Bonferroni-Holme correction). CCC Social was shown to correlate with the Night Wakings and Disordered Breathing scales of the CSHQ (although the latter did not survive Bonferoni Holm correction), with more sleep problems seen in those with better social/pragmatic skills relative to general language skill. CCC Social was included here to consider whether sleep variables co-vary more closely with structural or social/pragmatic aspects of language. The relative lack of correlations between CSHQ subscales and CCC Social does not indicate an absence of any relationship between social competence and sleep behaviour, just an absence of clear relationships between social difficulty over and above language difficulty, and sleep behaviour. The positive correlation between CCC Social and two CSHQ scales may reflect the fact that children in the LD group have higher CCC Social scores and more sleep problems in this sample.

In support of an association between fewer sleep problems and better language ability, we went on to show that parent-reported language difficulty (a binary measure) predicted CSHQ Total score. Interestingly though, while parents reported poorer sleep behaviours in those children with poorer language, when asked for numerical estimates of bed time, wake time and usual sleep amount, children with poorer language were shown to get *more* sleep than their peers rather than less.

In order to further understand the links between sleep behaviour and language ability in young children, Study 2 objectively measured sleep duration and efficiency using actigraphy in a subgroup of children with or without clinically significant language disorder. We focused on 4-to-6 year old children, as this is the earliest age at which language disorder is routinely diagnosed in clinic, and an age at which vocabulary development is rapid as children start school. The findings from Study 1 were used to pre-register hypotheses and analyses for Study 2 (https://osf.io/yftqb).

The predominant pattern to emerge from Study 1 was more sleep problems in children with poorer language; and while we also saw evidence for *longer* parent-reported sleep in those same children, we suspected that this might be due to the approximate nature of parent-reported bed and wake times. Under-estimates of time spent awake after lights out are particularly prevalent in parent-reported estimates of sleep (Dayyat et al., 2011). In Study 2 we therefore expected to see support for the idea that children with poor language have worse (objectively measured) sleep than their peers. Hypothesis 1: c*hildren with Language Disorder will show shorter sleep duration, and lower sleep efficiency, or more variability in these measures, compared to typically developing age-matched peers; we also hypothesise more parent-reported bedtime anxiety;* Hypothesis 2: l*anguage composite score will show a positive relationship with mean sleep duration, and sleep efficiency over and above the predictive power of social/pragmatic ability; while the latter will better predict sleep onset latency, and bedtime anxiety.*

Study 2

Method

Participants

Participants in Study 2 were a sub-sample from Study 1. Parents from Study 1 were re-contacted if their children fulfilled criteria for inclusion in Study 2, that is they were aged 4.0-to-6.11 and either showed no indication of neurodevelopmental disorder, or were reported to have language concerns and also had a CCC-2 profile indicative of language difficulties. More typically developing males than females were invited to take part in order to match gender ratio across groups. Children were excluded from participation if they did not have sufficient oral language to provide assent or if English was not their first language. Children were also excluded if they were being raised bilingual as at the age of this sample, bilingualism is likely to be an important factor explaining variability in English language skill and may overshadow any influence of sleep.

We recruited and tested 52 children in total for this study. However, having decided before pre-registration to only include children with structural language difficulties, we then excluded data from children who had a speech sound difficulty for which they were receiving speech and language therapy, but who did not show a profile of language disorder on standardised assessment and whose parents did not report a language difficulty on the CCC-2; on these grounds, 10 children were excluded. Two further children were excluded because they did not provide enough actigraphy data[2] (one from the LD group and one from the TD group). This left a sample of 40 children: 20 controls with no reported language issues (14 males, 6 female) with a mean age of 64.90 months (5 years, 5 months; *SD* = 9.84 months) and 20 children with language disorder (15 male, 5 female) with a mean age of 66.40 months (5 years, 6 months; *SD* = 11.53 months). One child in the LD group was reported to be taking melatonin to support sleep at the time of data collection. See Figure 1 for a description of CCC-2 scores for this sample in relation to the larger sample included in Study 1.

All those in the Language Disordered (LD) group were being seen by speech and language services for issues relating to vocabulary and/or syntax development at the time of recruitment. 14 children in the LD group were classified by the CCC-2 as having language profiles consistent with a diagnosis of DLD (CCC General $\leq$ 55 & CCC Social $\geq$ 9), while the remaining 5 either had a CCC General score slightly higher than 55 (range = 57-69), or a CCC Social score slightly lower than 9 (range = 4-6). The cognitive scores and questionnaire scores for the LD and TD groups can be seen in Table 4, with the one subscale of the CSHQ that shows a group difference illustrated in Figure 3. Note that although most of these children show considerable difficulties in more than one domain of language function, three children were unable to complete some assessments and one child did not score below 1*SD* on any task. Based on postcode data, mean national Indices of Multiple Deprivation (IMD) decile was 7.65 for the TD group and 6.65 for the LD group, a non-significant difference (t (38.0) = 1.24, p = 0.223).

The TD children who took part in Study 2 can be considered a representative subsample of Study 1 with respect to parental views on sleep. The representativeness of the Study 2 TD sub-sample is demonstrated by a non-significant two sample Kolmo-

[2] In the pre-registration 21 children are included in the TD group. One child was removed after pre-registration due to insufficient actigraphy data to provide reliable estimates of sleep. Their non-inclusion did not change the interpretation of the data.

gorov-Smirnov test of whether participants who were included in Study 2 can be considered to be drawn from the same population with respect to total CSHQ score as those not included ($D = 0.189$, $p = 0.549$).

Unfortunately, testing was interrupted by the COVID-19 pandemic; 25 children were tested before the UK lockdown on 23rd March, 2020 (17 TD and 8 LD), and 15 children were tested after. The children tested before lockdown were seen in person for their cognitive assessment, while the children tested after lockdown were tested via video call. This change meant that we were unable to use the Block Design subtest from the BAS-III for the children who were tested via video call; for these children we used the Matrices subtest from the BAS-III in order to measure visuospatial intelligence. We therefore report visuospatial intelligence for each group but do not use that measure as a co-variate. Regardless of how children were tested, parents provided written informed consent and each child gave verbal assent at the start of the first session. The study was granted ethical approval from the Department of Psychology's Departmental Ethics Committee at the University of York, as well as the Coventry and Warwickshire Research Ethics Committee on behalf of the UK National Health Service.

Measures

Data for this study consisted of: sleep measurements (up to ten nights of actigraphic recording, and up to ten nights of parent-reported sleep diary data – TD mean = 7.0 nights, $SD = 0.00$; LD mean = 7.25 nights, $SD = 1.21$); standardised language and cognition assessments; and parental questionnaires. For correlations between parent-report (CSHQ) and actigraphy measures of sleep and between parent-report and standardised measures of language, see Supplementary Materials (Tables SM2 & SM3).

Sleep Measures. Families were asked to complete seven consecutive nights of sleep measurement, using a Philips Respironics Actiwatch2 actigraphy watch and an online parental sleep diary (with nightly reminders provided via text or email). Children were asked to wear the watch on their non-dominant wrist during the night-time only. Children were not asked to wear the watch during the day as, after consultation with parents, it was felt that they may have removed and potentially misplaced the devices. Data from at least five nights was deemed sufficient to reliably establish objective measures of sleep duration and quality, including sleep onset latency and sleep efficiency (Acebo et al., 1999; Meltzer et al., 2012); participants who provided fewer than five nights were therefore excluded. Parents were asked to press a marker button on the watch to indicate when the child was left to sleep, and when they woke in the morning; the Actiwatch2 also has a luminance monitor. Parent diaries and luminance changes were used to mark the beginning and end of the rest period, from when children settled down to sleep to when they got out of bed in the morning. The actiwatch luminance monitor provides Lux-minutes (lux multiplied by sleep epoch length), to indicate the amount of light children were exposed to overnight. This measure did not differ between the TD (mean = 139.4 $SD = 417.6$) and LD (mean = 101.4 , $SD = 245.9$) groups: $t(30.77) = 0.352$, $p = 0.728$.

Actigraphy data were extracted via Respironics Actiware using the built-in algorithm. Data were collected in 30 second epochs. Sleep onset in the evening was calculated from the first epoch after which no activity was indicated for at least ten minutes (20 epochs). The two key estimates in this study were Sleep Duration and Sleep Efficiency; Sleep Duration refers to the total time that the child was asleep for (as distinct from the total time in bed), and Sleep Efficiency refers to the percentage of time the child was asleep for compared to total time in bed. Night waking was determined on an epoch-by-epoch basis, using an automated weighted calculation centred on the epoch of interest, and taking into account activity in the adjacent four epochs. The wake threshold was set to the default 'medium' (40 activity counts per minute). In 3-to-5 year old children the low (80 counts per second) and medium settings have both been shown to underestimate total sleep time relative to polysomnography (Meltzer et al., 2012), but as the high wake threshold (20 counts per second) can overestimate total sleep time in this age group, we kept the default. Sleep Onset Latency was also considered here and is defined as the time period between the start of the rest period and the first epoch marked as sleep. In pre-school children, sleep duration and efficiency metrics as measured by actigraphy correlate closely with concurrently measured polysomnography (intraclass correlations >.80), though number of awakenings show a weaker relationship (<.40) (Bélanger et al., 2013; Sitnick et al., 2008).

The study was presented to children as the PJ Heroes study, relating it to the children's TV programme 'PJ Masks', in which three children wear actigraphy-like watches to battle night-time villains. Children were given PJ Masks pyjamas and an Amazon voucher to thank them for their participation.

Questionnaires. CCC-2, CSHQ and descriptive Sleep History data from Study 1 were re-analysed for Study 2, and in addition, parents were asked to complete the Social Responsiveness Scale 2 (SRS; Constantino & Gruber, 2012); and Brown Attention Deficit Disorder scales (ADD; Brown, 2001). The SRS assesses difficulties in social behaviour associated with autism symptomology; parents were asked to complete this in order to establish whether sleep parameters were better explained by language or social/pragmatic factors. The ADD assesses attention behaviour in daily life, and was included here in order to describe the groups appropriately. The Sleep History questionnaire (see Supplementary Materials), included the question *Does your child get anxious about going to bed at night?* where parents were given the options 'no' (coded 1), 'somewhat' (coded 2) and 'yes' (coded 3).

Cognitive Battery. Children were assessed on cognitive and language ability using a series of standardised tasks in accordance with administration instructions: British Picture Vocabulary Scale, 3rd Edition (BPVS-III; Dunn et al., 2009); British Ability Scale 3rd Edition (BAS-3), Naming vocabulary subscale (Elliott & Smith, 2011); Non-word repetition subscale from the Comprehensive Test of Phonological Processing-2nd Edition (CTOPP-2; Wagner et al., 2013); Sentence Repetition subscale from the Clinical Evaluation of Language Fundamentals 5th Edition (CELF-5; Semel & Wiig, 2017); BAS-3, Pattern Construction subscale/ Matrices subscale. Cognitive assessment and questionnaire scores are given in Table 4.

Table 4. ***Mean standard scores (and SD) for cognitive assessments carried out in Typically Developing (TD) and Language Disordered (LD) groups, and parent questionnaires. * p< 0.05, ** p< 0.01, ***p<0.001. SDB = Sleep Disordered Breathing; NWR = non-word repetition***

		TD Mean (*SD*)	LD Mean (*SD*)	*t*-test
Standardised	BAS-3 Naming	115.71 (12.0)	87.79 (14.5)	t (35.1) = 6.60, p < 0.001***
	BPVS-2	111.00 (11.4)	90.28 (13.2)	t (34.0) = 5.20, p <0.001***
	CELF-5 Recalling Sentences	118.10 (14.1)	82.22 (15.4)	t (34.9) = 7.55, p <0.001***
	CTOPP-2 NWR	108.33 (19.1)	70.28 (12.9)	t (34.2) = 7.37, p < 0.001***
	BAS-3 non-verbal measure	101.52 (14.0)	88.32 (21.7)	t (30.4)= 2.26, p = 0.031*
Parent questionnaires	SRS total (T-score)	45.86 (5.1)	58.15 (12.3)	t (25.1) = -4.14, p < 0.001***
	ADD total (T-score)	44.19 (6.4)	53.80 (7.7)	t (37.0) = -4.35, p < 0.001***
	CCC-2 General	85.90 (18.3)	44.65 (13.2)	t (36.4) = 8.32, p <0.001***
	CCC-2 Social	-0.14 (7.8)	15.50 (7.0)	t (38.9) = -6.76, p <0.001***
	CSHQ_Bedtime resistance	8.19 (2.7)	8.30 (2.7)	t (38.9) = -0.13, p = 0.898
	CSHQ_Sleep onset delay	1.62 (0.7)	1.60 (0.8)	t (38.8)= 0.08, p = 0.935
	CSHQ_Sleep duration	3.86 (1.2)	4.15 (1.5)	t (35.7) = -0.70, p = 0.489
	CSHQ_Sleep anxiety	5.67 (1.9)	6.40 (2.0)	t (38.4)= -1.20, p = 0.239
	CSHQ_Night wakings	3.95 (1.2)	4.30 (1.5)	t (36.7)= -0.80, p = 0.430
	CSHQ_Parasomnias	8.57 (1.5)	9.25 (1.8)	t (37.0)= -1.33, p = 0.191
	CSHQ_SDB	3.05 (0.2)	3.55 (0.7)	t (22.6)= -3.13, p = 0.005**
	CSHQ_Daytime sleepiness	10.52 (1.9)	10.30 (2.5)	t (36.2)= 0.32, p = 0.748
	CSHQ_Total	42.81 (5.8)	46.60 (8.5)	t (33.4) = -1.65, p = 0.108

Confirmatory analysis plan

To assess Hypothesis 1, mean and night-to-night variability (standard deviation) of objective Sleep Duration and Sleep Efficiency estimates were established for each participant. To analyse group differences between the typically developing (TD) and LD groups, t-tests were run on the mean and variability observed for each objective behaviour estimate.

To assess Hypothesis 2, linear regressions were run to test whether performance on a composite of standardised scores (Language Composite) from all four language measures (Receptive Vocabulary, Expressive Vocabulary, Sentence Repetition, and Non-word Repetition), SRS total score, or an interaction between the two would predict mean objective Sleep Duration, mean objective Sleep Efficiency, and mean objective Sleep Onset Latency. A logistic regression was run (N = 40) to assess whether Language Composite scores, total SRS score or an interaction between the two, could predict the presence of parent-reported bedtime anxiety from the Sleep History questionnaire.

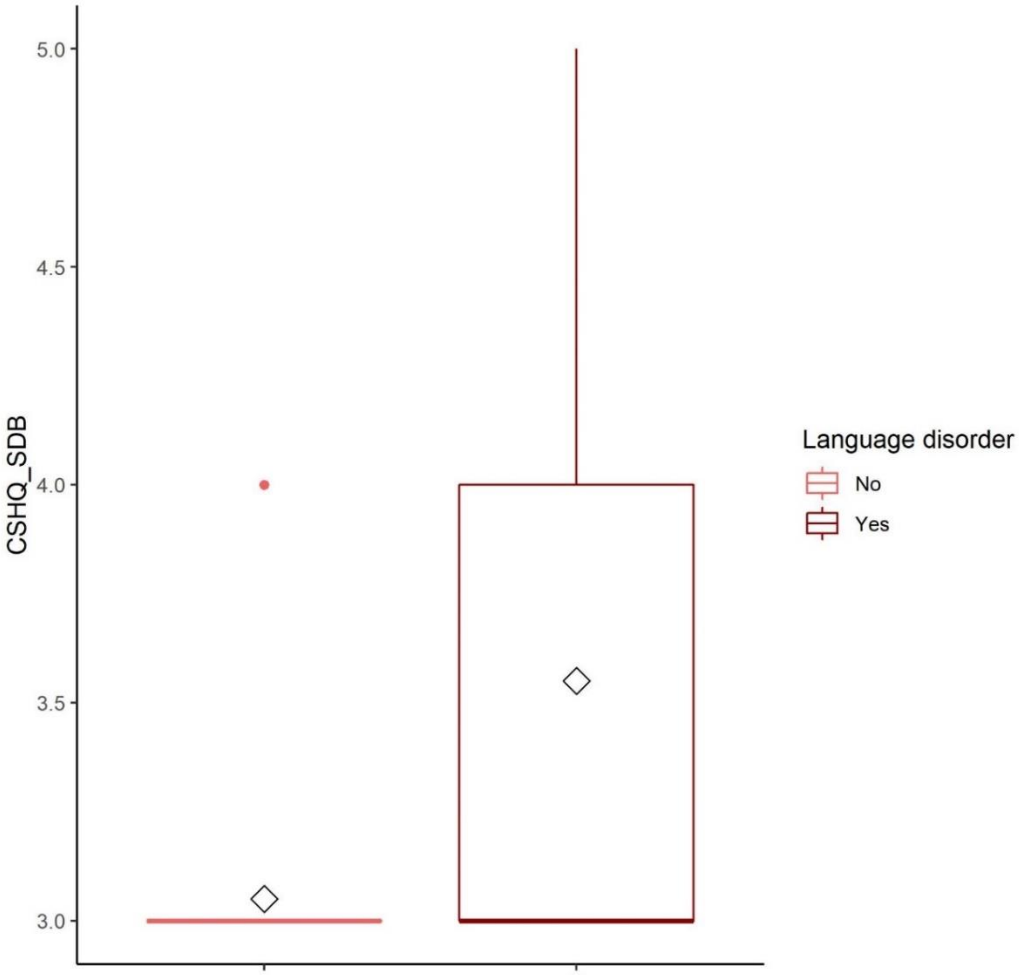

Figure 3. ***Box plot showing a group difference on the Sleep Disordered Breathing sub-scale of the CSHQ (sum of 3 items, each scored 1-3).***

Results
Confirmatory Analysis

Confirmatory Group Differences: Hypothesis 1. Mean Sleep Duration differed significantly between groups, but contrary to Hypothesis 1, the TD group showed shorter Sleep Duration (mean = 518.7 minutes, *SD* = 21.9) than the LD group (mean = 546.3, *SD* = 45.6), t (27.39) = -2.44, p = 0.022 (see Figure 4). No group differences emerged for night-to-night variability in Sleep Duration (TD mean = 45.4 minutes, *SD* = 14.7; LD mean = 41.1 minutes, *SD* = 15.9; t (37.76) = 0.88).

Mean Sleep Efficiency also differed between groups, and again contrary to Hypothesis 1, the TD group showed lower efficiency (mean = 78.6%, *SD* = 3.5) than the LD group (mean = 81.3%, *SD* = 4.1), *t* (37.00) = -2.28, *p* = 0.032. Night-to-night variability in Sleep Efficiency was equivalent across groups (TD mean = 5.5, *SD* = 1.8; LD mean = 5.3, *SD* = 2.5; *t* (34.73) = 0.34. Finally, a group difference in bedtime anxiety fell just short of significant in the anticipated direction, *W* = 148, *p* = 0.055. For the TD group, mean response on the three point scale was 1.10 (*SD* = 0.3), while for the LD group, mean response was 1.45 (*SD* = 0.69).

Previous actigraphy estimates (Acebo et al., 2005) for typically developing children aged 60 months (5;0 years) have shown a total sleep duration of 8.6 hours for girls (516 minutes) and 8.9 hours for boys (534 minutes) with a standard deviation of 48 minutes for both; and sleep efficiency estimates of 88.6% (*SD* = 4.5%) for girls, 87.9% (*SD* = 4.9%) for boys. The TD group in the current sample showed Sleep Duration in line with this previous estimate, though Sleep Efficiency fell below -*1SD* of the previous estimate.

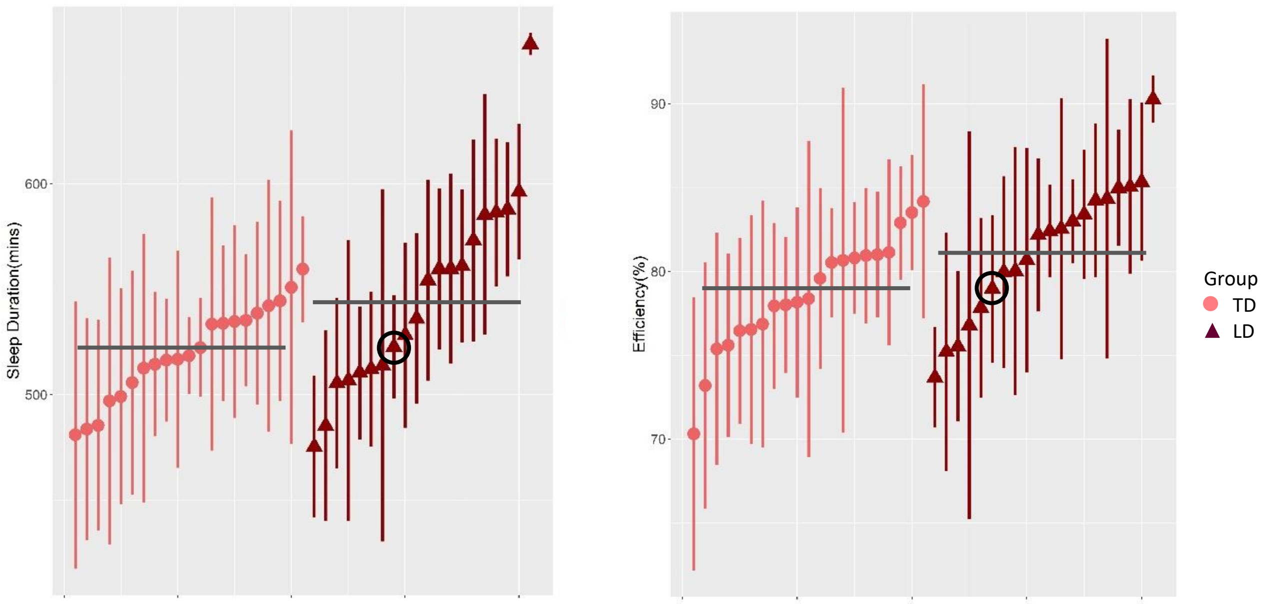

Figure 4. ***Individual mean and night-to-night variability (standard deviation) and group means for a) Sleep Duration and b) Sleep Efficiency for the typically developing group (TD) and the language disordered group (LD). Grey bars indicate the mean for each estimate and the individual circled in black was the only participant in the study to be taking melatonin at the time of testing. The error bars show standard deviation in each direction.***

Follow-on Exploratory Analyses. In our confirmatory analysis, mean night-to-night variability (intra-individual variability) in Sleep Duration did not differ between the groups. However, the summary statistics suggest that the LD group showed more inter-individual variability in mean values. We evaluated this possibility with an F-test for equality of variance, which supported the notion of more variability in mean Sleep Duration within the LD group than the TD group, F (19/19) = 0.23, p = 0.002. By contrast, variability in mean Efficiency did not differ between groups (F (19/19) = 0.72).

Confirmatory Linear Regressions: Hypothesis 2. Linear regressions were run to assess the predictive power of the Language Composite and SRS total score on objective Sleep Duration, Sleep Efficiency, and Sleep Onset Latency, as anticipated in Hypothesis 2. For each of these models, variance inflation factors were above 10 when the interaction term was included in the model (Language Composite VIF = 33.9, SRS VIF = 31.3, Language Composite*SRS VIF = 25.3), while variance inflation factors with the interaction term removed were acceptable (Language Composite VIF = 1.6, SRS VIF = 1.6). This possibility was anticipated in our pre-registration as the language composite significantly correlated with SRS total score (r(37)= -.55, p<0.001). Consequently, no models are presented with the interaction term included.

No models significantly predicted sleep parameters: for mean Sleep Duration, F(36,2,) = 2.67, p = 0.083; for mean Sleep Efficiency, F(36,2) = 1.47, p = 0.244; for mean Sleep Onset Latency, F(36,2) = 0.365, p = 0.697. Finally, the prediction of bedtime anxiety was assessed via ordinal logistic regression, and again no significant predictors emerged, although SRS approached significance: Language Composite odds ratio = 0.99 (97.5% CI: 0.93 – 1.05), and SRS odds ratio = 1.09 (97.5% CI: 1.00 – 1.22).

Further Exploratory Analyses

Confirmatory analyses for Study 2 broadly failed to support our hypotheses; we therefore ran a series of exploratory analyses in order to better understand these data and develop new hypotheses moving forward.

We were interested to explore differences between parent-reported sleep behaviour and objective sleep estimates of duration and efficiency in children with language disorder. The relationship between good parent-reported language (CCC General) and good parent-reported sleep behaviour (CSHQ Total) that we saw in Study 1 held in the sub-sample of children who completed Study 2: r(38) = -0.45, p = 0.003, so those with better parent-reported language also had better subjective sleep behaviour. We then considered the relationship between CCC General and objective estimates of Sleep Duration, which fell short of significance (r(38) = -0.28, p = 0.083), and Sleep Efficiency, which showed a negative correlation, r(38) = -0.32, p = 0.047. So children with poorer parent-reported general language scores slept more efficiently according to objective data.

The CSHQ seems to capture aspects of sleep behaviour that are unrelated to objective estimates of sleep quantity (Markovich et al., 2014). Our results suggest that parents of children with language difficulties show concern regarding the sleep behaviour of their children over and above what would be expected given estimates of sleep quantity (both subjectively and objectively estimated). We therefore considered group differences in parental anxiety about children's sleep. In the Sleep History questionnaire we asked parents *Are you currently worried about your child's sleep?* and *Were you worried about your child's sleep when they were younger?*. Running the same ordinal logistic models for these variables as we did to consider children's bedtime anxiety, it emerged that current parental concern about sleep was predicted by high SRS total score (Language Composite odds ratio = 0.99 (97.5% CI: 0.94 – 1.06, $p = 0.844$), and SRS odds ratio = 1.11 (97.5% CI: 1.01 – 1.24, $p = 0.050$)), while previous concern was predicted by low language composite (Language Composite odds ratio = 0.957(97.5% CI: 0.913 – 0.997, $p = 0.043$), and SRS odds ratio = 0.977 (97.5% CI: 0.909 – 1.046, $p = 0.504$)). Parental concern about children's sleep was more likely in the past if the child currently has language difficulties, while parental concern about current sleep is more likely if the children shows autism symptomology.

Finally, we needed to establish whether the relatively good objective measures of sleep duration and efficiency shown in the LD group were due to more of that group being tested during the COVID-19 pandemic lockdown. To check this, we split the LD group into those who had been tested before lockdown ($n = 8$) and those who were tested during lockdown ($n = 12$). Neither objective mean Sleep Duration ($t(17.9) = -0.89$), nor objective mean Sleep Efficiency ($t(16.8) = -1.63$, $p = 0.123$) differed between groups.

General Discussion

The aim of this project was to test the hypothesis that sleep may be atypical in children who have developmental difficulties in the language domain. In Study 1, an exploratory analysis was conducted of subjective, parent-reported data concerning the sleep and language abilities of 4-10 year old children using the CSHQ and CCC-2 questionnaires. In agreement with Botting and Baraka (2017), our analysis indicated that poor sleep behaviour was associated with poor language development, but we extended the previous work to show that this relationship exists when no children with a diagnosis or suspected diagnosis of autism are included in the analysis. The better children's general language ability was reported to be, the better also their reported sleep behaviour with respect to Sleep Duration, Sleep Anxiety, Night Wakings, and Parasomnias (Sleep Disordered Breathing and Daytime Sleepiness were also associated with language ability but did not survive Bonferroni-Holme correction). Furthermore, overall CSHQ score was predicted by whether or not children were described by their parents as having a difficulty with language development. The only measures from the CSHQ to indicate anything other than a positive relationship between sleep behaviour and language skill were parents' numerical estimates of bed time and sleep duration, where, unexpectedly, *better* language skill was associated with *later* bed time and *less* overall sleep.

We took these data forward to pre-register Study 2, in which a sub-sample of 4-to-6 year old children from Study 1 with clinical language deficits, along with age matched peers, wore an actigraphy watch for 5-10 nights. Here, contrary to our hypotheses (but consistent with the subjective estimates of bed time and total overall sleep from Study 1), objective sleep estimates were negatively related to objectively measured language ability, again suggesting that those with language deficits actually slept for longer and more efficiently than their language-typical peers. So while weaker language skills are associated with parent-reported negative sleep behaviours (such as anxiety and night wakings), at the same time, both subjective and objective estimates of actual sleep episodes suggest that weaker language skills are associated with longer sleep duration and higher sleep efficiency.

Parents of children with more language difficulties reported a high degree of concern about their child's sleep, beyond what would be anticipated given objective estimates of sleep. This pattern of seeing more severe or broad difficulties with sleep in subjective parent-report compared to objective measures, has also been seen in the case of ADHD (Chin et al., 2018), ASD (see Díaz-Román et al., 2018), and visual impairment (Hayton et al., 2021). This pattern suggests that measures like the CSHQ are recording something quite different, and complementary, to actigraphy-derived objective sleep patterns.

One reason for heightened parental concern might be children's sleep history. In Study 2, the likelihood of parents reporting current concern about their child's sleep was positively predicted by autism symptomology, but the likelihood of parents reporting that they were concerned about their child's sleep in the past was predicted by language ability. Four parents of typically developing children expressed some degree of concern about their child's sleep in the past compared to ten parents from the language disordered group – all but one (who reported apnoea) said their child struggled to initiate and maintain sleep as infants and did not sleep through the night until at least 18 months. For example, one parent of a child with language disorder reported *'From about 5 months up until 18 months, would wake between midnight and 3am and would not return to sleep until about 6/ 7 am.'* The finding that language scores only predicted the extent of past parental concern about their child's sleep may speak to the complex and temporally extended nature of parental perceptions of sleep.

Parents highlighted some areas of difficulty that were not possible to assess with actigraphy. Sleep disordered breathing was more likely to be reported in children with poor language in Study 1, and in Study 2 this was the only area of the CSHQ were the language disordered group differed significantly from their typically developing peers. Sleep disordered breathing has been associated with deficits in both phonology and vocabulary skill (see de Castro Corrêa et al., 2017; Mohammed et al., 2021), and may be a contributing factor to the aetiology of language difficulty as experienced by a sub-group of children. Sleep disordered breathing may affect language development either by reducing the quantity of sleep children get and thereby resulting in daytime sleepiness, and/or by disrupting night-time sleep architecture resulting in a poverty of consolidation opportunities. Although we did not see disrupted (less efficient) sleep in our smaller clinical sample in Study 2, sleep disordered breathing can result in changes to sleep architecture without necessarily interrupting sleep efficiency (Shahveisi et al., 2018), and actigraphy is not thought to be a good indicator of the sleep fragmentation seen in sleep disordered breathing (O'Driscoll et al., 2010).

Unexpectedly, we saw with both subjective and objective data that children with language disorders actually slept for longer and more efficiently than their typically developing peers. A possible interpretation of this finding is that the maturation of the sleep cycle might be generally delayed in the language disordered group relative to age matched peers. Sleep duration, efficiency, and global sleep patterns (Iglowstein et al., 2003) change gradually through infancy and childhood, with the amount of sleep needed over a 24 hour period decreasing, and with night-time sleep getting more efficient (Acebo et al., 2005). Infants who go on to demonstrate lower language ability show immature sleep relative to peers with better language (Dionne et al., 2011; Knowland et al., 2021; Smithson et al., 2018), that is, more of their overall sleep occurs as naps during the day. If we see a continuation of delayed sleep maturation by the early school years, then what looks like better sleep could be construed as less mature sleep. In our data, longer night-time sleep duration could indicate a higher need for sleep in the context of less opportunity for day time napping (given the age of the children). The group effect of increased efficiency in the language disordered sample is more difficult to explain as sleep typically gets more efficient over developmental time (Acebo et al., 2005). This group effect may have emerged because the typically developing children included in Study 2 showed unusually low sleep efficiency. Alternatively, it could be reflective of the language disordered children needing more sleep over 24 hours, given that when habitually napping pre-school children miss a nap their subsequent night-time sleep is both longer and more efficient compared to a typical night (Lassone et al., 2016).

Longitudinal work with young children showing early language delay would allow an analysis of trajectories of change in sleep behaviour. Such trajectories should consider changes in parental evaluation of, and feelings about, their child's sleep, alongside objective measures. Both subjective and objective measures are highly informative but are not equivalent. This seems to be especially true in groups of children with neurodevelopmental disorders. As this story unfolds it is likely to reveal a dynamic interaction between multiple factors including neural maturation, behavioural manifestation of disorder, parental sensitivity to child development and the perceptions of the child themselves around sleep.

It should also be noted that even if sleep behaviour is unremarkable in children with language disorders, that does not guarantee that sleep performs the same functions in these children that it does in children who are developing as expected in the language domain (Earle et al., 2017). Future studies in this area therefore need to consider both the nature of sleep and the role that sleep plays in supporting language development over time in different developmental populations.

Limitations

The success of this work should naturally be evaluated within the context of its limitations. The size of the sample, particularly in Study 2, was limited. There are myriad influences on language development, and children present with profiles of strength and weakness across multiple dimensions. This heterogeneity in symptomology and aetiology means it is challenging to draw conclusions that can be extended beyond the current sample. The non-equality of variance in sleep duration seen across our groups here may well reflect that aetiological heterogeneity.

It should be noted that the summary statistics for the typically developing and language disordered groups in Study 2 both demonstrated relatively poor subjective sleep according to the CSHQ. The clinical threshold for concern on the CSHQ is a sum score of 41. Here, 66% of the LD group exceeded this threshold, as did 50% of the TD group, compared to 23% of the control group in the original description of the measure (Owens et al., 2000). This suggests that the TD group in Study 2 may experience more sleep-related difficulties than are typically observed in the general population, as supported by the lower than expected sleep efficiency for the TD group based on actigraphy data. This possibly reflects a sampling bias where parents whose children experience sleep difficulties are more likely to volunteer for sleep studies.

Testing for this study was interrupted by the COVID-19 pandemic and resulting national UK lockdown in 2020. We did not find an effect of lockdown on either sleep duration or efficiency for children in the language disordered group, and we have demonstrated elsewhere that sleep duration was not interrupted in children over the UK lockdown (Knowland et al., in press). We are therefore confident in our results, but of course the circumstances must be taken into account. In summary, this project is a starting point; the work should be replicated with a larger sample in less interesting times.

Summary & Conclusions

The aim of this paper was to investigate whether children with poor structural language development exhibit poor sleep and sleep behaviour. Over two studies we saw that children who had worse parent-reported language abilities also showed worse parent-reported sleep behaviours, such as more sleep anxiety and more night waking. Conversely, in both subjective and objective estimates of sleep duration, children with language disorder slept for longer and also more efficiently than their language-typical peers. Given that a weak relationship between objective estimates of sleep and the CSHQ has been shown before (Hayton et al., 2021; Markovich et al., 2014), we suggest that subjectively reported sleep behaviour and objective sleep estimates be thought of as complementary, together building a complete picture of the behavioural, cognitive and emotional components of sleep in young children. It is clear that the dynamic relationships between sleep and language are relevant not only to children's development but also the wider picture of family functioning and parental concern, and as such this is a topic that deserves further careful consideration.

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Data, Code and Materials Availability Statement

The dataset supporting the conclusions of this article are available on the Open Science Forum (https://osf.io/y4evw/) along with analysis scripts. A number of questionnaires and assessments were used in the construction of these data: a Sleep History questionnaire developed by the research team is available in Supplementary Materials at the end of this manuscript; the Children's Sleep Habits Questionnaire (CSHQ; Owens, Spirito & McGuinn, 2000) is available online at https://depts.washington.edu/dbpeds/Screening%20Tools/ScreeningTools.html; the following materials are copyrighted, on which grounds the editor has granted exemption from sharing (19th April, 2021):

- Children's Communication Checklist-2 (CCC-2; Bishop, 2003)
- Social Responsiveness Scale 2 (SRS; Constantino & Gruber, 2012)
- Brown Attention Deficit Disorder scales (ADD; Brown, 2001)

- British Picture Vocabulary Scale, 3rd Edition (BPVS-III; Dunn, Dunn, Styles & Sewell, 2009)
- British Ability Scale 3rd Edition (BAS-3; Elliott & Smith, 2011)
- Comprehensive Test of Phonological Processing- 2nd Edition (CTOPP-2; Wagner, Torgesen, Rashotte & Pearson, 2013)
- Clinical Evaluation of Language Fundamentals 5th Edition (CELF-5; Semel & Wiig, 2017)

Ethics Approval and Consent

Approval for this work was granted by the Department of Psychology Research Ethics Committee at the University of York. All parents gave informed, written consent, and all children gave verbal assent before any data were collected.

Authorship and Contributorship Statement

All authors designed the study, edited the manuscript and approved the final version. MR collected the data. VK analysed the data and wrote the manuscript.

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Supplementary Materials

Descriptive sleep history

Q1. How old is your child (years, months; e.g., 12 years 6 months)
Years ____________ Months __________

Q2. What was your child's gender at birth?
Male
Female

Q3. Do they identify with a different gender now?
Yes
No

Q4. What is your child's main language? __________________________________

Q5. Does your child speak any other languages as well as they speak their main language? ________________________________

Q6. In total, how many children (0-18) live in your household? ___________

Q7. Of these, how many are older than the child you are filling in this questionnaire about? __________

Q8. What is the highest educational qualification achieved by someone in your child's household? ____

Q9. Does your child have difficulties with language development?
Yes
No
I'm not sure

Q10. Does your child receive support for their language development at school, or have they received support in the past? *{Asked if Yes or I'm not sure in response to Q9}*
____

Q11. Does your child see a speech and language therapist to support their language development, or have they seen one in the past? *{Asked if Yes or I'm not sure in response to Q9}* ____

Q12. Please describe your child's language difficulties and what their diagnosis is, if they have one. (Your description here might include whether your child has difficulties with understanding spoken language and/or with speaking, and whether they have a diagnosis such as Developmental Language Disorder.) *{Asked if Yes or I'm not sure in response to Q9}* ____

Q13. Does your child have a diagnosis, or possible diagnosis, of any other developmental disorders?
ASD
ADHD
Developmental Co-ordination Disorder
Dyslexia
Other ___________
None

Q14. Are you currently worried about your child's sleep?
Yes
No
Somewhat

Q15. Please tell us what currently concerns you about your child's sleep: *{Asked if Yes or Somewhat in response to Q14}* ____

Q16. Have you ever sought support for your child's sleep from a GP or other health professional? *{Asked if Yes or Somewhat in response to Q14}*
Yes
No

Q17. Were you worried about your child's sleep when they were younger?
Yes
No
Somewhat

Q18. Please tell us why you were worried about your child's sleep when they were younger, and how old your child was when their sleep was a concern: *{Asked if Yes or Somewhat in response to Q17}* ____

Q19. Have you ever sought support for your child's sleep from a GP or other professional? *{Asked if Yes or Somewhat in response to Q17}*______________________________

Q20. What does a good night of sleep look like for your child?
____

Q21. How many times a week do you typically see this pattern of good sleep?
____

Q22. What does a bad night of sleep look like for your child?
____

Q23. How many times a week do you typically see this pattern of bad sleep?
____

Q24. Does your child currently take daytime naps?
Yes
No

Q25. How many times a day does your child usually nap? *{Asked if Yes in response to Q24}*_________

Q26. When your child naps in the day how long do they usually sleep for? *{Asked if Yes in response to Q24}*_________

Q27. How many days a week does your child nap? *{Asked if Yes in response to Q24}*

____

Q28. At what age did your child stop napping in the day? Please tell us in Years and Months if you can (it might help to remember if it was linked with an event like starting nursery) _________

Q29. Does your child get anxious about going to bed at night?

Yes

Somewhat

No

Q30. Can you describe your child's bedtime routine? This might start when they have a bath, watch a special TV programme or when you ask them to go to bed.

____

Q31. How long does it take from when you start this routine to when your child falls asleep?

____

Q32. Once you've left your child's bedroom, how many times do you typically have to go back to their room or put them back to bed before they fall asleep?

____

	UnWeighted					Weighted				
	B	**Lower 95% CI**	**Upper 95% CI**	***t***	***p***	**B**	**Lower 95% CI**	**Upper 95% CI**	***t***	***p***
Intercept	47.98	42.72	53.24	17.866	<0.001***	44.96	40.03	49.88	17.879	<0.001***
LD group	2.72	0.15	5.29	2.071	0.040*	3.21	0.98	5.44	2.820	0.005***
Age	-0.07	-0.11	-0.02	-2.664	0.008**	-0.04	-0.08	0.01	-1.530	0.128
Sex	1.49	-0.75	3.74	1.305	0.194	2.05	-0.24	4.34	1.756	0.081
Attention	9.63	0.68	18.59	2.108	0.036*	8.90	-0.21	18.01	1.915	0.057
Literacy	1.86	-2.76	6.48	0.790	0.431	2.93	-1.30	7.15	1.359	0.176
Social	7.65	0.48	14.83	2.091	0.038*	6.72	-1.22	14.66	1.659	0.099

Table SM1. ***Unweighted and weighted regression models predicting CSHQ Total scores. *p<0.05, ***p<0.001. Unweighted model: F (6,189) = 4.40, p < 0.001; Weighted model: F (11.2, 189) = 3.213, p = 0.005.***

		Actigraphy measures					
		Sleep Duration (mins)	**Sleep Efficiency (%)**	**Sleep on-set latency (mins)**	**Average activity/ min**	**Bed time**	**Get-up time**
Parent-report CSHQ	**Bedtime resistance**					*r* (38)=-.09, *p*=.585	
	Sleep onset delay			*r*(38)=.46, *p*=.003			
	Sleep duration	*r* (38) = .08, *p*=.607					
	Sleep anxiety			*r*(38)=-.12, *p*=.460			
	Night wakings		*r*(38)=-.05, *p*=.768				
	Parasomnias				*r*(38)=.012, *p*=.941		
	SDB		*r*(38)=.24, *p*=.129				
	Daytime sleepiness	*r*(38)=.20, *p*=217	*r* (38)=.181, *p*=.264				
	Total score	*r*(38)=.12, *p*=.478	*r*(38)=.20, *p*=.215	*r*(38)=-.11, *p*=.491	*r*(38)=.05, *p*=.784	*r*(38)=-.08, *p*=.627	*r*(38)=.24, *p*=.132
	Bed-time					*r*(36)=.35, *p*=.033	
	Get-up time						*r*(30)=60, *p*<0.001
	Sleep duration (mins)	r(30)=.49, p=.004					

Table SM2. ***Pearsons correlations between parent-reported Child Sleep Habits Questionnaire (CSHQ) responses and actigraphy-derived measures of total sleep time, efficiency, bed time and get up times. Correlations are reported for theoretically relevant associations.***

Parent report CCC-2		Cognitive battery (standardised scores)				
		BAS-3 Naming	**BPVS-2**	**CELF-5 Recalling Sentences**	**CTOPP-2 Non-word Repetition**	**BAS-3 non-verbal measure**
	CCC General	*r* (37) = 0.58, *p*<0.001	*r*(36) = 0.50, *p* = 0.001	*r*(36) = 0.69, *p*<0.001	*r*(36) = 0.72, *p* <0.001	*r*(37) =0.36, *p* = 0.025
	CCC Social	*r*(37)=-0.56, *p*<0.001	*r*(36)=-0.49, *p*= 0.002	*r*(36)=-0.64, *p*<0.001	*r*(36)=-0.69, *p*<0.001	*r*(37)=-0.27, *p*= 0.095

Table SM3. ***Pearsons correlations between parent-reported Children's Communication Checklist 2nd Edition responses and standardized cognitive assessments. British Ability Scales 3rd Edition (Naming); British Picture Vocabulary Scale 2nd Edition; Clinical Evaluation of Language Fundamentals 5th UK Edition (Recalling sentences); Comprehensive Test of Phonological Processing 2nd Edition (Non-word Repetition); British Ability Scale 3rd Edition (Matrices or Block Design).***

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