



Review Article

A review of developmental consequences of poor sleep in childhood

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ABSTRACT

Sleep is a fairly diverse and complex construct to operationalize in a scientific and naturalistic context. We report a systematic review and meta-analysis of reviews published in the last 5 years on poor sleep and developmental outcomes. Following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines, 42 articles (or 1117 studies) qualified. They reported outcomes related to poor sleep investigated as sleep disorders (38.1%), sleep 'in general' (26.2%), sleep duration (23.8%), in terms of circadian rhythm (4.8%), intra-individual variability (2.4%), and napping (2.4%). Sleep was primarily subjectively reported (30.2%), yet the methodology of sleep assessment was often neither tabulated nor discussed. Overall, most papers had a health-scope, being primarily weight problems expressed as body mass index. Its relationship with performance was measured with the Wechsler intelligence tests, the child behavior checklist and the continuous performance test, whereas meta-analytic papers specifically focused on cognition with sleep disorder (i.e. sleep-disordered breathing; 38.6%), on health (i.e. weight) with sleep duration (25%) and behavior with sleep 'in general' (15.9%), having a high true variance. Nevertheless, an aggregated effect size d of 0.35 (95% confidence interval: 0.27–0.42) suggests that poor sleep is moderately affecting a child's performance and health.

In conclusion, poor sleep can no longer be disregarded, yet methodologies that are more rigorous and a scope beyond health may foster a better understanding of the role of (poor) sleep across childhood neurodevelopment.

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1. Poor sleep

Relative to sleep duration and the effects of sleep disorders, there has been insufficient emphasis on other aspects of sleep adequacy such as circadian alignment and environmental impacts on childhood sleep. The majority of scientific studies appear to focus on sleep duration, while especially in childhood this may be challenging. For example, a cut-off of 10 h sleep for school-aged children creates 'arbitrary' categories, which may not always turn out to be suitable for every child included (Supplementary Fig. S1). Superimposed on the schemes of the guidelines by the National Sleep Foundation [1] and the American Academy of Sleep Medicine [2] (Supplementary Fig. S1) are the meta-analyzed sleep patterns generated by Galland et al. [3]. This shows that the averaged sleep duration of, for instance, school-aged children falls at the lower boundaries of the recommended number of nightly hours across the age ranges, and in particular below such a 10-h cut-off. Notwithstanding, the averaged lower limits of sleep duration – or

the 'reality' in the absence of large-scale objective sleep studies given that subjective reports tend to be overestimations [4] – nearly always fall in the questionable zones across childhood. As a result, should we question the guidelines, the averages (hence reality) or the methodology? Indeed, the cut-offs, and especially sleep recommendations, have been and are heavily discussed [1,2,5,6]. For instance, Matticcianni et al. [7–11] have extensively reported on sleep duration now and in the past. Similarly, consensus statements regarding indicators of good sleep quality (e.g., sleep latency, number of awakenings >5 min, wake after sleep onset, and sleep efficiency) at different ages across the lifespan have been published, and may aid our observation of poor sleep [5].

Given that the sleep-state is a highly dynamic process, which is rapidly developing in the first few years of life, two recent trends towards a better understanding of the role of poor sleep in pediatrics can be noticed. One trend is the focus on daytime sleep behavior in young children. Napping [12] indeed facilitates simple experimental manipulations which appear less intrusive to family life. Yet, it remains challenging to generalize such findings to nighttime sleep due to possible differences in sleep architecture, circadian timing, developmental aspects and ecological validity.

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Another trend is the interest in the microstructure of sleep, and especially its association with cognitive performance (e.g. Refs. [13–17]). Likely, a growing interest in brain mapping, such as by the US BRAIN and the Human Brain Project of the European Union, may further intensify this research topic. As a side-effect, there could be an upsurge of objective sleep studies in typically developing children. This may, in turn, improve our understanding of the role of (poor) sleep across development and underpin the current consensus guidelines.

Consequently, when reflecting upon the concept of poor sleep, we might consider it in terms of sleep quantity, sleep quality and sleep timing (or circadian alignment) with their variability in relation to wake behavior (Supplementary Fig. S2). Alternatively, the wake-state cannot be fully understood without the sleep-state (and vice versa). Better understanding of their reciprocal influence, and especially the impact on subsequent daytime performance, warrants a comprehensive operationalization of sleep. That is, when determining the timing, quantity and quality of sleep, both homeostatic and circadian processes modulated by hypothalamic areas, and biopsychosocial factors, are believed to interact [18–21]. Their dysfunction, perhaps experienced as 'hyper'-somnolence or challenge-seeking wakefulness [22,23] is universally perceived to affect daytime performance. Despite consensus guidelines, and a growing body of scattered findings, many questions regarding the role of (poor) sleep in childhood development are left unanswered.

In pediatric research, we are moreover cognizant of intra- and inter-individual vulnerabilities in development. The interrelation of sleep with such developmental salience has not yet received the scientific attention it deserves; accordingly, our individual sleep needs are potentially overlooked in the conceptualization of poor sleep (Supplementary Fig. S2). Hence, the operationalization of the multidimensional concept of sleep should involve sleep behaviors (e.g., lights out, bedtime, timing of sleep, napping, week versus weekend changes), sleepiness and sleeplessness (i.e. its degree, timing, and duration), dim light melatonin onset, sleep macrostructure and microstructure parameters. Comprehensive assessment may elucidate its role throughout development, while detailed operationalization, and prolonged objective measurement, may support the advancement of novel non-pharmacological treatment models in health sciences, based on manipulating sleep in its entirety.

The purpose of the review is to summarize current knowledge regarding the influence of poor sleep, in its various forms, on childhood development and to identify deficiencies and areas for future exploration. We will focus on reviews and meta-analyses published in the last 5 years.

2. Methods

2.1. Procedure

The searches were performed in PubMed, Web of Science, and Cochrane Library Reviews focusing on literature of the last 5 years and 'reviews/meta-analyses' only. All database searches were updated on 01 June 2018 using the following search terms: "sleep*", "health OR cognition/learning/school performance/intelligence OR behavior OR social/emotional/socio-emotional OR sensorimotor/sensory/motor", and "child" (i.e. neonate – adolescent)* with filters for English language.

The inclusion of the literature was based on systematic reviews and meta-analyses focusing on sleep duration, sleep problems, sleep regularity, circadian rhythm and sleep habits (i.e. potential determinants of poor sleep). These reviews should summarize the association between poor sleep and childhood development. Child development entails the biological and psychological developments in human beings between birth and the end of

adolescence. Studies were excluded if they focused on participants with mental or physical illness, or described interventions/treatments. Letters, original papers and personal opinions were not included. Applying the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines [24], the following steps were undertaken: (1) the title/keywords were assessed, if the article contained information regarding the rationale of our review; (2) the remaining titles/abstracts were screened; and (3) the articles themselves were read for appropriateness; and (4) relevant data was abstracted (see Fig. 1).

2.2. Statistical analysis

Systematic reviews were quantified when possible. Meta-analyses were performed using Comprehensive Meta-Analysis software (version 3.3.070; Biostat, Englewood, NJ, USA).

Meta-analytic results (hereafter abstracted effect sizes (aES)) were re-calculated into one metric (Cohen's d), such that a positive ES indicates adversity. Results reflect relative weight under the random effects model. The value of I^2 , the proportion of the observed variation that is true, ranges from 0% to 100% with 0% indicating no heterogeneity, 25% low heterogeneity, 50% moderate heterogeneity, and 75% high heterogeneity. The prediction interval of I^2 expresses the range of the common (shared) effect (%) by the included studies.

3. Results

3.1. Paper characteristics

Of the 792 references for cognition, behavior, socio-emotional, healthy and sensorimotor development (see Fig. 1), 362 remained for more detailed processing. After reading, 42 were retained for data abstraction (Table 1, Supplementary Tables S1–S3).

These review/meta-analytic papers involved 1117 studies investigating poor sleep and neurodevelopmental outcomes. That is, they reviewed: sleep disorders (38.1%), sleep 'in general' (e.g., sleep quality; 26.2%), sleep duration (23.8%), circadian rhythm (4.8%), intra-individual variability (2.4%) and napping (2.4%). When categorizing the papers on their reported sleep assessment, 30.2% involved subjective measurements of sleep, 22.5% involved objective measurements of sleep (e.g., polysomnography and actigraphy) and in 48.7% of the review/meta-analytic papers, it was not clearly tabulated whether they reported on subjective/objective measures of sleep. Overall, most papers had a health-scope, being primarily weight problems expressed as body mass index (Supplementary Table S2). The relationship between 'poor' sleep and performance was chiefly measured with the Wechsler series, the child behavior checklist and the continuous performance test (Supplementary Table S3).

Overall, a moderate effect (number of aESs = 39, $d = 0.35$, 95% confidence interval (CI): 0.27–0.42; z -value = 9.5, $p < 0.00001$; $I^2 = 97.5$, 95% prediction interval (PI): 0–92%) was found, suggesting that, given the current methodology, poor sleep adversely affected health and performance across childhood. The explained variance by this broad collection of studies was 21.4%. It is noteworthy that, when grouping the aESs, the focus of the papers was shown to be 38.6% on cognition with sleep disorder (i.e. sleep-disordered breathing (SDB)), 25% on health with sleep duration, and for 15.9% on behavior with sleep 'in general'.

3.2. Healthy development

3.2.1. Meta-analysis

The aggregated effect size (d) for 'health' based on nine aESs was 0.28 (95% CI: 0.23–0.34; z -value = 9.8, $p < 0.00001$; $I^2 = 85.4$, 95%

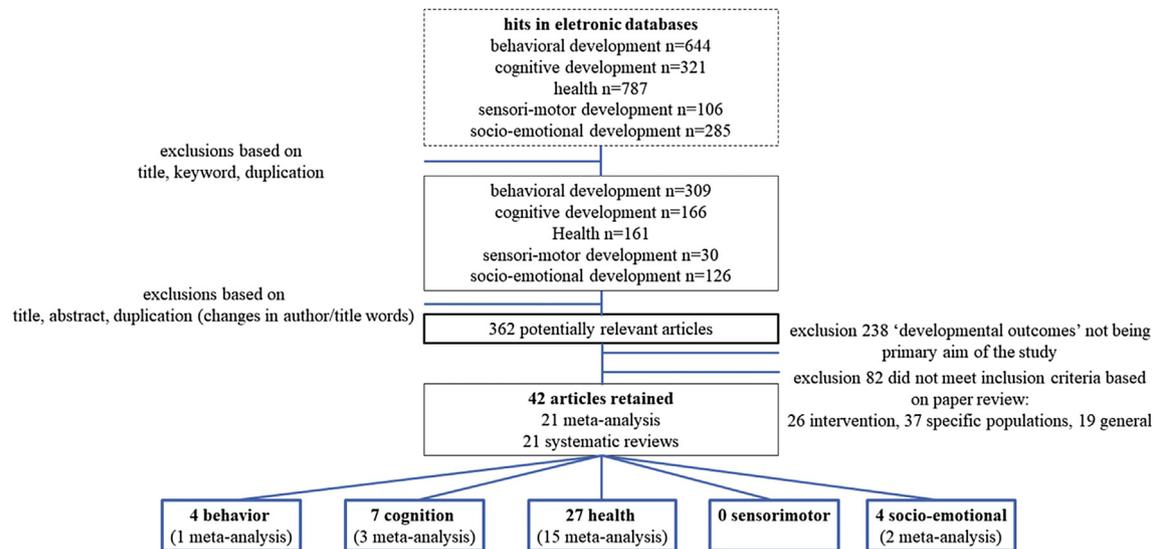


Fig. 1. Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flowchart.

PI: 9.9–45.9%). Two hot-topics could be distinguished: the relationship between sleep duration and obesity [25–31], and the relationship between SDB and performance [32–35]. Moreover, two meta-analyses investigated the association between SDB and obesity/cardiovascular risk [36,37], and another two papers, despite being intervention studies for SDB, reported baseline aES for neuropsychological performance [32,38].

Possibly due to the era, one meta-analysis studied the current evidence towards the association between media-usage with sleep [39].

Meta-analysis of longitudinal studies as well as cross-sectional studies, showed that short sleep duration in children is significantly associated with overweight/obesity [25–27,30]. In fact, with every 1 h/day increment in sleep duration [29], the risk of overweight/obesity was found to reduce by 21%. This was echoed by a recent meta-analysis [31] suggesting a heightened risk ratio especially in middle childhood for short sleep. Others [26] showed that both short sleep duration and poor sleep quality should be considered, and the latter is especially adversative in the youngest. However, when looking at the studies tabulated, the arbitrary cut-offs overlap in their lower and upper boundaries of both the sleep and weight measures, which may blur conclusions. Insufficient data could be abstracted from Quist et al. [28] to be included in our meta-analysis. Yet, their findings support the association between inadequate sleep and health problems, e.g. in terms of abdominal adiposity, insulin sensitivity, blood lipids and blood pressure.

Pooled aESs generated from studies investigating SDB and performance suggest that attention deficit hyperactivity disorder symptoms [34], executive dysfunction measured objectively and subjectively [35], and academic underperformance [33] are related to SDB. Ehsan et al. [36] reported an increased daytime heart rate in children suffering from SDB (not included in the meta-analysis). Although aES statistics were in the small to medium range, treatment [32,38] showed improved functioning in general. However, a meta-regression [37] showed that residual SDB, especially in those with obesity, remains a double-edged sword (not included in the meta-analysis).

Lastly, in terms of unhealthy 'sedentary' behavior, inadequate sleep quantity, poor sleep quality and excessive daytime sleepiness was associated, even when not using the media devices at night [39].

3.2.2. Systematic reviews

Shochat et al. [40] systematically reviewed 30 adolescent studies on general health outcomes (e.g. health promoting, somatic), overweight and obesity, and health conditions (e.g. pain, cardiovascular, headache, abdominal, metabolic syndrome) per primarily self-reports (25 self-reports, five actigraphy, one mother-report, three objective measure unspecified), and concluded that adequate sleep is associated with a positive health outcome.

Overall, five clusters of systematic reviews investigating poor sleep and health can be outlined: (1) sleep duration and obesity, (2) SDB and performance, (3) sleep and physical activity, (4) sleep disorders and performance, and (5) sleep in young children and performance.

Several reviews concluded a lack of consistent evidence regarding the association between poor sleep and lipid profiles in adolescents [41], cognition, harms/injuries, and cardiometabolic biomarkers [42], or other health indicators (e.g., sedentarism and unhealthy dietary patterns) [43,44]. Each of them further highlighted that the underlying explanatory mechanisms between sleep duration and particularly weight issues are still uncertain.

Regarding the underperformance of children with SDB, receptive and expressive language difficulties [45] and intellectual difficulties [46] were reported. In addition, uncertainties exist here; i.e. which function is most affected and is it 'impairment' when performance falls within the normal range.

A more desirable health is reported in youth when studies interrelating exercise and sleep are systematically reviewed [47,48]. Yet, these associations may be influenced by participants' age, health status, and the mode and intensity of physical activity.

When poor sleep is considered in terms of sleep disorders (excluding SDB), several systematic reviews were found on: bruxism [49], narcolepsy [50,51] and restless legs syndrome [52]. It was stated that snoring, mouth breathing, restless sleep, drooling, stomach position during sleep, and lack of sleep are risk factors related to bruxism in children [49]. Whilst frequently identified as being associated with hypersomnolence, have been academic dysfunction and emotionally-based problems, such as anxiety, depression and low self-esteem [50,51]. Findings are further inconsistent regarding intellectual performance of children with narcolepsy, where some studies suggest giftedness yet in dissimilar domains [50,51]. Also,

Table 1
Descriptives of the 42 papers included.

Author	Year	Country	Guideline	Search engines	Years searched	No. of Studies retrieved ^a	No. of studies selected	Systematic review/ meta-analysis
Tonetti et al. [56]	2015	Italy	PRISMA	Scopus Web of Science	Without any restriction	1647	31	Meta-analysis
Lowe et al. [55]	2017	Canada	Cochrane Collaboration	PubMed, Scopus, Web of Science, PsychInfo (EBSCOhost (CINAH), Ovid (Medline, Embase, PsycArticles, PsycInfo), Cochrane, Web of Science, Scopus, Informit Health Database, PubMed	To December 2016	1145	61 (17 pediatric)	Meta-analysis
Short et al. [57]	2018	Australia		PubMed, PsychInfo		21747	19	Meta-analysis
de Bruin et al. [54]	2017	Netherlands		CINAHL, Embase, PsycINFO, PubMed, Scopus	1981–2015	5581	16	Systematic review
Becker et al. [59]	2017	USA	PRISMA	MEDLINE, Embase, Cochrane Library databases	Between 2000 and 2015	1397	52	Systematic review
Tham et al. [53]	2017	Singapore			January 2005 to December 2015	262	10 on cognitive development +20 on growth	Narrative review
Reynaud et al. [60]	2017	France	Cochrane Handbook, PRISMA	Medline, Web of Science, PsycINFO and ERIC	Up to 30 April 2016	3291	26	Systematic review
Shochat et al. [40]	2014	Israel		PubMed and PsycNET (PsycARTICLES PsycINFO)	Up to December 2012	898	76	Systematic review
Minges et al. [58]	2016	USA	PRISMA	Ovid Embase, Ovid MEDLINE, Ovid PsycINFO, Web of Science, Global Health, CINAHL		1029	Six studies: pre-post, no control (n = 3), randomized controlled trial (n = 2), and quasi-experimental (n = 1) designs	Systematic review
Bowers et al. [64]	2017	USA		PsycINFO, PubMed, Scopus, ProQuest	In September 2016 and updated in March 2017	163	20	Meta-analysis
Guo et al. [49]	2017	China	PRISMA, Cochrane Handbook for Systematic Reviews of Interventions	PubMed, Excerpta Medica Database (Embase), Cochrane Library database, Web of Science, Chinese National Knowledge Infrastructure (CNKI), Chinese Biomedical Literature Database (CBM), Wanfang Data (WF)	Last search updated on 15 September 2016; no restriction on language or publication years	5637	14	Systematic review
Beris et al. [50]	2018	Australia		MEDLINE and Embase databases	From 1960 through June 2017	212	20	Systematic reviews
Augustinavicius et al. [17]	2014	Canada	Meta-analysis of Observational Studies in Epidemiology guidelines	MEDLINE, PSYCINFO, Embase, PubMed	Up to 1 March 2013	953	24	Meta-analysis
Van Geel et al. [61]	2016	Netherlands		PsycINFO, MEDLINE, ERIC, Embase, LILACS		212	21	Meta-analysis
Schlarb et al. [62]	2014	Germany	PRISMA	MEDLINE, Web of Science, EBSCO, Ovid, PubMed, Google Scholar, PsycINDEX		1497	13 (9 children)	Systematic review
de Luca Canto et al. [63]	2014	Brazil	PRISMA	Cochrane, Embase, MEDLINE, PubMed, Virtual Health Library (BVS –Database that include articles in Spanish and Portuguese from MEDLINE, LILACS, Wholis, BBO and AdoLec)	In the past 5 years; End search date was 6 June 2014 across all databases	1012	7	Systematic review
Fatima et al. [25]	2015	Australia		MEDLINE, Embase, PubMed, CINAHL	Until May 2014	2070	11 for meta-analysis and 22 for systematic review	Meta-analysis
Ruan et al. [29]	2015	China	MOOSE	PubMed, Embase, Google Scholar	Through May 2015	168	25 (32 independent cohorts)	Meta-analysis
Fatima et al. [26]	2016	Australia	MOOSE Meta-analysis statement for reporting systematic reviews and meta-analysis	PubMed, Embase, and MEDLINE	Published until November 2015	1761	18 (of which 9 in meta-analysis)	Meta-analysis
Li et al. [27]	2017	USA		PubMed, Embase and the Cochrane Library	Up to April 2015	1733	12	Meta-analysis
Quist et al. [28]	2016	Denmark		PubMed	Until 10 August 2015	75	75	Meta-analysis
Wu et al. [30]	2017	China		Medline, Cochrane Library, Embase and Science Citation Index databases	From January 1980 through January 2015	5110	13	Meta-analysis
Miller et al. [31]	2018	UK		PubMed, Embase, Web of Science, Cochrane	Up to 25 September 2017	2569	42 (20 for overweight/obesity, 14 for BMI z-score, and 16 for BMI).	Meta-analysis

Sedky et al. [34]	2014	USA		PubMed/Medline, PsychInfo and Cochrane databases, Google Scholar	Through September 2012	48	20	Meta-analysis
Galland et al. [33]	2015	New Zealand	PRISMA	PubMed, Web of Science, CINAHL, PsycINFO	Up to 1 March 2015	488	16	Meta-analysis
Mietchen et al. [35]	2016	USA	PRISMA	PsychInfo, PubMed, hand search, Web of Science.	Up through December 2015	1717	14	Meta-analysis
Song et al. [32]	2016	USA	PRISMA	PubMed/MEDLINE, Scopus, Web of Science, Cochrane Library	Inception through 2 September 2015	206	19	Meta-analysis
Yu et al. [38]	2017	China		PubMed, Embase and Cochrane library		621	11	Meta-analysis
Lee et al. [37]	2016	Taiwan	PRISMA Meta-analysis of Observational Studies in Epidemiology group.	PubMed, MEDLINE, Embase, Cochrane Review	January 1997 to July 2014	1103	51	Meta-analysis
Ehsan et al. [36]	2017	USA	PRISMA	PubMed, CINAHL, Embase, Scopus	All indexed years	1701	25	Meta-analysis
Carter et al. [39]	2017	USA	PRISMA	British Education Index, NAHL, Cochrane Library, ERIC, International Biography of Social Sciences, Medline via Ovid (Embase, Medline, Psych INFO); PubMed, Science Direct, Scopus, Web of Science	From 1 January 2011 to 15 June 2015	467	11	Meta-analysis
de Azevedo Abreu et al. [41]	2015	Brazil	PRISMA	Medline via PubMed, LILACS, Web of Science, Scopus, Adolec	August 2014	859	7	Systematic review
Chaput et al. [42]	2016	Canada	PRISMA	Ovid interface: MEDLINE (1946 to January 19, 2015), Embase (1980–2015 week 3), PsycINFO (1906–2015 week 3), and CINAHL (1961–2015 week 3)		5825	141	Systematic review
Chaput et al. [43]	2017	USA	PRISMA	MEDLINE, Embase, PsycINFO and the Cochrane Central Register of Controlled Trials (CENTRAL)	No limits	1385	69	Systematic review
Felso et al. [44]	2017	Hungary		Ovid MEDLINE, Scopus and Cochrane Central Register of Controlled Trials (CENTRAL) databases	From inception until March 2016	3540	33	Systematic review
de Castro Corrêa [45]	2017	Brazil		LILACS, PubMed, Scopus, and Web of Science	2004 to 2014	122	6	Systematic review
da Silva Gusmao Cardoso et al. [46]	2018	Brazil		MEDLINE/PubMed, LILACS, SciELO, ISI Web of Science, PsycINFO	From 2002 to 2016	649	34	Systematic review
Saunders et al. [47]	2016	Canada		MEDLINE, Embase, SPORTdiscus, CINAHL, PsycINFO	Published in 2008 or later	489	14	Systematic review
Dolezal et al. [48]	2017	USA	PRISMA	PubMed and Google Scholar	Between January 2013 and March 2017	2122	34	Systematic review (including meta-analyses and individual studies)
Blackwell et al. [51]	2017	UK	PRISMA	The Cochrane Library, Embase Ovid, MEDLINE PsycINFO	Between 2005 and 2015; on 28 August 2015	710	8	Systematic review
Angriman et al. [52]	2017	Italy	PRISMA	PubMed, Ovid (including PsycINFO, Ovid MEDLINE®, and Embase), Web of Knowledge (Web of Science, Biological abstracts, BIOSIS, FSTA)	November 2015	1185	42 (33 tabulated)	Systematic review
Thorpe et al. [12]	2015	Australia	PRISMA	MEDLINE (via Ebscohost), PsycINFO (via Ebscohost), CINAHL (via Ebscohost), Web of Science, Scopus, ERIC (via Ebscohost).		781	26	Systematic review

BMI, body mass index; MOOSE, Meta-analysis Of Observational Studies in Epidemiology; PRISMA, Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines.

^a Some counts might still include duplicates.

restless legs syndrome in children is associated with a number of somatic and neuropsychiatric conditions [52].

Notably due to being primarily ‘caregiver report’ studies and potential multilayered relationships (e.g. attention and concentration problems, or executive dysfunction leading to school difficulties), the question remains whether their dysfunctioning is a (co)morbidity or (co)occurrence.

Inconsistent evidence similarly exists regarding (habitual) napping in infants possibly benefiting cognition, behavior and health. The latter is hypothetically due to the focus being largely on weight gain and obesity rather than healthy growth [12,53]. Alternatively, it is suggested that beyond the age of 2 years, napping influences subsequent sleep macrostructure.

3.3. Cognitive development

Around the same period, two reviews [54,55] focused on sleep manipulation, and in particular sleep restriction (Table 1), while only three meta-analyses relating poor sleep to cognitive performance have been published. Tonetti et al. [56] focused on circadian preference (eveningness), Lowe et al. [55] reported human and animal sleep restriction findings, and Short et al. [57] investigated objectively measured sleep duration. Whereas others systematically reviewed, e.g., school start times [58], intra-individual variability in sleep–wake patterns [59], or sleep parameters in preschoolers [60] and infants [53] (Table 1, Supplementary Tables S2, S3).

3.3.1. Meta-analyses

The *d* for ‘cognition’ based on 19 aES was 0.35 (95% CI: 0.21–0.49; *z*-value = 5.0, *p* < 0.00001; *I*² = 98.6, 95% PI: 0–99.8%). Tonetti et al. [56] concluded that evening orientation is associated with worse academic performance, more so in younger students than in university students. Note, these findings were generated primarily from subjective measures (Supplementary Table S2). Lowe et al. [55] included 17 pediatric studies in addition to adult and animal studies, and reported that overall sleep restriction was associated with cognitive underperformance. Interestingly, they indicated that cumulative days of sleep restriction may increase this negative impact of poor sleep, with the predicted effect sizes inflating from moderate to high. Recalculating across the pediatric studies, the frequency of domains and tests applied, showed a preponderance of attention/executive function investigations (Supplementary Tables S2, S3) with the majority being in 15-year-olds. That is to say, all subdomains were adversely affected by sleep restriction (i.e., especially inhibition, reaction time and accuracy). More recently, Short et al. [57], including 19 studies within the age range of 6- to 13-year-olds, concluded a medium meta-correlation only for the relationship between objective sleep duration and full intelligence quotient (IQ)/verbal IQ. No significant meta-association could be reported for fluid IQ, memory, executive function, processing speed and attention when reviewing 10 cross-sectional studies and nine experimental studies, which primarily used actigraphy. The authors additionally showed that the baseline sleep duration of only four observational studies fell into the recommended 9–11 h sleep duration guideline by the National Sleep Foundation [1] and the American Academy of Sleep Medicine [2]. All of the lower boundaries from the observational studies fell well below this 9-h cut-off. While only five of the experimental studies had a baseline at or slightly above this 9-h cut-off. Furthermore, none of the long sleep durations or sleep extensions surpassed even a 10-h cut-off.

3.3.2. Systematic reviews

de Bruin et al. [54], reporting only pediatric studies (substantial overlap with Lowe et al. [55]), reviewed sleep restriction and extension outcomes in adolescents. When quantifying their review,

the number of nights with sleep manipulation ranged from 1 to 10 (including studies investigating napping) and involved manipulations ranging from ‘no sleep’ to ‘± 1-h shifts’ (including also +5-min shifts and napping shifts). Fifty percent of the studies were performed in a lab setting (39% at home and 11% a combination thereof). In terms of sleep manipulation, 59% applied sleep restriction whilst 17% applied sleep deprivation, 6% sleep extension, 6% a combination and 12% other (e.g., napping). Actigraphy was the most commonly used tool (50% of the studies), followed by polysomnography (28%), sleep log (11%), and a combination thereof (11%). Supplementary Fig. S3 representing a quantification of this systematic review shows that all domains of cognitive functioning are affected by sleep manipulations. That is to say, sleep restriction primarily affected: for the attention domain, the psychomotor vigilances; for working memory, the phonological working memory processes; for learning memory, the learning processes; for memory consolidation, the memory delayed recall functions; for creative/abstract thinking domain, the higher abstract thinking functions. Similarly for sleep extension designs, affected: for attention domain are psychomotor vigilances and sustained attention processes; for working memory are phonological working memory processes; for learning memory domain are learning, memory delayed recall, memory immediate recall and phonological working memory; for executive function domain are cognitive flexibility. Briefly, many functions benefit from sleep extension. In the 17 cognitive studies reviewed by Shochat et al. [40] based on primarily self-reports by adolescents, similar findings have been suggested. On the contrary, methodological flaws in the experimental designs prevent more firm conclusions. In Supplementary Table S4, we summarize potential study weaknesses specific to experimental designs investigating sleep manipulations.

A systematic review of non-experimental sleep manipulation studies, such as by delayed school start times [58], indicated reduced daytime sleepiness, depression, caffeine use, tardiness to class, and trouble staying awake.

Becker et al. [59] reported inconsistent results when investigating primarily the impact of intra-individual sleep variability. That is, differences exist in the domain affected (e.g., verbal, visuo-constructive/spatial abilities, intellectual functioning, sustained attention, P3 latencies) and in relation to the time of day with respect to the performance. Whereas the only study investigating school grades showed no association. Interestingly, the authors consider the intra-individual variability in sleep/wake patterns as characteristic of child and adolescent sleep. Such a perspective may partially explain the contradicting conclusions [12,53] regarding the truly beneficial role of sleep in the development of young children. That is, higher nighttime sleep proportions, and to a lesser extent also better sleep efficiency in infancy [53], was associated with improved executive functioning, reasoning, problem-solving skills; whereas performance after napping was reported to be improved (e.g., abstraction of grammatical relations, memory consolidation). Few objective sleep studies in preschoolers [60] were found, though especially nighttime sleep duration associated positively with chiefly receptive vocabulary. Yet, others [12] are more critical towards the applied methodologies in these studies.

Hence, a clear need for more systematic studies using stronger designs can be inferred.

3.4. Sensorimotor development

No reviews or meta-analyses were found.

3.5. Socio-emotional development

Because socio-emotional and behavioral development show significant overlap in applied tools, for instance as in the child

behavior checklist, we consequently meta-analyzed their aESs together. Their d based on 11 aESs was 0.38 (95% CI: 0.28–0.49; z -value = 7.3, $p < 0.00001$; $I^2 = 86.9\%$, 95% PI: 0.8–75.1%).

3.5.1. Meta-analysis

Only Augustinavicius et al. [17] meta-analyzed polysomnographic features. For early-onset depression, they reported that the most robust finding was the longer sleep onset latency in childhood. Their results are furthermore in equivalence with sleep ontogeny, showing that age was a significant predictor of sleep micro-architecture. That is, reporting weak associations in early childhood but specifically for early depression-onset, a tendency for poorer coherence between beta/delta/theta across the hemispheres in this population. A more on-trend topic, and potentially not unrelated, is meta-analyzed by van Geel et al. [61], showing a medium association between victimization and sleeping problems.

3.5.2. Systematic reviews

More aggression and antisocial behaviors in evening types across childhood were systematically put forward by Schlarb et al. [62]. Whereas poor sleep perceived as a sleep disorder such as bruxism was significantly associated with psychosocial factors (e.g., emotional stress, higher arousal index, and chiefly externalizing behavioral problems) in children older than 6 years [63]. Shochat et al. [40], focusing on adolescents, demonstrated the association between (primarily self-reported) poor sleep (six sleep duration, seven sleep problems, one tiredness, six insomnia, two sleep patterns, one sleep quality, one bedtime, one sleepiness, one sleep need) and a plethora of psychosocial health outcomes. Again, weak associations were concluded, but they remain suggestive of poorer psychosocial functioning such as in terms of anxiety, low self-esteem, depression, conduct problems or an adversely affected mental health status.

Becker et al. [59] reported mixed findings when describing the association between intra-individual sleep variability and emotional functioning, such as anxiety, depression, social problems, and behavioral reactivity. Of potential importance in these relationships are familial, cultural and environmental factors that may 'cause', 'moderate', 'modulate' or overall 'confound' our understanding of the true impact of poor sleep on socio-emotional functioning. Yet, glancing at the tabulated correlations, beta's, means or proportions, only small to moderate relationships have been revealed. Although Reynaud et al. [60] did not tabulate the size of the associations, when quantifying their review: (1) for externalizing behavior (aggressiveness, anger, attention problems, conduct problems, hyperactivity, impulsivity, opposition, and non-specific externalizing behaviors), 11 inverse associations were found with nighttime sleep duration, and positive associations for (2×) insomnia, (10×) nightwakenings, (4×) sleep onset latency, (8×) sleep period, (3×) bedtime, (1×) wake-up time but none with total sleep time and sleep efficiency; (2) for internalizing problems: one inverse association was found with total and nighttime sleep duration, and positive associations for (6×) nightwakenings, (2×) sleep onset latency, (3×) sleep period, (2×) bedtime. Sociability gave another associative profile, with mixed results for night wakenings, sleep onset latency, sleep period and wake-up time, and one negative association with bedtime.

3.6. Behavioral development

3.6.1. Systematic reviews and one meta-analysis

In the literature, systematic reviews have been primarily carried out for behavioral performance. Our following list of potential (and maybe overlooked) risk behaviors is food for thought. Shochat et al. [40] systematically reviewed 23 studies reporting risk behaviors

(23 self-reports and two interviews) in 10- to 19-year-olds in association with sleep (10 sleep duration, four insomnia, eight sleep problems, seven sleep patterns, one sleep quality, one sleepiness, one tiredness). Under risk behaviors fall: smoking, drinking and driving, safety violations, delinquency, violence, suicide, illicit drug use, sexual activities, truancy, unintentional injuries, aggressive behavior. The authors ascribed the weaker relationships found in literature to the (co)occurrence/morbidity of emotional status, psychosocial functioning and adolescent-like life events.

Potentially due to such adolescent developmental salience, two studies addressed the school starting time debate in this age-range. A systematic review of delayed school start times, such as by 25–60 min, corresponded to a total sleep time increase of approximately 1 h [58] with concomitant reports of improved behavior (see Section 3.3) [58,64].

In preschoolers, non-specific behavior problems showed, albeit small but positive associations with nightwaking, sleep onset latency, sleep period, and to lesser extent, bedtime and wake-up time, and an inverse association with total sleep duration [60]. Moreover, intra-variability of sleep across childhood was related to poorer adjustment and greater risky behaviors [59].

3.7. A posteriori meta-analysis by sleep categorizations

When the aESs were categorized in terms of sleep, we found an overall moderate impact. The aggregated d based on 18 aES for sleep disorder were 0.39 (95% CI: 0.24–0.54; z -value = 5.0, $p < 0.00001$; $I^2 = 98.2\%$, 95% CI: 0–100%), for sleep duration were 0.29 (11 aESs, 95% CI: 0.24–0.35; z -value = 10.7, $p < 0.00001$; $I^2 = 85.4\%$, 95% PI: 10.6–47.8%), for sleep 'in general' were 0.31 (10 aESs, 95% CI: 0.21–0.41; z -value = 5.8, $p < 0.00001$; $I^2 = 93.1\%$, 95% PI: 0–67%).

4. Discussion

Based on 42 literature reviews (or 1117 studies) published during the past 5 years, we may conclude that poor sleep is moderately affecting performance and health during childhood. Although more designs that are rigorous are needed, several main conclusions can be drawn based on the current available data. First, the impact of poor sleep can no longer be disregarded, neither by science nor society as quantified by our meta-analyses. Second, a vast amount of knowledge is generated by subjective measures, in particular of sleep. Third, the scientific literature is dominated by a health-scope. Consequently, insufficient understanding of the role of sleep particularly in childhood neurodevelopment (beyond health) can be inferred. To date, findings with respect to child neurodevelopment remain scattered, mixed and heterogeneous. This meta-analytic review therefore demonstrates a clear need for robust methodologies and replication studies, as well as naturalistic data collection.

4.1. Healthy development

A big boom in studies investigating sleep in relation to weight have been noticed in the past years [65–68]. Without going into much detail, mostly negative linear associations have been proposed with short sleep [69,70]; that is, with a lesser amount of sleep more likely being associated with be(com)ing overweight to obese. However, a large proportion of 'short' sleepers are not obese, and as a large proportion of 'long' sleepers are obese [71]. Studies have also controlled for a multitude of diverse confounders and covariates (e.g., parental weight, gender, sedentary lifestyle), and not in the least studies varied in the operationalization of weight and sleep, i.e. the cut-offs and measures [65]. Therefore, this meta-

analytic review demonstrates that sleep is associated with weight, in spite of the ongoing discussion regarding the type of relationship and the 'best' methodology.

When we broaden our health scope, we may touch upon the literature with regard to SDB in particular. Whilst relationships between SDB, weight problems and cognitive abilities in pairs have been well-documented in the literature [40,72,73], the obesity epidemic gave rise to a more intricate discussion. Spruyt et al. [65,74,75] showed that each might play a (mediator) role, and therefore the need for a more holistic perspective when investigating a health problem in childhood arises. Also, this meta-analytic review showed the role of poor sleep towards unhealthy development with a probable upcoming epidemic in childhood: sedentarism. Nevertheless, studies need to keep in mind the directionality of relationships. Co-morbidities and/or co-occurrences were similarly not clear in reviewed sleep disorders such as bruxism, narcolepsy and restless legs syndrome.

4.2. Cognitive development

A keen interest in cognition was seen given that seven reviews, of which three were meta-analyses, have been published in the last 5 years. Findings concur with several older reviews on the association between primarily sleep duration and cognitive performance across childhood. For instance, Astill et al. [76] reported weak but significant meta-correlations for cognition, executive function, multiple-domain cognition and school performance with sleep duration. The authors failed to find a meta-association between sleep duration and sustained attention, explicit and implicit memory as well as intelligence upon investigating 86 studies within the age range of 5–12 years. The authors could neither conclude a meta-association with sleep efficiency, nor was the performance linked to an optimal sleep duration. Dewald et al. [77] is the only one who reported a small effect size with sleepiness. Despite the small effect sizes, and largely inconsistent findings, our findings equally suggest that during childhood the role of sleep in cognitive development cannot be ignored. In particular, executive functioning, reasoning and problem-solving abilities appear to be sensitive to poor sleep.

It remains a critical note that reported associations in the scientific literature have been vastly generated from 'baseline sleep' [57] that repeatedly falls under the recommended sleep durations [1,2], or depends on sleep ranges that do not overlap with guidelines [1,2]. This should be a critical reflection when designing sleep manipulation studies. Furthermore, given the reported weaknesses in current experimental designs, which primarily focus on attention and/or executive function, the interrelation of the sleep–wake state and the multidimensionality of the concept 'sleep' should not be ignored. Of course, a publication bias can be expected. Hence, an attitude towards a more comprehensive investigation of sleep in its entirety is advocated.

4.3. Sensorimotor development

Copes et al. [78] reported as early as 1972 that sleep deprivation has an impact upon motor performance in children. For the sensorimotor domain, the publication by Walker et al. [79] in young adults has likely been pivotal, popularly concluding that practice with sleep makes perfect when subjects were tested on a sequential finger-tapping task. In addition, his study indicated the importance of the amount of stage N2. Yet, we need to remain critical that this is a motor skill 'learning' task. More recently, studies focusing on the sensorimotor development across childhood have been noticed. For instance, one [80] showed that when children had the opportunity to nap, they exhibited more efficient

problem solving in a motor task; i.e. returning to walking after crawling through a tunnel for newly walking infants. Or briefly, a study [81] while unable to demonstrate any circadian association with motor skill acquisition, emphasized that especially the youngest group benefited the most from any sleeping opportunity (i.e. nap, nighttime sleep).

In developmental psychology, it is further well-acknowledged that sensorimotor development is critical in fostering the abilities to explore and to interact with the environment. Optimal integration of sensory information with coordinated motor movements gives rise to fundamental milestones, important for other developmental domains (e.g., socio-emotional).

4.4. Socio-emotional development

High odds ratios for socio-emotional problems given poor sleep in infancy have been reported [82], despite the small number of subjects falling in the clinical range (4.6%). Key players were sleeping less than 11 h, were experiencing more than 3 awakenings, a sleep onset latency of more than 30 min and a parental report of problematic sleeping. The systematic reviews reported in this paper testify this challenge in operationalizing poor sleep, and hence an inconsistency in this developmental association is concluded. Alternatively, few objective measurements of socio-emotional functioning have been applied.

Regarding socio-emotional development, we furthermore showed the importance of reflecting on results from a sleep–wake perspective. Previously we found that, in agreement with the eye-tracking literature, preferences for pleasant stimuli or happy faces and in particular preference for the eye area by infants [83]. Upon including sleep parameters, findings showed that infants that had more sleep and less intra-daily variability as a (circadian) parameter had significantly better processing of the unpleasant stimuli and, to the same extent, of the neutral stimuli. But studies do not always need to be 'high tech', as shown by Sano et al. [84]. When repeatedly asking via visual analog scales the mood of college students, they showed that sleep regularity is a more important discriminator in predicting mood. Similar results have been confirmed based on facial muscle movement [85] or another study showing that a strong association between performance (decision-making) and self-regulation is moderated by sleep (baseline versus no napping conditions) [86]. In addition, we showed that the chronicity of poor sleep is another important determinant for socio-emotional signs to become of clinical significance [87]. Henceforward, a more comprehensive operationalization of the concept of (poor) sleep may expose the inconsistencies reported in literature.

The only meta-analysis of polysomnographic features in early-childhood-onset depression similarly denoted the challenge in operationalizing poor sleep and the importance of investigating the interrelation of sleep with developmentally salient characteristics. For instance, topographic differences in the two processes of sleep regulation (i.e. homeostatic and circadian) may elucidate neurodevelopmental vulnerabilities [21].

4.5. Behavioral development

Previously, we showed clearly the hand-in-hand association between the socio-emotional and behavioral performance with sleep, and the importance of investigating associations in terms of changes within the individual; i.e. individual sleep needs [87]. More specifically, sleeping more in the short term, but showing decreasing sleep duration in the longer term, was associated with clinically significant negative changes in adaptive skills. However, a continued decrease in sleep was associated with more behaviors

warranting professional help. Per Shochat et al. [40], adolescents show risky behaviors and psychosocial problems, in particular with inadequate sleep durations. Shifts in school start times concur with improved 'behavior' per the systematic reviews included in this paper. Another supportive conclusion of this adverse association is based on the systematic review of intra-variability of sleep across childhood.

Thus, for socio-emotional and behavioral development, we can infer that poor sleep can negatively influence emotion/behavior at various stages of the regulatory process, being identification, selection and implementation of strategies, potentially leading to poor social interaction.

Lastly, whichever way we group the aESSs, a moderate association between poor sleep and performance and health remains. This is suggestive of a robust association despite the current methodologies reported in scientific literature.

5. Conclusion

This meta-review highlights moderate and diverse associations between poor sleep and neurodevelopment of a child. First, it shows that current associations are based on few sleep manipulation studies, which fall on the extreme lower end of recommended hours of sleep during childhood. In addition, while the habitual sleep duration studies may suggest a slightly larger association, the reported sleep durations remain at the floor levels or lower levels of the guidelines. Second, very few studies conceptualized sleep in its entirety. Not only the circadian (mis)alignment, but especially the 'forbidden zone'/time on task effect on performance has been consistently ignored when linking sleep to daytime performance across childhood. Lastly, sleep fluctuations in childhood might be a biological need and/or ecological opportunity, which necessitates a more comprehensive investigation of sleep to further improve our scientific and clinical work.

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Conflict of interest

The authors have no conflicts of interest to disclose.

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References

- [1] Hirshkowitz M, Whitton K, Albert SM, et al. National Sleep Foundation's updated sleep duration recommendations: final report. *Sleep Health* 2015;1(4):233–43.
- [2] Paruthi S, Brooks LJ, D'Ambrosio C, et al. Consensus statement of the American Academy of sleep medicine on the recommended amount of sleep for healthy children: methodology and discussion. *J Clin Sleep Med* 2016;12(11):1549–61.
- [3] Galland BC, Taylor BJ, Elder DE, et al. Normal sleep patterns in infants and children: a systematic review of observational studies. *Sleep Med Rev* 2012;16(3):213–22.
- [4] Dayyat EA, Spruyt K, Molfese DL, et al. Sleep estimates in children: parental versus actigraphic assessments. *Nat Sci Sleep* 2011;3:115–23.
- [5] Ohayon M, Wickwire EM, Hirshkowitz M, et al. National Sleep Foundation's sleep quality recommendations: first report. *Sleep Health* 2017;3(1):6–19.
- [6] Pelayo R. Commentary on national sleep foundation sleep quality recommendations. *Sleep Health* 2017;3(1):20–1.
- [7] Matricciani L, Olds T, Petkov J. In search of lost sleep: secular trends in the sleep time of school-aged children and adolescents. *Sleep Med Rev* 2012;16(3):20311.
- [8] Matricciani L, Blunden S, Rigney G, et al. Children's sleep needs: is there sufficient evidence to recommend optimal sleep for children? *Sleep* 2013;36(4):527–34.
- [9] Matricciani L, Olds T, Williams M. A review of evidence for the claim that children are sleeping less than in the past. *Sleep* 2011;34(5):651–9.
- [10] Matricciani LA, Olds TS, Blunden S, et al. Never enough sleep: a brief history of sleep recommendations for children. *Pediatrics* 2012;129(3):548–56.
- [11] Matricciani L. Subjective reports of children's sleep duration: does the question matter? A literature review. *Sleep Med* 2013;14(4):303–11.
- [12] Thorpe K, Staton S, Sawyer E, et al. Napping, development and health from 0 to 5 years: a systematic review. *Arch Dis Child* 2015;100(7):615–22.
- [13] McDevitt EA, Alaynick WA, Mednick SC. The effect of nap frequency on daytime sleep architecture. *Physiol Behav* 2012;107(1):40–4.
- [14] Hoedlmoser K, Heib DP, Roell J, et al. Slow sleep spindle activity, declarative memory, and general cognitive abilities in children. *Sleep* 2014;37(9):1501–12.
- [15] Bruni O, Novelli L, Miano S, et al. Cyclic alternating pattern: a window into pediatric sleep. *Sleep Med* 2010;11(7):628–36.
- [16] Kurth S, Riedner BA, Dean DC, et al. Traveling slow oscillations during sleep: a marker of brain connectivity in childhood. *Sleep* 2017;40(9):zsx121.
- [17] Augustinavicius JL, Zanjani A, Zakzakis KK, et al. Polysomnographic features of early-onset depression: a meta-analysis. *J Affect Disord* 2014;158:11–8.
- [18] Borbely AA. The S-deficiency hypothesis of depression and the two-process model of sleep regulation. *Pharmacopsychiatry* 1987;20(1):23–9.
- [19] Borbely AA. A two process model of sleep regulation. *Hum Neurobiol* 1982;1(3):195–204.
- [20] Achermann P. The two-process model of sleep regulation revisited. *Aviat Space Environ Med* 2004;75(3 Suppl):A37–43.
- [21] Borbely AA, Daan S, Wirz-Justice A, et al. The two-process model of sleep regulation: a reappraisal. *J Sleep Res* 2016;25(2):131–43.
- [22] Horne J. Sleepiness as a need for sleep: when is enough, enough? *Neurosci Biobehav Rev* 2010;34(1):108–18.
- [23] Horne J. The end of sleep: 'sleep debt' versus biological adaptation of human sleep to waking needs. *Biol Psychol* 2011;87(1):1–14.
- [24] Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA Statement. *Open Med* 2009;3(3):e123–30.
- [25] Fatima Y, Doi SA, Mamun AA. Longitudinal impact of sleep on overweight and obesity in children and adolescents: a systematic review and bias-adjusted meta-analysis. *Obes Rev* 2015;16(2):137–49.
- [26] Fatima Y, Doi SA, Mamun AA. Sleep quality and obesity in young subjects: a meta-analysis. *Obes Rev* 2016;17(11):1154–66.
- [27] Li L, Zhang S, Huang Y, et al. Sleep duration and obesity in children: a systematic review and meta-analysis of prospective cohort studies. *J Paediatr Child Health* 2017;53(4):378–85.
- [28] Quist JS, Sjodin A, Chaput JP, et al. Sleep and cardiometabolic risk in children and adolescents. *Sleep Med Rev* 2016;29:76–100.
- [29] Ruan H, Xun P, Cai W, et al. Habitual sleep duration and risk of childhood obesity: systematic review and dose–response meta-analysis of prospective cohort studies. *Sci Rep* 2015;5:16160.
- [30] Wu Y, Gong Q, Zou Z, et al. Short sleep duration and obesity among children: a systematic review and meta-analysis of prospective studies. *Obes Res Clin Pract* 2017;11(2):140–50.
- [31] Miller MA, Krusbrink M, Wallace J, et al. Sleep duration and incidence of obesity in infants, children, and adolescents: a systematic review and meta-analysis of prospective studies. *Sleep* 2018;41(4):zsy018.
- [32] Song SA, Tolisano AM, Cable BB, et al. Neurocognitive outcomes after pediatric adenotonsillectomy for obstructive sleep apnea: a systematic review and meta-analysis. *Int J Pediatr Otorhinolaryngol* 2016;83(4):205–10.
- [33] Galland B, Spruyt K, Dawes P, et al. Sleep disordered breathing and academic performance: a meta-analysis. *Pediatrics* 2015;136(4):E934–46.
- [34] Sedky K, Bennett DS, Carvalho KS. Attention deficit hyperactivity disorder and sleep disordered breathing in pediatric populations: a meta-analysis. *Sleep Med Rev* 2014;18(4):349–56.
- [35] Mietchen JJ, Bennett DP, Huff T, et al. Executive function in pediatric sleep-disordered breathing: a meta-analysis. *J Int Neuropsychol Soc* 2016;22(8):839–50.
- [36] Ehsan Z, Ishman SL, Kimball TR, et al. Longitudinal cardiovascular outcomes of sleep disordered breathing in children: a meta-analysis and systematic review. *Sleep* 2017;40(3):zsx015.
- [37] Lee CH, Hsu WC, Chang WH, et al. Polysomnographic findings after adenotonsillectomy for obstructive sleep apnoea in obese and non-obese children: a systematic review and meta-analysis. *Clin Otolaryngol* 2016;41(5):498–510.
- [38] Yu Y, Chen YX, Liu L, et al. Neuropsychological functioning after adenotonsillectomy in children with obstructive sleep apnea: a meta-analysis. *J Huazhong Univ Sci Technolog Med Sci* 2017;37(3):453–61.
- [39] Carter B, Rees P, Hale L, et al. Association between portable screen-based media device access or use and sleep outcomes: a systematic review and meta-analysis. *JAMA Pediatr* 2016;170(12):1202–8.
- [40] Shochat T, Cohen-Zion M, Tzischinsky O. Functional consequences of inadequate sleep in adolescents: a systematic review. *Sleep Med Rev* 2014;18(1):75–87.
- [41] Abreu GdA, Barufaldi LA, Bloch KV, et al. A systematic review on sleep duration and dyslipidemia in adolescents: understanding inconsistencies. *Arq Cardiol* 2015;105(4):418–25.

- [42] Chaput JP, Gray CE, Poitras VJ, et al. Systematic review of the relationships between sleep duration and health indicators in school-aged children and youth. *Appl Physiol Nutr Metab* 2016;41(6 Suppl 3):S266–82.
- [43] Chaput JP, Gray CE, Poitras VJ, et al. Systematic review of the relationships between sleep duration and health indicators in the early years (0–4 years). *BMC Public Health* 2017;17(Suppl 5):855.
- [44] Felso R, Lohner S, Hollody K, et al. Relationship between sleep duration and childhood obesity: systematic review including the potential underlying mechanisms. *Nutr Metab Cardiovasc Dis* 2017;27(9):751–61.
- [45] Correa CC, Cavalheiro MG, Maximino LP, et al. Obstructive sleep apnea and oral language disorders. *Braz J Otorhinolaryngol* 2017;83(1):98–104.
- [46] da Silva Gusmao Cardoso T, Pompeia S, Miranda MC. Cognitive and behavioral effects of obstructive sleep apnea syndrome in children: a systematic literature review. *Sleep Med* 2018;46:46–55.
- [47] Saunders TJ, Gray CE, Poitras VJ, et al. Combinations of physical activity, sedentary behaviour and sleep: relationships with health indicators in school-aged children and youth. *Appl Physiol Nutr Metab* 2016;41(6 Suppl 3):S283–93.
- [48] Dolezal BA, Neufeld EV, Boland DM, et al. Interrelationship between sleep and exercise: a systematic review. *Adv Prev Med* 2017;2017. 1364387.
- [49] Guo H, Wang T, Li X, et al. What sleep behaviors are associated with bruxism in children? A systematic review and meta-analysis. *Sleep Breath* 2017;21(4):1013–23.
- [50] Ludwig B, Smith S, Heussler H. Associations between neuropsychological, neurobehavioral and emotional functioning and either narcolepsy or idiopathic hypersomnia in children and adolescents. *J Clin Sleep Med* 2018;14(4):661–74.
- [51] Blackwell JE, Alammar HA, Weighall AR, et al. A systematic review of cognitive function and psychosocial well-being in school-age children with narcolepsy. *Sleep Med Rev* 2017;34:82–93.
- [52] Angriman M, Cortese S, Bruni O. Somatic and neuropsychiatric comorbidities in pediatric restless legs syndrome: a systematic review of the literature. *Sleep Med Rev* 2017;34:34–45.
- [53] Tham EKH, Schneider N, Broekman BFP. Infant sleep and its relation with cognition and growth: a narrative review. *Nat Sci Sleep* 2017;9:135–49.
- [54] de Bruin EJ, van Run C, Staaks J, et al. Effects of sleep manipulation on cognitive functioning of adolescents: a systematic review. *Sleep Med Rev* 2017;32:45–57.
- [55] Lowe CJ, Safati A, Hall PA. The neurocognitive consequences of sleep restriction: a meta-analytic review. *Neurosci Biobehav Rev* 2017;80:586–604.
- [56] Tonetti L, Natale V, Randler C. Association between circadian preference and academic achievement: a systematic review and meta-analysis. *Chronobiol Int* 2015;32(6):792–801.
- [57] Short MA, Blunden S, Rigney G, et al. Cognition and objectively measured sleep duration in children: a systematic review and meta-analysis. *Sleep Health* 2018;4(3):292–300.
- [58] Minges KE, Redeker NS. Delayed school start times and adolescent sleep: a systematic review of the experimental evidence. *Sleep Med Rev* 2016;28:86–95.
- [59] Becker SP, Sidel CA, Van Dyk TR, et al. Intraindividual variability of sleep/wake patterns in relation to child and adolescent functioning: a systematic review. *Sleep Med Rev* 2017;34:94–121.
- [60] Reynaud E, Vecchierini M-F, Heude B, et al. Sleep and its relation to cognition and behaviour in preschool-aged children of the general population: a systematic review. *J Sleep Res* 2017;27(3). e12636.
- [61] van Geel M, Goemans A, Vedder PH. The relation between peer victimization and sleeping problems: a meta-analysis. *Sleep Med Rev* 2016;27:89–95.
- [62] Schlarb AA, Sopp R, Ambiel D, et al. Chronotype-related differences in childhood and adolescent aggression and antisocial behavior—a review of the literature. *Chronobiol Int* 2014;31(1):1–16.
- [63] De Luca Canto G, Singh V, Conti P, et al. Association between sleep bruxism and psychosocial factors in children and adolescents: a systematic review. *Clin Pediatr* 2015;54(5):469–78.
- [64] Bowers JM, Moyer A. Effects of school start time on students' sleep duration, daytime sleepiness, and attendance: a meta-analysis. *Sleep Health* 2017;3(6):423–31.
- [65] Spruyt K, Gozal D. The underlying interactome of childhood obesity: the potential role of sleep. *Child Obes* 2012;8(1):38–42.
- [66] Fobian AD, Elliott L, Louie T. A systematic review of sleep, hypertension, and cardiovascular risk in children and adolescents. *Curr Hypertens Rep* 2018;20(5):42.
- [67] Matthews KA, Pantesco EJ. Sleep characteristics and cardiovascular risk in children and adolescents: an enumerative review. *Sleep Med* 2016;18:36–49.
- [68] Reutrakul S, Van Cauter E. Sleep influences on obesity, insulin resistance, and risk of type 2 diabetes. *Metabolism* 2018;84:56–66.
- [69] Agras WS, Hammer LD, McNicholas F, et al. Risk factors for childhood overweight: a prospective study from birth to 9.5 years. *J Pediatr* 2004;145(1):20–5.
- [70] Snell EK, Adam EK, Duncan GJ. Sleep and the body mass index and overweight status of children and adolescents. *Child Dev* 2007;78(1):309–23.
- [71] Reilly JJ, Armstrong J, Dorosty AR, et al. Early life risk factors for obesity in childhood: cohort study. *BMJ* 2005;330(7504):1357.
- [72] Castaneda A, Jauregui-Maldonado E, Ratmani I, et al. Correlation between metabolic syndrome and sleep apnea. *World J Diabetes* 2018;9(4):66–71.
- [73] Medic G, Wille M, Hemels ME. Short- and long-term health consequences of sleep disruption. *Nat Sci Sleep* 2017;9:151–61.
- [74] Spruyt K, Gozal D. A mediation model linking body weight, cognition, and sleep-disordered breathing. *Am J Respir Crit Care Med* 2012;185(2):199–205.
- [75] Spruyt K, Dayyat E, Bennett JL, et al. Short sleep duration and irregular sleep patterns are associated with increased metabolic risk in school aged children. *Sleep* 2010;33. A320-A320.
- [76] Astill RG, Van der Heijden KB, Van Ijzendoorn MH, et al. Sleep, cognition, and behavioral problems in school-age children: a century of research meta-analyzed. *Psychol Bull* 2012;138(6):1109–38.
- [77] Dewald JF, Meijer AM, Oort FJ, et al. The influence of sleep quality, sleep duration and sleepiness on school performance in children and adolescents: a meta-analytic review. *Sleep Med Rev* 2010;14(3):179–89.
- [78] Copes K, Rosentswieg J. The effects of sleep deprivation upon motor performance of ninth-grade students. *J Sports Med Phys Fit* 1972;12(1):47–53.
- [79] Walker MP, Brakefield T, Morgan A, et al. Practice with sleep makes perfect: sleep-dependent motor skill learning. *Neuron* 2002;35(1):205–11.
- [80] Berger SE, Scher A. Naps improve new walkers' locomotor problem solving. *J Exp Child Psychol* 2017;162:292–300.
- [81] Yan JH. Children benefit differently from night- and day-time sleep in motor learning. *Hum Mov Sci* 2017;54:297–307.
- [82] Hysing M, Sivertsen B, Garthus-Niegel S, et al. Pediatric sleep problems and social-emotional problems. A population-based study. *Infant Behav Dev* 2016;42:111–8.
- [83] Sun W, Li SX, Wang G, et al. Association of sleep and circadian activity rhythm with emotional face processing among 12-month-old infants. *Sci Rep* 2018;8(1):3200.
- [84] Sano A, Yu AZ, McHill AW, et al. Prediction of happy–sad mood from daily behaviors and previous sleep history. *Conf Proc IEEE Eng Med Biol Soc* 2015;2015:6796–9.
- [85] Schumacher AM, Miller AL, Watamura SE, et al. Sleep moderates the association between response inhibition and self-regulation in early childhood. *J Clin Child Adolesc Psychol* 2017;46(2):222–35.
- [86] Miller AL, Seifer R, Crossin R, et al. Toddler's self-regulation strategies in a challenge context are nap-dependent. *J Sleep Res* 2015;24(3):279–87.
- [87] Spruyt K, Alaribe CU, Nwabara OU. Daily dynamics in sleep and behavior of young African-American children: a convoluted dyad? *Int J Psychophysiol* 2016;99:57–66.