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Title:

Effects of sleep disorders on academic achievement and cognitive functioning in children and adolescents: A meta-analysis of polysomnographic studies

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Abstract

An adequate amount of good quality sleep is important for optimal cognitive functioning and successful academic achievement. Children with sleep disorders often experience cognitive impairments, underscoring the need for thorough assessment and effective management. This meta-analysis examines the impact sleep disorders on cognitive functioning outcomes in children and adolescents (3-18 years old). Across 50 studies, 3001 children with sleep disorders or disorders associated with sleep troubles and 1425 controls confirmed by polysomnographic assessments were included. Results indicated that children with sleep-related breathing disorders showed small to large deficits in cognitive areas such as general intelligence ($p < .001$), memory (all $ps < .022$), attention (all $ps < .007$), cognitive flexibility ($p < .001$), processing speed (all $ps < .001$), and language (all $ps < .037$). In contrast, children with insomnia showed no significant impairments compared to controls (all $ps > .11$), though data was limited. Those with central disorders of hypersomnolence had lower immediate and long-term memory ($p = .023$, $p = .016$) and sustained attention ($p < .001$). Children with neurological or neurodevelopmental-related sleep disorders showed deficits in verbal IQ ($p = .038$), memory ($p < .001$), inhibitory control ($p = .016$), cognitive flexibility ($p < .001$), processing speed ($p = .016$), and expressive language ($p = .005$). Further research is needed on these latter groups. Clinicians, school professionals and parents need to understand how sleep disorders may detrimentally impact neuropsychological functioning, to make recommendations for children suffering from sleep disorders.

Keywords: sleep disorders; cognitive functioning; academic achievement; children; adolescents.

Abbreviations

Sleep characteristics or disorders:

- BSP: behavioral sleep disorders
- DIMS: difficulty initiating and maintaining sleep
- ID: insomnia disorders
- N1, N2, N3: the three stages of NREM sleep
- OSA: obstructive sleep apnea
- REM sleep: rapid eye movement sleep
- SBD: sleep breathing disorders
- SRBD: sleep-related breathing disorders
- SRND: sleep-related neurological or neurodevelopmental disorders
- SWA: slow wave activity
- SWS: slow wave sleep (N3)

Cognitive function, tests or disorders:

- ADHD: attention deficit and hyperactivity disorders
- ASD: autism spectrum disorders
- AVLT: auditory verbal learning test
- BASC: behavior assessment system for children
- CMS: children memory scale
- CPT: continuous performance test
- DAS: Differential Ability Scale
- D-KEFS: Delis-Kaplan Executive Function System
- EF: executive functioning
- GDS: Gordon diagnosis system
- GMLT: Groton maze learning test
- GPA: grade point average
- HVLT: Hopkins verbal learning test
- LAVLT: Luria auditory verbal learning test
- LTM: long-term memory
- NEPSY: neuropsychological test battery
- RAVLT: Rey auditory verbal learning test
- SRA TEA: Scientific research associates - Test of Educational Ability
- SRTT: serial reaction time task
- STM: short-term memory
- TEA-CH: test of attention in children
- WASI: Wechsler Abbreviated Scale of Intelligence
- WIAT: Wechsler individual achievement test
- WISC-R/ WISC-III/ WISC-IV: Wechsler Intelligence Scale for Children (revised, third version and fourth version)

WRAML/WRAML-2: Wide Range Assessment of Memory and Learning (first and second editions)

WRAT: Wide range achievement test

1. Introduction

An adequate amount of good quality sleep is important for optimal health, behavioral and cognitive functioning (Chaput et al., 2016; Mitru et al., 2002; Sadeh et al., 2002; Tham et al., 2017). Despite the high prevalence of sleep issues, affecting 25-40% of the pediatric population (Mindell & Meltzer, 2008; Vriend et al., 2013), sleep problems are rarely assessed during general pediatric visits (Blunden et al., 2004). However, it is well established that children and adolescents with sleep problems report academic difficulties and cognitive deficits (Gaultney, 2010; Lowe et al., 2017).

Cross-sectional or experimental studies manipulating sleep duration in pediatric population suggest that quality or quantity of sleep is related to cognitive measures, including executive functioning (Sadeh et al., 2002), attention (Fallone et al., 2001), intelligence (Busby & Pivik, 1983), verbal creativity, abstract thinking (Randazzo et al., 1998) and behavioral evaluations (Aronen et al., 2009). In children aged 5 to 13, a meta-analysis showed that shorter sleep durations are associated with lower cognitive efficiency, poorer performance in full scale and verbal intelligence quotient (Short et al., 2018). Studies using experimental sleep extension have shown that children who extended their sleep by an average of 30 minutes exhibited improvements in short-term memory, reaction time, emotional lability, and restless-impulsive behavioral scores (Gruber et al., 2012; Sadeh, Gruber, & Raviv, 2003). An inadequate amount of sleep or poor-quality sleep has an immediate detrimental consequence on behavioral and cognitive functioning, but also a long-term negative effect. Touchette and colleagues (2007) showed that a modest but chronic reduction of 1 hour of sleep per night in early childhood was associated with lower cognitive functioning at school entry (Touchette et al., 2007). Short sleep duration increased the risk of being categorized as low performing on vocabulary tests by 3.1, suggesting that language acquisition could be significantly impeded by chronically shortened sleep duration throughout childhood.

Shortened sleep duration has also been linked to behavioral problems, particularly externalizing problems such as hyperactivity-impulsivity scores (Gruber et al., 2012; Touchette et al., 2007), rather than the classical signs of sleepiness observed in adults (e.g., yawns, closing eyes) (Boonstra et al., 2007). However, several studies have found no association between sleep deficits, which are not confirmed by polysomnographic recordings, and cognitive deficits (Eliasson et al., 2002; Loessl et al., 2008). Behavioral problems can be associated with impairments in high-order cognitive functions, such as executive functions. These cognitive functions, which are regulated by the prefrontal cortex, are known to be sensitive to sleep deprivation (Muzur et al., 2002). Based on this evidence, an insufficient quantity or quality of sleep during childhood or adolescence may impair executive functioning supported by the prefrontal cortex, thereby diminished learning abilities and achievement in children and adolescents.

Children and adolescents suffering from sleep restriction showed difficulties in executive functioning, sustained attention and long-term memory (Lowe et al., 2017). A recent meta-analysis on children with sleep-disordered breathing highlighted significant impairments in several cognitive domains (e.g., intelligence, attention, executive functioning, memory, visuo-spatial skills and language) (Menzies et al., 2022). Among adolescents, the presence of sleep disorders, such as insomnia, as well as poor sleep habits, has been linked to a higher prevalence of low academic results (Gaultney, 2010). Numerous studies have identified strong association between sleep duration or sleep quality, and academic achievement (Buckhalt et al., 2012; Dewald et al., 2010; El-sheikh et al., 2007). Many studies have established that shortened total sleep time as well as a poor sleep quality are associated with poor global school performance(BaHammam et al., 2006; Sadeh, 2007). Ravid and colleagues (2009) found that children aged 5 to 6 who failed their first grade showed longer sleep latencies, increased arousals from sleep and lower sleep efficiency compared to children who succeeded their first grade (Ravid et al., 2009), suggesting that sleep disturbances are associated with delays in academic achievement. Another study showed adolescents who felt sleepy throughout the day, showed lower academic results in science, mathematics and literature compared to those who did not (Unalan et al., 2013). Among 177 adolescents, later sleep hours during the weekdays were correlated with smaller brain grey matter volumes in frontal, anterior cingulate, and precuneus cortex regions (Urrila et al., 2017). The volume of the medial prefrontal-anterior cingulate cortex was also associated with poor academic performance. These regions are critical hubs for executive functions and cognitive regulation, both of which play a significant role in academic achievement. A systematic review showed the relationships between inadequate sleep and structural changes in the prefrontal cortex and hippocampus, which are essential for cognitive, memory and emotional processing (Dutil et al., 2018). Epidemiological studies revealed temporal relationships between early sleep difficulties and later behavioral problems (Dutil et al., 2018). Long-lasting sleep dysregulation, such as in untreated children with chronic sleep difficulties, may result in impaired brain development, neuronal damages and could lead to permanent loss of developmental milestones (Jan et al., 2010).

This meta-analysis aims to better characterize the neuropsychological functioning of children and adolescents aged 3-18 who suffer from sleep disorders, in comparison to their peers without have sleep difficulties. Given sleep disorders are prevalent in the pediatric population, we included only control children who underwent full-night polysomnographic recordings to ensure they did not have undiagnosed sleep disorders. By summarizing the effects of various categories of sleep disorders on different subdomains of neuropsychological functioning, this analysis may assist clinicians and educational professionals in better identifying the cognitive and academic challenges faced by children and adolescents with sleep disorders. This understanding may facilitate the implementation of cognitive accommodations and educational support adapted to the needs of these children.

2. Materials and Methods

2.1. Selection of studies

Studies were selected with keywords in databases (PsychInfo and PubMed) from January 1980 to March 2024: sleep disorders OR sleep-related breathing disorders OR sleep-related movement disorders OR insomnia OR parasomnia OR circadian rhythms sleep disorders OR hypersomnolence OR obstructive sleep apnea OR Periodic leg movement disorders) AND (children OR adolescents) AND (cognition OR cognitive functioning OR memory OR consolidation OR learning OR attention OR academic performances OR inhibition OR flexibility OR executive functioning) AND polysomnography.

2.2. Inclusion and exclusion criteria

Studies retained should evaluate neuropsychological functioning by using standardized psychometric tests or recognized cognitive tasks. Children and adolescents with sleep disorders must be aged between 3 to 18 (note that an exception has been made for the study conducted by (Huang and colleagues (2016) which involved participants with narcolepsy aged up to 20 years old). Peer-reviewed articles and short communications in English or French were included. Neuropsychological functioning had to be expressed by means and standard deviations, standard errors or confidence intervals. Children suffering from sleep disorders had to be untreated for their sleep problems and should be compared to a control group with no physical, neurological, developmental, psychiatric, or sleep disorders. Given sleep disorders are prevalent in the pediatric population, the control group of the selected studies should undergo a polysomnographic recording during a full night's sleep. For studies which measured the impact of a medical treatment or behavioral intervention, the results included were only those before medical treatment or behavioral intervention.

2.3. Selection

One researcher (AER) screened all titles and abstracts, with a second researcher (SM) screening a randomly selected 10% to assess inter-rater reliability, yielding 95% agreement. When the eligibility of one study was not possible to determine based on the abstract, the entire article was read. Following discussion, concordance was reached at 100%. Reference lists of studies included for full-text review were also examined to identify any additional studies missed in the primary search. Discordant eligibility was resolved by a consensus between two of the reviewers (AER and SM).

2.4. Data extraction

Before conducting the meta-analyses, AER extracted key data from each study, including the first author's name, publication year, participant numbers and ages for both the sleep disorders and control groups, cognitive tasks and domains, as well as group means and standard deviations (calculated from confidence intervals or standard errors if not reported). No essential data were missing in the selected studies.

2.5 Data analysis

Analysis of the data was done using the R meta package (v4.17-0; Balduzzi, Rücker, & Schwarzer, 2019). Some studies reported error and/omission rates instead of good answers. In this case, data was transformed into a percentage of good answers. Means, standard deviations for each score as well as number of participants were collected. Random effect sizes were calculated. Random effects of the model assume each study has a different underlying effect size due to differing sample demographic variables such as age and disease severity (Rosenthal, 1995). Effect sizes were expressed as standardized mean differences (Cohen's d) and 95% confidence interval (95% CI) were given for each study. Cohen’s d was calculated according to the following formula: d = [(mean controls - mean experimental)/pooled sleep disorders]. Effect estimates were interpreted as small (0.20), moderate (0.50) or large (0.80) (Cohen, 1992). Publication bias was assessed with funnel plots and Egger’s regression test (Egger et al., 1997). Heterogeneity of effect sizes were investigated for each group of comparisons with I2 statistics. A value of 0% indicates no observed heterogeneity, 25% low heterogeneity, 50%, moderate heterogeneity and 75%, high heterogeneity. Prediction intervals were calculated for studies with a high level of heterogeneity.

2.6. Classification of sleep disorders

Based on the International Classification of Sleep Disorders - Third edition (ICSD-3) (Sateia, 2014), studies were selected according to four sleep disorders categories: 1) sleep-related breathing disorders, 2) insomnia disorders, 3) central disorders of hypersomnolence 4) other sleep disorders. The latter category was defined as sleep-related neurological or neurodevelopmental disorders according to Stores’ review (Stores, 2016), which suggests including sleep disorders related including epilepsy, attention deficit and hyperactivity disorders (ADHD) and autism spectrum disorders (ASD).

2.7. Classification of cognitive functioning

Cognitive functioning was classified into general intelligence, memory function and four cognitive subdomains described below (see Table S1 for details).

General intelligence refers to intellectual and reasoning abilities measured though IQ. In this review, we divided general intelligence into four categories: full scale IQ, Verbal IQ, Performance IQ, and Verbal and non-verbal reasoning.

Memory refers to the ability to retain information for a short or an extended period. Memory is requested in every academic situation during which new information must be learned or previous knowledge remembered. Memory was divided into four categories. The first category is Short-term memory (STM), which refers to the ability to maintain and recall a limited amount of information during a short time (approximately 30 seconds). The remaining three categories relate to memory in the context of long-term memory (LTM) evaluation: Immediate recall, which refers to the ability to recall a large amount of information immediately after their presentation, Memory of consecutive trials corresponds to the ability to improve one's performance through successive learning trials, and Long-term memory (LTM) refers to the ability to encode, maintain and recall information after a period of time, generally about 20-30 minutes in the classical paradigm of LTM. Given the lack of clarity around the impact of sleep on procedural/implicit memory in children and the experimental nature of the tasks used, this review will focus on declarative/explicit memory, which involves conscious recollection of facts and events (episodic or semantic memory).

Attention involves the ability to focus on a specific task while ignoring irrelevant information, i.e. distractions. In this review, attention was divided into two categories: Selective attention refers to the focus on specific information in a larger environment for a short period of time and Sustained attention refers to the capacity to remain focused on a specific task for a long period.

Executive functioning (EF) is the ability to carry out goal-directed behavior using complex mental processes. It plays a key role in the adaptation to changing situations. It makes it possible to take the time to think before acting, inhibit distraction and mentally manipulate ideas (Diamond, 2013). EF was divided into five categories: Inhibitory control refers to the ability to inhibit or control automatic responses, behavior or thoughts and ignore irrelevant information, Working memory refers to the ability to maintain, manipulate and recall a limited amount of information for a short period, Cognitive flexibility (or mental shifting) refers to the ability to change one's perspectives, how one thinks about something, how one has to change one's strategy to solve a problem (Miyake et al., 2000), Planning refers to the ability to think about the several activities required to achieve a specific goal, and Processing speed and fluency refers to the time it takes a person to perform a mental task (processing speed) and the speed of a mental task (fluency).

Language skills, and more specifically verbal language, was divided into two categories: Receptive language refers to the ability to understand information and Expressive language refers to the ability to communicate information to another person.

3. Results

3.1. Study selection

Figure 1 shows the selection process of studies and data extraction. A total of 1965 papers were identified at this stage. After removing duplicates and studies which did not follow criteria for inclusion and exclusion, a total of 50 studies were included in the meta-analysis.

Figure 1. Systematic review flow diagram.

3.2. Study characteristics

Of the 50 studies reviewed (see Table 1 for details), 6 focused on academic achievement, 38 on cognitive functioning only, and 6 assessed both. In studies examining academic performance, there were 5,258 children with sleep disorders and 14,905 control children. Studies on cognitive functioning included 9,555 children with sleep disorders and 10,057 control children. The mean participant age was 9.7 years, ranging from 4 to 19 years.

Table 1. Individual study characteristics for systematic review.

Authors	Population (sample size)	Age*	PSG	Test	Fig.	Cognitive subdomains
Baglietto et al. (2001)	Epilepsy (n = 9) Control group (n = 9)	6-11	Yes	WISC-R	S1	Full Scale IQ, Verbal IQ, Performance IQ
				Experimental task	S2	Short-term memory
				Experimental task	S3	Selective attention and impulsivity
				Speech	S4	Processing speed and fluency
				Stroop test	S4	Inhibitory control
				Benton's naming test	S5	Expressive language
				Speech	S5	Receptive language
Barnes, Gozal, & Molfese (2012)	Mild OSA (n = 14) Control group (n = 14)	4-8	Yes	NEPSY	S3	Selective attention and impulsivity
Beebe, Wells et al. (2004)	PS (n = 17) Mild OSA (n = 9) MS OSA (n = 6) Severe OSA (n = 6) Control group (n = 17)	6-12	Yes	WISC-III	S2	Short-term memory
				WRAML	S2	Immediate recall
				WRAML	S2	Long-term memory: Learning of consecutive trials, Long-term memory: Delayed recall
				NEPSY	S3	Selective attention and impulsivity
				GDS	S3	Sustained attention
				WCST	S4	Cognitive flexibility
				Stroop	S4	Inhibitory control
				NEPSY	S4	Processing speed and fluency
Beebe, Ris (2004)	PS (n = 26) Mild OSA (n = 58) MS OSA (n = 42) Control group (n = 37)	10-16.9	Yes	BASC	S6	Teacher's rating
				CMS	S2	Immediate recall
				CMS	S2	Long-term memory: Learning of consecutive trials, Long-term memory: Delayed recall
				WISC-IV	S5	Expressive language
Blunden et al. (2000)	PS/OSAS (n = 16) Control group (n = 16)	5.7-10.8	Yes	WPPSI-R/WISC-III	S1	Full Scale IQ, Verbal IQ, Performance IQ
				WRAML	S2	Immediate recall
				ACPT	S3	Selective attention and impulsivity, Sustained attention
Blunden et al. (2005)	PS (n = 11) BSP (n = 13) PS + BSP (n = 9) Control group (n = 31)	6.2-16.8	Yes	WASI	S1	Full Scale IQ, Verbal IQ, Performance IQ
				CMS	S2	Long-term memory: Learning of consecutive trials, Long-term memory: Delayed recall
				ACPT	S3	Selective attention and impulsivity
				ACPT, TEA-Ch	S3	Sustained attention
				CMS	S4	Working memory
Bourke et al. (2011)	PS (n = 59) Mild OSA (n = 24) MS OSA (n = 19) Control group (n = 35)	7-12	Yes	WASI	S1	Full Scale IQ, Verbal IQ, Performance IQ
				WASI	S1	Verbal and non-verbal reasoning
				WASI	S5	Expressive language
Brockmann et al. (2018)	Mild OSA (n = 19) Control group (n = 14)	6-11	Yes	WISC IV	S1	Full Scale IQ, Verbal IQ, Performance IQ
				WISC IV	S1	Verbal and nonverbal reasoning
				WISC IV	S4	Working memory
				WPPSI-IV	S4	Processing speed and fluency
Cha et al. (2017)	OSA (n = 11) Control group (n = 12)	13-18	Yes	ISLT, GMT	S2	Long-term memory: Learning of consecutive trials, Long-term memory: Delayed recall

Csábi et al. (2016)	SBD (n = 10) Control group (n = 10)	8-9	No*	Experimental task	S2	Long-term memory: Learning of consecutive trials, Long-term memory: Delayed recall
de Carvalho et al. (2013)	SBD (n = 631) Control group (n = 102)	7-10	No	Academic performances	S6	Academic results
Esposito et al. (2013)	MS OSA (n = 79) Control group (n = 92)	9	No*	MCST	S4	Cognitive flexibility
Friedman et al. (2003)	OSA (n = 39) Control group (n = 20)	5-9	Yes	K-ABC	S2	Short-term memory
Gagnon et al. (2023)	Narcolepsy (n = 19) Control group (n = 23)	10.2 (2.1)	Yes	WISC-IV CMS CMS WISC-IV WISC-IV	S1 S2 S2 S4 S4	Full Scale IQ, Verbal IQ, Performance IQ Immediate recall Long-term memory: Delayed recall Processing speed and fluency Working memory
Galer et al. (2015)	Idiopathic focal epilepsies (n = 15) Control group (n = 8)	6-12	Yes	Experimental task Experimental task	S2 S2	Immediate recall Long-term memory: Learning of consecutive trials
Giordani et al. (2008)	OSA (n = 40) Control group (n = 26)	5-12	Yes	WIAT-II WASI CMS CMS	S6 S1 S2 S4	Academic results Verbal and nonverbal reasoning Long-term memory: Learning of consecutive trials, Long-term memory: Delayed recall Working memory
Gottlieb et al. (2004)	SBD (n = 48) Control group (n = 119)	5	Yes*	WPPSI-R WPPSI-R CPT NEPSY	S1 S4 S3 S4	Full Scale IQ Processing speed and fluency Sustained attention Planning
Gruber et al. (2014)	Poor sleep efficiency (n = 25) Control group (n = 43)	07-11	No**	School performance	S6	Academic results
Hagström et al. (2020)	PS (n = 17) Control group (n = 27)	6-10	Yes	WISC-III NEPSY NEPSY NEPSY NEPSY	S1 S4 S4 S4 S4	Full Scale IQ, Verbal IQ, Performance IQ Cognitive flexibility Planning Processing speed and fluency Expressive and receptive language
Halbower et al. (2006)	Severe OSA (n = 14) Control group (n = 12)	6-12	Yes	WISC-III et WISC-IV CPT D-KEFS	S1 S3 S4	Full Scale IQ Sustained attention Processing speed and fluency
Hannon et al. 2012)	OSA and obesity (n = 17) Control group (obese) (n = 20)	12-18	Yes	WRAT RAVLT Stroop WASI	S6 S2 S4 S5	Academic results Short-term memory Inhibitory control Expressive language
Hill et al. (2006)	SBD (n = 31) Control group (n = 17)	3-7	Yes	NEPSY WPPSI-III	S3 S4	Selective attention and impulsivity Processing speed and fluency
(Hogan et al. (2008)	SBD (n = 14) Control group (n = 10)	3-7	Yes	WPPSI-III WPPSI-III	S3 S4	Selective attention and impulsivity Processing speed and fluency
Holley et al. (2014)	Epilepsy (n = 23) Control (n = 50)	6-14	Yes	WISC-IV	S4	Processing speed and fluency
Honaker et al. (2009)		7-8	Yes	NEPSY	S1	Verbal and nonverbal reasoning

	PS (n = 76) OSA (n = 76) Control group (n = 76)			DAS, NEPSY NEPSY Language DAS, NEPSY	S5 S5 S5	Expressive language Receptive language Expressive and receptive language
(Huang et al., 2016)	Narcolepsy (n = 71) Control group (n = 20)	8-20	Yes	CPT WCST	S2 S3	Sustained attention Cognitive flexibility
Hysing et al. (2016)	Insufficient sleep duration (n = 1200) Control group (n = 132)	16-19	No	Academic performance	S6	Academic results
Kaemingk et al. (2003)	SBD (n = 77) Control group (n = 72)	6-12	Yes	Academic performances WASI CAVLT-2	S6 S1 S2	Academic results Verbal IQ, Performance IQ Immediate recall, Learning of consecutive trials, Long-term memory: Delayed recall
Kennedy et al. (2004)	PS (n = 13) Control group (n = 13)	5.3-10.7	Yes	WPPSI-R/WISC-III WRAML ACPT ACPT	S1 S2 S3 S3	Full Scale IQ, Verbal IQ, Performance IQ Long-term memory: Delayed recall Selective attention and impulsivity Sustained attention
Kheirandish-gozal et al. (2014)	OSA (n = 10) Control group (n = 7)	7-11	Yes	Stroop PPVT-III	S4 S5	Inhibitory control Receptive language
Kohler et al. (2009)	SBD (n = 44) Control group (n = 48)	3-12	Yes	Stanford Binet Experimental task	S1 S4	Full Scale IQ, Verbal IQ, Performance IQ, Verbal and nonverbal reasoning Working memory
Kurnatowski et al. (2006)	OSA (n = 87) Control group (n = 74)	6-9	Yes	Luria auditory verbal and learning test	S2	Immediate recall, Long-term memory: Learning of consecutive trials, Long-term memory: delayed recall
	OSA (n = 34) Control group (n = 30)	10-13	Yes	Token test	S5	Receptive language
Lau et al. (2015)	OSA (n = 23) Control group (n = 22)	8-12	Yes	HK-WISC Experimental task Experimental task	S2 S2 S4	Short-term memory Short-term memory Working memory
Lewin et al. (2002)	Severe OSA (n = 5) Control group (n = 10)	4-12	Yes	DAS DAS	S1 S4	Full Scale IQ, Verbal IQ, Performance IQ Processing speed and fluency
Maski et al. (2015)	ASD (n = 22) Control group (n = 20)	9-16	Yes	Experimental task	S2	Immediate recall, Long-term memory: Learning of consecutive trials, Long-term memory: delayed recall
Montgomery-Downs, Crabtree, & Gozal, (2005)	Moderate OSA (n = 19) Control group (n = 19)	4	Yes	DAS	S1	Verbal IQ
O'Brien, Mervis, Holbrook, Bruner, Smith, et al. (2004)	SBD (n = 35) Control group (n = 35)	6.7 (0.5)	Yes	DAS DAS DAS	S1 S1 S2	Verbal IQ, Performance IQ Verbal and nonverbal reasoning Short-term memory
O'Brien, Mervis, Holbrook, Bruner, Klaus, et al. (2004)	PS (n = 87) Control group (n = 31)	5-7	Yes	DAS DAS NEPSY	S5 S5 S5	Expressive language Receptive language Expressive and receptive language
Ortega et al. (2010)	Insufficient sleep duration (n = 298) Control group (n = 1266)	13-18.5	No	SRA TEA	S6	Academic results
Perez-Chada et al. (2007)	PS (n = 1699) Control group (n = 210)	13 (1.5)	No	Academic performances	S6	Academic results

Piccinelli & Unit (2008)	Rolandic epilepsy (n = 20) Control group (n = 21)	7.9 - 12.9	Yes	WISC-R	S1	Full Scale IQ
Rhodes et al. (1995)	MS OSA (n = 5) Control group (n = 9)	13 (1.8)	Yes	WRAML	S2	Immediate recall
Sawyer et al. (2009)	Sleep problems (n = 36) ADHD + sleep problems (n = 32) Control group (n = 119)	7-18	Yes	Experimental task Experimental task Experimental task	S2 S4 S4	Immediate recall Cognitive flexibility Processing speed and fluency
Shetty et al. (2023)	PS (n = 10) Mild OSA (n = 10) MS OSA (n = 10) Control group (n = 10)	3-12	Yes	Standfort-Binet intelligence scale NEPSY-II NEPSY-II	S1 S4 S5	Full Scale IQ, Verbal IQ, Performance IQ Cognitive flexibility Expressive and receptive language
Sivertsen, Glozier, Harvey, & Hysing (2015)	DSP (n = 261) Control group (n = 8163)	16-19	No	Academic performance	S6	Academic results
Stores, Montgomery, & Wiggs (2006)	Excessive daytime sleepiness (n = 18) Narcolepsy (n = 42) Control group (n = 23)	4-18	No	Composite educational difficulties scores	S6	Teacher's rating
Tan et al. (2014)	Mild and MS OSA (n = 15) Control group (n = 16)	10-18	Yes	WIAT-II WASI WRAML-2	S6 S1 S2	Academic results Full Scale IQ, Verbal IQ, Performance IQ Immediate recall
Urbain et al. (2011)	Epilepsy (n = 4) Control group (n = 24)	7-10	Yes	Experimental task: Words pairs (session 1)	S2	Immediate recall
Vitelli et al. (2015)	SBD (n = 36) SBD and obesity (n = 38) Control group (n = 28)	8 (2)	Yes	WISC-R WISC-R WISC-R	S1 S1 S4	Full Scale IQ, Verbal IQ, Performance IQ Verbal and nonverbal reasoning Processing speed and fluency
Yuan et al. (22012)	MS OSA (n = 6) Control group (n = 21)	8-16	Yes	WISC-IV WRAML-2 Color word interference test D-KEFS WISC-IV, D-KEFS	S1 S2 S4 S4 S4	Verbal and nonverbal reasoning Immediate recall Inhibitory control Cognitive flexibility Processing speed and fluency

Notes. Age is given in age in range or mean (SLEEP DISORDERS). PSG: Yes*: PSG data were available in 85% of children; No*: children underwent an overnight polygraphy; No**: actigraphic recordings for all children. Fig.: figures in supplementary data representing forest plots for general intelligence (S1), memory functioning (S2), attentional functioning (S3), executive functioning (S4), language (S5) and academic performance (S6). POPULATION: ADHD: attention deficit and hyperactivity disorder; ASLEEP DISORDERS: autism spectrum disorder; SBD: sleep breathing disorders, (MS) OSA: (moderate/severe) obstructive sleep apnea; PS: primary snoring. TESTS: BASC: behavior assessment system for children; CAVLT: children auditory verbal learning test; CMS: children memory scale; CPT: continuous performance test; DAS: Differential Ability Scale; D-KFES: Delis-Kaplan Executive Function System; GDS: Gordon diagnosis system ; GMLT: Groton maze learning test; HVLT: Hopkins verbal learning test; LAVLT: Luria auditory verbal learning test, NEPSY: neuropsychological test battery; RAVLT: Rey auditory verbal learning test; SRA TEA: Scientific research associates - Test of Educational Ability ; SRTT: serial reaction time task; STM: short-term memory; TEA-CH: test of attention in children; WASI: Wechsler Abbreviated Scale of Intelligence; WIAT: Wechsler individual achievement test; WISC-R/ WISC-III/ WISC-IV: Wechsler Intelligence Scale for Children (revised, third version and fourth version); WRAML/WRAML-2: Wide Range Assessment of Memory and Learning (first and second editions); WRAT: Wide range achievement test.

3.3. Cognitive functioning

The primary meta-analysis revealed that compared to controls, children and adolescents with sleep disorders obtained significantly lower scores for all subdomains of **general intelligence** with a moderate effect of 0.66 [0.54; 0.77] (p < .001) (Figure S1): FSIQ (0.72 [0.49; 0.94], p < .001), verbal IQ (0.75 [0.41; 1.09], p < .001), performance IQ (0.59 [0.35; 0.83], p < .001), verbal and non-verbal reasoning (0.61 [0.46; 0.77], p < .001). Children and adolescents with sleep disorders showed lower performance in **memory functioning** than controls with a moderate effect of 0.57 [0.41; 0.74] (p < .001) (interval prediction: -0.72; 1.86), Figure S2. While there was no significant effect for short-term memory (0.20 (-0.06; 0.45], p = .100), the mean effect size ranged from small and moderate (immediate recall: 0.63 [0.32; 0.94], p < .001; learning of consecutive trials: 0.42 [0.06; 0.77], p = .021) to large (delayed recall: 0.81 [0.49; 1.12], p < .001). **Attention** was also impaired in children and adolescents with sleep disorders compared to controls with a moderate effect of 0.78 [0.49; 1.07] (p < .001) (Figure S3), with the mean effect size ranged from moderate (sustained attention: 0.61 [0.22; 1.00], p = .002) to large (selective attention: 0.86 [0.48; 1.24], p < .001). Compared to controls, children and adolescents with sleep disorders obtained significantly lower performance for **executive functioning** with a small effect of 0.38 [0.25; 0.50] (z = 5.75, p < .001) (Figure S4). However, the difficulties of sleep disorders children and adolescents were observed for cognitive flexibility (0.36 [0.09; 0.64], p = .008) and processing speed (0.49 [0.30; 0.69], p < .001), but not for the three other subdomains (inhibitory control (0.38 [-0.05; 0.82], p = .085; planning: 0.10 [-0.64; 0.84], p = .793; working memory: 0.19 [-0.05; 0.43], p = .122). Finally, **language scores** were lower in children and adolescents with sleep disorders for all subdomains with a moderate effect of 0.59 [0.36; 0.82] (p < .001) (Figure S5). The mean effect size ranged from small (receptive language: 0.37 [0.22; 0.51], p < .001; global score: 0.20 [0.01; 0.38], p = .037) to large (expressive language: 1.20 [0.65; 1.76], p < .001).

Given the predominance of studies on sleep-related breathing disorders compared to other conditions, these results should be interpreted cautiously. Analysis of heterogeneity revealed that general intelligence and executive functioning had a moderate heterogeneity ($I^2 = 73\%$, $Chi^2 = 343.6$, $p < .001$ and 67%, $Chi^2 = 189.0$, $p < .001$ respectively). Memory, attention, and language showed high heterogeneity ($I^2 = 83\%$, $Chi^2 = 455.2$, $p < .001$; $I^2 = 80\%$, $Chi^2 = 152.3$, $p < .001$; and $I^2 = 90\%$, $Chi^2 = 318.3$, $p < .001$, respectively), indicating significant variation in the results. The 95% prediction intervals confirm the wide range of possible effect sizes across studies, suggesting that no consistent or substantial impact is expected for memory [-0.74; 1.88], attention, [-0.73; 2.29] and language, [-0.70; 1.87].

The second meta-analysis examined cognitive outcomes separately in subgroups of children with different sleep disorders: sleep-related breathing disorders, chronic insomnia, central disorders of hypersomnolence and sleep-related neurological/neurodevelopmental disorders. Results for cognitive functioning according to sleep disorders are presented in Table 2. There were significant subgroups difference in all cognitive domains: general intelligence ($p = .003$), memory ($p < .001$), attention ($p = .007$), executive functioning ($p < .001$) and language ($p = .003$).

A moderate effect was observed for children and adolescents with sleep-related breathing disorders or sleep-related neurological/neurodevelopmental disorders (0.70 [0.58; 0.82], $p < .001$ and 0.64 [0.15; 1.14], $p = .010$, respectively) in general intelligence, but there was no effect for children and adolescents with chronic insomnia ($p = .287$) or central disorders of hypersomnolence ($p = .550$). In sleep-related breathing disorders children, the mean effect size ranged from moderate (FSIQ, PIQ, verbal and non-verbal reasoning) to large (verbal IQ) (all ps < .001). Notably, children and adolescents who snore, regardless of the OSA, showed lower FSIQ compared to controls (all ps < .001). Children and adolescents with sleep-related neurological/neurodevelopmental disorders (here epilepsy) obtained lower scores than controls only for verbal IQ (p = .038). The meta-analysis on memory revealed a large effect (2.30 [1.22; 3.37], p < .001) in children and adolescents suffering from sleep-related neurological/neurodevelopmental disorders and a small effect (0.38 [0.23; 0.53], p < .001) in children and adolescents suffering from sleep-related neurological/neurodevelopmental disorders. The only study assessing memory in central disorders of hypersomnolence (5 comparisons) included in this meta-analysis showed a moderate effect (0.61 [0.25; 0.97], p < .001), with lower performance in immediate recall after a learning session and delayed recall. As seen in Figure S2, children and adolescents with sleep-related breathing disorders had significantly lower performance in long-term memory (learning of consecutive trials, p < .001; delayed recall: p < .001), but not in short-term memory (p = .196). While children and adolescents with sleep-related neurological/neurodevelopmental disorders showed preserved abilities in short-term (children with epilepsy, p = .176) and immediate memory (children and adolescents with epilepsy, ADHD or ASD, p = .129), they experienced a loss of information when they had to recall information after consecutive trials or a delay (children and adolescents with epilepsy or ASD, all ps < .001). The most affected subgroup in terms of attentional functioning was sleep-related breathing disorders with a large effect (1.04 [0.66; 1.42], p < .001) and impaired performance in both selective (p < .001) and sustained attention (p = .007). Children and adolescents with central disorders of hypersomnolence obtained lower performance in sustained attention (p < .001), but selective attention was not assessed in the selected studies, and there were only 2 comparisons. The studies investigating selective attention in insomnia disorders and sleep-related neurological/neurodevelopmental disorders did not reveal significant difference (p = .114 and p = .829, respectively). The subdomains of executive functioning were partially investigated in the different sleep disorders. Sleep-related breathing disorders children and adolescents, in which the 5 subdomains were explored, obtained lower performance in cognitive flexibility (p < .001) and processing speed (p < .001). These subdomains were also affected in sleep-related neurological/neurodevelopmental disorders children and adolescents (cognitive flexibility in children and adolescents with ASD, p < .001; and processing speed in those with epilepsy, p = .016), as well as inhibitory control (in children and adolescents with epilepsy, but not with ASD, p = .016). Contrastingly, there was no effect for working memory in children and adolescents with sleep-related breathing disorders (p = .096), insomnia disorders (p = .290) and central disorders of hypersomnolence (p = .292). This subdomain was not assessed in children and adolescents with sleep-related neurological/neurodevelopmental disorders). The few comparisons in chronic insomnia (p = .786) and central disorders of hypersomnolence (p = .162) did not reveal impaired performance in executive functioning. Language abilities were impaired in children and adolescents with sleep-related breathing disorders in the three subdomains (expressive language, receptive language, and global score, all ps < .001). A large effect was observed for expressive language in children and adolescents with sleep-related neurological/neurodevelopmental disorders (p = .005), but the other subdomains were not investigated in the selected studies. No study has been included regarding language outcomes for insomnia disorders and central disorders of hypersomnolence.

Table 2. Results on cognitive functioning domains according to sleep disorders categories.

	SRBD	ID	CDH	SRND
General intelligence	**Moderate effect** **0.70 [0.58; 0.82]** p < .001	No effect 0.24 [-0.13; 0.62] p = .202	No effect -0.16 [-0.69; 0.37] p = .549	**Moderate effect** **0.64 [0.15; 1.14]** p = .010
Full scale IQ	**Moderate effect** **0.78 [0.53; 1.04]** (k= 21) p < .001	No effect 0.35 [-0.35; 1.01] (k = 1) p = .287	No effect 0.19 [-0.44; 0.83] (k = 1) p = .550	No effect 0.48 [-0.35; 1.21] (k = 2) p = .256

Verbal IQ	**Large effect** **0.83 [0.49; 1.16]** (k = 20) p < .001	No effect 0.25 [-0.40; 0.90] (k =1) p = .447	Opposite effect [1] -0.69 [-1.32; -0.06] (k =1) p = .030	**Large effect** **1.05 [0.06; 2.05]** (k =1) p = .038
Performance IQ	Moderate effect 0.64 [0.41; 0.94] (k =19) p < .001	No effect 0.13 [-0.52; 0.77] (k =1) p = .699	No effect 0.02 [-0.59; 0.62] (k =1) p = .960	No effect 0.87 [-0.10; 1.85] (k =1) p = .079
Verbal and non-verbal reasoning	Moderate effect 0.61 [0.46; 0.77] (k =23) p < .001	N/A	N/A	N/A
Memory	**Small effect** **0.38 [0.23; 0.53]** p < .001	No effect -0.03 [-0.44; 0.38] p = .897	**Moderate effect** **0.61 [0.25; 0.97]** p < .001	**Large effect** **2.30 [1.22; 3.37]** p < .001
Short-term memory	No effect 0.15 [-0.08; 0.37] (k = 12) p = .196	N/A	N/A	No effect 0.94 [-0.42; 2.31] (k = 2) p = .176
Long-term memory: immediate recall	**Moderate effect** **0.55 [0.23; 0.87]** (k = 18) p < .001	No effect -0.29 [-0.67; 0.08] (k = 1) p = .123	**Moderate effect** **0.66 [0.09; 1.22]** (k = 2) p = .023	No effect 1.35 [-0.39; 3.10] (k = 1) p = .129
Long-term memory: memory after consecutive trials	**Small effect** **0.23 [0.03; 0.42]** (k = 9) p = .022	No effect 0.39 [-0.26; 1.05] (k = 1) p = .239	N/A	**Large effect** **2.82 [1.95; 3.68]** (k = 1) p < .001
Long-term memory: delayed recall	**Moderate effect** **0.50 [0.21; 0.79]** (k = 22) p < .001	No effect 0.04 [-0.61; 0.69] (k = 1) p = .905	**Moderate effect** **0.58 [0.11; 1.05]** (k = 3) p = .016	**Large effect** **3.75 [3.02; 4.48]** (k = 4) p < .001
Attention	**Large effect** **1.04 [0.66; 1.42]** p < .001	No effect 0.21 [-0.12; 0.53] p = .210	**Moderate effect** **0.69 [0.33; 1.05]** p < .001	No effect -0.11 [-1.15; 0.92] p = .829
Selective attention	**Large effect** **1.30 [0.80; 1.79]** (k = 12) p < .001	No effect 0.37 [-0.09; 0.84] (k = 2) p = .114	N/A	No effect -0.11 [-1.15; 0.92] (k = 3) p = .829
Sustained attention	**Moderate effect** **0.75 [0.20; 1.29]** (k = 11) p = .007	No effect 0.05 [-0.43; 0.53] (k = 2) p = .848	**Moderate effect** **0.69 [0.33; 1.05]** (k = 2) p < .001	N/A
Executive functioning	**Small effect** 0.46 [0.34; 0.57] p < .001	No effect -0.11 [-0.94; 0.71] p = .786	No effect -0.37 [-0.88; 0.15] p = .162	**Large effect** **0.81 [0.41; 1.21]** p < .001
Inhibitory control	No effect 0.28 [-0.15; 0.72] (k =7) p = .203	N/A	N/A	**Large effect** **1.26 [0.24; 2.29]** (k =1) p = .016
Cognitive flexibility	**Moderate effect** **0.58 [0.35; 0.81]** (k = 15) p < .001	N/A	Opposite effect [1] -0.73 [-1.09; -0.37] (k = 2) p < .001	**Moderate effect** **0.74 [0.34; 1.14]** (k = 1) P < .001
Planning	No effect 0.10 [-0.64; 0.84] (k = 2) p = .793	N/A	N/A	N/A
Working memory	No effect 0.22 [-0.04; 0.49] (k = 10) p = .096	No effect 0.35 [-0.30; 1.00] (k = 1) p = .290	No effect -0.33 [-0.94; 0.28] (k = 1) p = .292	N/A

Processing speed and fluency	**Small effect** **0.49 [0.33; 0.65]** (k = 21) p < .001	Opposite effect [1] -0.48 [-0.87; -0.12] (k = 1) p = .010	No effect 0.43 [-0.20; 1.05] (k = 1) p = .181	**Moderate effect** **0.84 [0.16; 1.53]** (k = 3) p = .016
Language	**Moderate effect** 0.57 [0.33; 0.80] p < .001	N/A	N/A	**Large effect** 1.00 [0.30; 1.71] p = .005
Expressive language	**Large effect** **1.19 [0.04; 2.35]** (k = 13) p < .001	N/A	N/A	**Large effect** **1.00 [0.30; 1.71]** (k = 2) p = .005
Receptive language	**Small effect** **0.36 [0.21; 0.51]** (k = 7) p < .001	N/A	N/A	N/A
Global score	**Small effect** **0.20 [0.01; 0.38]** (k = 12) p = .037	N/A	N/A	N/A

Notes. SRBD: sleep-related breathing disorders; ID: insomnia disorders; CDH: central disorders of hypersomnolence; SRND: sleep-related neurological or neurodevelopmental disorders.NA: no data available. k means number of comparisons; IQ: intelligent quotient. Significant effects, where children with sleep disorders scored lower than the control group, are shown in bold. [1] Children with sleep disorders performed better than the control group.

3.4. Academic achievement

The first meta-analysis on academic achievement revealed that compared to controls, children and adolescents with sleep disorders obtained significantly lower performance or rating with a small effect of 0.44 [0.33; 0.55] (p < .001) (Figure S6). Studies investigated academic performance showed a small effect (0.39 [0.26; 0.52], p < .001) and those investigating teacher's ratings showed a moderate effect (0.64 [0.41; 0.87], p < .001) in children and adolescents suffering from sleep disorders compared to controls.

The second meta-analysis examined academic outcomes separately in subgroups of children and adolescents with different sleep disorders (Table 3). When focusing on academic performance, small effects were observed in children and adolescents suffering from sleep-related breathing disorders (0.42 [0.30; 0.54], p < .001) and insomnia disorders (0.41 [0.19; 0.63], p < .001) compared to controls. Teachers reported learning and attentional problems with a moderate effect (0.55 [0.36; 0.75], p < .001) in children and adolescents with sleep-related breathing disorders but not with central disorders of hypersomnolence (p = .311). This effect was observed in adolescents with mild OSA or moderate to large OSA compared to controls ($p < .001$), but not in adolescents suffering from only snoring ($p = .335$). Note that there was no study on sleep-related neurological/neurodevelopmental disorders that met our criteria.

3.5. Publication bias

The Egger's regression test was significant for the domains of memory, attention and language (all ps < .001), but not for intelligence ($p = 0.544$), executive functioning ($p = .898$) and academic performance ($p = .422$). The significant p-value observed in the Egger's regression test may be attributed to a few studies with notably high effects. Blunden et al. (2000) conducted a study evaluating memory and attentional functioning in children with primary snoring or OSA, finding large effects. When their two comparisons were excluded from our analysis, the Egger's regression test for attentional functioning became non-significant ($p = .523$). However, even with these comparisons removed, the results still indicated a moderate impairment in attentional processes associated with sleep disorders, with an effect size of 0.59 [0.39, 0.72] ($I^2 = 56\%$). Considering memory functioning, studies on children with sleep-related neurological or neurodevelopmental disorders revealed very large effects in learning across consecutive trials and in delayed recall. When these studies (Galer et al., 2015; Maski & Kothare, 2013; Urbain et al., 2011) and the study of Blunden et al. (2000) were excluded from the analysis, the Egger's regression test became non-significant ($p = .158$), though a small effect size of 0.39 [0.25, 0.52] remained ($I^2 = 75\%$).

Table 3. Results on academic performance domains according to sleep disorders categories.

	SRBD	ID	CDH	SRND
Academic achievement	**Small effect** **0.42 [0.30; 0.54]**	**Small effect** **0.41 [0.19; 0.63]**	No effect 0.63 [-0.59; 1.85]	N/A

	p < .001	p < .001	p = .311	
Academic performance	**Small effect** **0.34 [0.21; 0.47]** (k= 14) p < .001	**Small effect** **0.41 [0.19 0.63]** (k = 8) p < .001	N/A	N/A
Teachers' rating	**Moderate effect** **0.55 [0.36; 0.75]** (k = 9) p < .001	N/A	No effect 0.63 [-0.59; 1.85] (k =2) p = .311	N/A

Notes. Significant effects, where children with sleep disorders scored lower than the control group, are shown in bold.

4. Discussion

The aim of this meta-analysis was to further characterize the effects of pediatric sleep disorders on neuropsychological functioning and academic achievement. Cognitive functioning was found to be impaired in at least two of the sleep disorders groups.

4.1. General intelligence

General intelligence was reduced in children suffering from sleep-related breathing disorders compared to controls, with poorer performance in verbal IQ compared to performance (non-verbal) IQ. Verbal IQ is often tested through verbal comprehension and vocabulary, these skills being linked to language abilities, which are affected in children suffering from sleep-related breathing disorders (see below). As they are timed, several IQ tests are highly dependent on processing and psychomotor speed, which is affected in children with sleep disorders (more specifically children with sleep-related breathing disorders and sleep-related neurological/neurodevelopmental disorders). Slow processing speed may contribute to lower general intelligence in children with sleep disorders, especially in performance IQ. Excessive daytime somnolence, sleep fragmentation and/or intermittent hypoxia during sleep are related to cognitive deficits (such as memory, attentional and executive difficulties) and may participate in the observed reduced IQ in pediatric sleep disorders populations.

Full scale IQ was not reduced in children suffering from sleep-related neurological/neurodevelopmental disorders while they showed difficulties in verbal IQs. However, it should be noted the two studies in this category of sleep disorders involved children with epilepsy. The control children in both studies exhibited comparable IQs of approximately 110 points, whereas the children with epilepsy demonstrated an IQ of 108 (children with Rolandic epilepsy) in one study and 94 in the other (children suffering from benign epilepsy of childhood with centrotemporal or Rolandic spikes). A reduction in IQ is frequently reported in epileptic children, it is estimated that over 23% of school-aged children with epilepsy show decreased FSIQ (Mohamed et al., 2020). Although epilepsy can negatively affect IQ, Baglietto et al. (2001) found that learning disabilities in children suffering from benign epilepsy of childhood were correlated with a marked increase in epileptiform discharges during sleep and an early onset of epilepsy. This suggests that it is difficult to disentangle the specific contribution of sleep disorders or epileptiform discharges to cognitive problems in these children. The only study involving children with insomnia did not show a negative impact of this disorder on general intelligence functioning.

Children with OSA exhibit reduced grey matter volume (Philby et al., 2017), and in adults, variations in prefrontal and posterior temporal cortical thickness have been shown to be particularly linked with intellectual ability (Narr et al., 2007). In this meta-analysis, children suffering from all types of sleep-related breathing disorders, and not only children with OSA, showed lower general intelligence than controls in all subdomains. Among the 6 comparisons involving primary snorers, four of them showed lower full-scale IQ suggesting the primary deficit in habitual snoring is already an important enough disorder to reduce cognitive efficiency. Despite having an IQ within the norm, children with sleep-related breathing disorders are on average 10 points lower than control children. This reduction is not insignificant given the high correlation between IQ and academic achievement (Lynn et al., 2007). It is interesting to note that performance on working memory tasks is known to correlate highly with IQ (Kovacs & Conway, 2016). However, sleep-related breathing disorders children in this review do not show impaired working memory.

While FSIQ offers a general overview of children's cognitive functioning, it only represents one aspect of their abilities. To gain a more comprehensive understanding of a child's strengths and weaknesses, it is important to assess different cognitive areas separately, especially in children with sleep disorders.

4.2. Memory

Memory is involved in all stages of academic learning, including language comprehension, reading and arithmetic's performance (Fandakova & Bunge, Silvia, 2016). We observed short-term memory, which is commonly assessed in school psychometric tests, is not impacted, whereas long-term memory is impaired in children suffering from sleep disorders. We observed that long-term memory was impaired at least in two memory subdomains in children suffering from sleep-related breathing disorders, central disorders of hypersomnolence and sleep-related neurological/neurodevelopmental disorders compared to controls, but not children with ID (only one comparison). It has been proposed that prefrontal-hippocampal circuitry underlies the encoding of long-term memory (Wilhelm et al., 2012). The volume of the hippocampus was significantly smaller in adults with OSAS compared to controls (Dusak et al., 2013). Adults with OSAS reported deficits in episodic memory which suggests prefrontal and/or subcortical dysfunction (Naëgelé et al., 2006). In childhood, reductions in grey matter volume were found in children with OSAS throughout the superior frontal and prefrontal areas compared to controls (Philby et al., 2017b). Moreover, frontotemporal functional connectivity during encoding and retrieval contributes to performance in episodic memory during middle childhood (Blankenship & Bell, 2015). These findings suggest that OSAS may have significant implications for brain development, potentially affecting learning and behavioral outcomes.

Significant effects are observed on memory in children suffering from sleep-related neurological/neurodevelopmental disorders or neurodevelopmental conditions compared to controls. It could be explained by the fact the studies included in this meta-analysis involved children suffering from epilepsy. Many children suffering from epilepsy had centrotemporal or Rolandic spikes (Baglietto et al., 2001; Galer et al., 2015; Urbain et al., 2011). The medial temporal lobe, including the hippocampus and connected areas, is known to be involved in long-term memory (Squire et al., 2004). A growing number of studies showed impaired sleep-dependent memory consolidation in children suffering from sleep disorders (Cellini, 2017; Maski et al., 2017). We observed that children suffering from insomnia disorders showed no deficit in short-term memory, but difficulties in long-term memory and in working memory, a subdomain of executive functioning.

4.3. Attention

Attention represents a core of cognitive activity based on child self-regulation function, which is a strong predictor of academic achievement (Rabiner et al., 2016; Tamayo Martinez et al., 2021). In early childhood, the child self-regulation function is mainly built with parental responsiveness (von Suchodoletz et al., 2011) which plays a central role in selective and sustained attention in children (Wass et al., 2018). Sleep and self-regulation are closely linked: children who sleep better tend to develop stronger self-regulatory abilities, and well-regulated children often experience better sleep quality (Breitenstein et al., 2021). Previous studies demonstrated associations between sleep problems and attention problems from infancy to early childhood (Sadeh et al., 2015). In-laboratory studies examining associations between sleep deficits and sustained attention show contradictory results (Astill et al., 2012; Short et al., 2013). Hoyniak and colleagues (2015) found longer P3 latencies (EEG) with poorer sustained attention (Hoyniak et al., 2015).

In this meta-analysis, we found children suffering from sleep-related breathing disorders reported moderate to large deficits in attention compared to controls. Children who had been treated for sleep-related breathing disorders showed an improvement in tasks associated with fluid intelligence, which describes the cognitive skills reliant on one's ability to adapt to new situations fostered by improvement in attention (Biggs et al., 2014). Attention deficits could potentially be reversible by sleep-related breathing disorders improvement. Children who underwent tonsillectomy or adenotonsillectomy, achieved higher scores in intellectual performance evaluations and school performance evaluations in writing, mathematics and reading subtests (Ikeda et al., 2012), than before surgery.

The only study on sleep-related neurological/neurodevelopmental disorders included in this meta-analysis targets children with epilepsy and showed no effect. Unfortunately, we were unable to select studies exploring attention in children with neurodevelopmental disorders such as ADHD, due to the lack of PSG recordings. More than 40% of children with ADHD experienced moderate or severe sleep problems (Sung et al., 2008). Nearly 20% of children with ADHD showed moderate-to-severe sleep problems at least once a week and one third of ADHD children who are treated by stimulants displayed nightly insomnia (Stein et al., 2012). Given the association between sleep problems and attentional difficulties (Yin et al., 2022) addressing sleep issues from an early age may help reduce attention-related problems in early childhood.

4.3. Executive functioning

Executive functioning (EF) is a strong predictor of children's academic performance. EF refers to mental processes related to the prefrontal cortex, which are needed when someone engages in a cognitive activity for which intuition, or automatisms would not be sufficient (Diamond, 2013). All new complex cognitive skills which are not yet automated, such as language comprehension, reasoning, or mathematical calculation, solicit the EF (P. J. Anderson & Reidy, 2012). Some learning-related behaviors which are likely to benefit academic achievement, are also linked to EF, such as inhibiting distraction in class, following classroom rules, and completing homework. For this reason, EF is frequently reported as associated with academic achievement in childhood (Best et al., 2007; Sikora et al., 2002) to the point of having replaced the IQ as the most studied variable with respect to academic performance (Pascual, Moyano, & Robres, 2019; Ruchkin, Grafman, Cameron, & Berndt, 2003) this last decade. Working memory, which is also considered as a subdomain of executive functioning, can be conceived as an activated subset of long-term memory (Ruchkin et al., 2003). It provides a temporary storage space to process information. Sleep deprivation, which influences neural activation in frontal and parietal cortices, has been shown to affect working memory (Frenda & Fenn, 2016).

In this meta-analysis, we observed varying effects on components of EF, this may suggest specific dissociations between EF components. Chen and colleagues (2021) found that self-reported everyday sleep disturbances in children had a stronger association with working memory and inhibitory control compared to cognitive flexibility (Chen et al., 2021). Our results suggest that in children suffering from sleep-related breathing disorders, cognitive flexibility and processing speed were affected while working memory, planning and inhibitory control were not. A recent study showed that grey matter volume development in the frontal cortex, which is associated with problem solving and executive functioning, is sensitive to the effects of OSA (Yu et al., 2023). Few subdomains of EF were investigated in children suffering from insomnia disorders and central disorders of hypersomnolence and the few included studies showed no effect. Concerning children and adolescents with sleep-related neurological/neurodevelopmental disorders, our results are in congruence with findings showing that sleep and EF were linked in this population (moderate-large effects on EF) (Joyce

& Dimitriou, 2017; Landry-Roy et al., 2018; Sciberras et al., 2015). Children suffering from sleep-related neurological/neurodevelopmental disorders reported difficulties in managing emotions and adapting behaviors which underpinned EF deficits requiring flexibility, self-control, and discipline (Diamond & Lee, 2011). In this population, children suffering from sleep disorders increased the expression of behavioral problems and generate more family conflicts (Dorris et al., 2008).

Several mechanisms are likely to explain the links between EF and sleep disorders. Drowsiness and fatigue frequently observed in children suffering sleep disorders may reduce cognitive resources, which are essential for the implantation of higher-order cognitive functions such as EF (Buckhalt et al., 2009; Engleman & Douglas, 2004; Spiegelhalder et al., 2009). Anderson et al. (2009) found impairments in EF were associated with subjective sleepiness, but not sleep duration in adolescents, particularly among adolescents with lower levels of education (Anderson et al., 2009). EF deficits might also be sustained by sleep disorders-induced frontal lobe dysfunction, the most sensitive brain region to sleep deprivation. Until adolescence, the main role of sleep is to participate in brain maturation (Giedd, 2009). Several studies found changes in cortical thickness in the frontal and parietal lobes in children suffering from OSA, which likely indicates disruption to cortical developmental processes (Macey et al., 2018). Brain imaging studies have highlighted reduced sleep duration in adolescents correlates with reduced grey matter in frontal and parietal regions (Urrila et al., 2017).

4.6. Language

Language development is a strong predictor of academic achievement (Hohm et al., 2007). Cognitive stimulation of phonological representations is managed during sleep. Sleep has a crucial role in fostering language development by promoting phonological learning in children (Knowland et al., 2019). A less mature sleep consolidation from 6 to 18-19 months of age is associated with increased risk for poor language development (Dionne et al., 2011). One longitudinal study has found that short persistent sleep duration is associated with poor receptive vocabulary performance in middle childhood (Seegers et al., 2016).

In this meta-analysis, children suffering from sleep-related breathing disorders reported moderate to large deficits in language. A study found children suffering from sleep-related breathing disorders performed better in oral reading fluency than those whose sleep-related breathing disorders did not improve, but some differences with specific tasks involving oral language remained when compared to controls (Harding et al., 2021). In other words, language deficits could potentially be reversible by sleep-related breathing disorders improvements or interventions. We also found that children suffering from sleep-related neurological/neurodevelopmental disorders reported large effects in expressive language. Children suffering from ASD often present with both sleep difficulties during infancy and language difficulties development (Olsson et al., 2013).

Further research is needed to disentangle potential links between biological, environmental and social factors to understand the underlying mechanisms for each specific sleep disorders. Future polysomnographic studies in children aged of 3 to 18 years of age should understand the effects of insomnia, hypersomnia, parasomnia, circadian sleep problems and sleep disorder comorbidities on language deficits in order to improve academic achievement. A combination of sleep interventions (depending on sleep disorders) with strategies which promote early language skills (e.g. storytelling during bedtime routine) might optimize language development and in turn, may foster academic achievement in children suffering from sleep disorders.

4.7. Limitations

Given the incidence of sleep disorders and assessment in subjective measures in the general population (Mindell & Meltzer, 2008; Owens, 2008), we chose to select to those for which the sleep quality of the children in the control group were confirmed by polysomnographic recordings. Studies about children aged from 3 to 18 years of age suffering from sleep-related breathing disorders represent the most prevalent data about sleep disorders effects on academic achievement and in various domains of cognitive functioning. Very few studies target children suffering from sleep disorders other than sleep-related breathing disorders confirmed by polysomnographic recordings with reliable neuropsychological tasks and control groups. It is not yet possible to draw up the complete profiles of academic achievement and cognitive impairments in children suffering from sleep disorders. Some studies specifically focused their evaluation on EF without assessing the impact of sleep disorders on other functions such as memory or language.

The high heterogeneity observed in this meta-analysis can be explained by the large number of sleep disorders categories and the use of different cognitive tasks to assess the same cognitive function. Some cognitive domains are measured with standardized psychometric tests (such as general intelligence), whereas other cognitive domains are assessed with a wide variety of cognitive tasks or with no standard psychometric test (such as memory). A large number of studies used sleep duration to understand the impact of sleep disorders on neuropsychological functioning. Since sleep duration is not the only criterion for adequate sleep, it would be interesting to use other sleep disorders criteria.

5. Conclusions

This meta-analysis aimed to synthesize research on the cognitive effects of sleep disorders in children and adolescents, highlighting the need to examine cognitive repercussions across diverse sleep disorder profiles due to significant heterogeneity between studies. Five main findings emerged: (1) marked cognitive difficulties in children with sleep-related breathing disorders, (2) a scarcity of studies on children with insomnia disorders and polysomnographic monitoring of control groups, (3) attention and long-term memory difficulties in children with central hypersomnolence disorders, (4) impairments in verbal, memory, and executive functions in children with neurological or neurodevelopmental sleep disorders, and (5) a limited number of studies examining both cognitive functioning and academic difficulties.

At the individual level, a deeper understanding of how sleep disorders contribute to cognitive and academic challenges is essential for guiding effective assessment and intervention strategies, particularly within schools. As academic-related stress can disrupt sleep patterns, which in turn may impair academic performance (Gomez Fonseca & Genzel, 2020), the management of academic difficulties with sleep should be understand in a bidirectional way. In other words, sleep could alter academic achievement whereas cognitive impairments could induce stress and alter sleep by developing sleep disorders, such as insomnia. This integrated approach emphasizes the need for interdisciplinary collaboration to ensure that children facing these challenges receive comprehensive care, addressing both their sleep and cognitive needs for optimal academic success.

Supplementary Materials

Table S1: Tasks used in the selected studies to measure different domains in cognitive functioning and academic achievement; Figure S1: Forest plot of effect sizes with 95% CI by sleep disorders and cognitive subdomains of general intelligence; Figure S2: Forest plot of effect sizes with 95% CI by sleep disorders and cognitive subdomains of memory; Figure S3: Forest plot of effect sizes with 95% CI by sleep disorder sand cognitive subdomains of attention; Figure S4: Forest plot of effect sizes with 95% CI by sleep disorders and cognitive subdomains of executive functioning; Figure S5: Forest plot of effect sizes with 95% CI by sleep disorders and cognitive subdomains of language; Figure S6: Forest plot of effect sizes with 95% CI by sleep disorders and subdomains of academic performance.

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