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CLINICAL REVIEW

Children's sleep and health: A meta-review

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SUMMARY

Sleep is essential for children's health and well-being. Characteristics of children's sleep such as sleep duration, timing, quality and variability are increasingly being associated with a wide range of health outcomes. The purpose of this study is to conduct a meta-review (systematic review of systematic reviews) to examine the relationship between sleep and health in children. A systematic search of four electronic databases (Medline, PsychInfo, Scopus, and Embase) was conducted to identify systematic reviews that examine the association between characteristics of children's sleep and health. Key findings, as well as areas in need of further research were synthesised descriptively. A total of 39 systematic reviews were identified for inclusion, covering areas of cognition, psychosocial health, cardiometabolic health, adiposity and other outcomes such as musculoskeletal pain. There is substantial and consistent evidence relating sleep duration to adiposity and emotional outcomes. The relationships between sleep quality and timing and blood lipids and glycaemic control merit further research. Links between sleep and metabolic syndrome in children appear to be weak and inconsistent. Key areas identified in need for further research included studies that objectively assess children's sleep and move beyond cross-sectional study designs and consider characteristics of sleep other than duration. It was also noted that covariates applied across studies varied considerably and the issue of residual confounding was raised in a number of reviews. Lastly, all reviews reported studies adopted a traditional approach of examining only one aspect of children's sleep. Systematic reviews support the notion that sleep is important for children's health. However, further studies that objectively assess sleep and consider characteristics of sleep other than duration and outcomes other than adiposity are needed. An understanding of sleep as a multidimensional construct and as a component of the 24-h d, is also needed to better understand the relationship between sleep and health in children.

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Introduction

Sleep is essential for children's health and well-being. Short sleep has been associated with poorer cognitive [1] and cardiometabolic [2] health outcomes in children. Similar findings have also been reported for children's sleep quality, timing and variability [3–5]. Children's sleep is therefore of special interest, particularly given that many childhood lifestyle behaviours and conditions track into adulthood [6]. Although the importance of sleep has long been recognised, including sleep within population health promotion messages and strategies is relatively new [6,7].

Sleep medicine has traditionally focused on sleep disorders and deficiencies, with less focus on how sleep may be a predictor of health. In 2014, Buysse [7] coined the term “sleep health” as a metric for research and population health purposes, to describe multiple sleep characteristics important for health. Although a definition of sleep health was proposed, broader consensus on how to best define and measure sleep health was encouraged [7]. A comprehensive review on the association between children's sleep and health may help to develop the concept of sleep health, as well as provide important insight for population health promotion and surveillance [6,7].

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Systematic literature reviews are considered among the highest level of scientific evidence and are a robust approach to identify and synthesise available literature [8,9]. However, synthesising the entire body of literature on children's sleep and health has a number of challenges. Firstly, there is an enormous body of literature that examines the link between children's sleep and health, and it is rapidly growing [6]. Secondly, there are a large number of different sleep characteristics that may influence health [10]. Thirdly, sleep has been linked to a very wide range of health outcomes, both physical and psychological [2,11].

Meta-reviews (or "review of reviews") are increasingly used to summarise evidence where systematic reviews are difficult due to the volume of literature that needs to be reviewed and synthesised, or where several reviews have already been published, with different findings or foci [12]. Meta-reviews have several advantages. In synthesising published systematic reviews, areas of particular interest and/or controversy are identified, as are areas in need of further research. A meta-review therefore provides a method by which findings may be rapidly mapped in an effort to better understand what has been done, what has been found, what needs to be done, and what could be done better. This is an important step towards synthesising the available literature on the children's sleep-health link.

To date, there has been no meta-review of the association between children's sleep and health. The aim of this study is therefore to conduct a meta-review in order to synthesize findings of all systematic literature reviews that examine the association between children's sleep and health. We consider sleep duration, timing, quality and variability as exposures, and health outcomes in terms of cognitive performance, psychosocial and cardiometabolic health and adiposity.

Methods

A systematic literature search was undertaken to identify all studies that apply a systematic literature search to examine the link between characteristics of nocturnal sleep and health in apparently healthy children (<18.99 y). Studies that examine the effects of naps or medically-diagnosed sleep problems (e.g., obstructive sleep apnoea) were not considered. A detailed summary of the systematic search process (inclusion/exclusion criteria) is outlined in Appendix 1. This systematic review was registered in the PROSPERO register of systematic reviews (CRD42019116817).

Search strategy

The search strategy used for this review involved searching four databases: Medline, PsychInfo, Scopus, and Embase. These databases were selected following consultation with an academic librarian and a preliminary search, using the selected search terms, which suggested a broad range of relevant literature would be identified using these databases.

The search terms used for each database included: Sleep* and "systematic review*" or "systematic literature review" or "systematic search" or "meta analysis" or "meta-analysis" or "meta-analysis" or "meta-review" or "metareview" and child* and adolescen* or boy* or girl* or youth* or teen. The truncation symbol (*) was used to ensure terms with alternative suffixes were detected. MeSH terms and subject headings were also searched. No date limits were set. A preliminary search was run in April 2018 and final search run in January 2019.

Studies included for review

The title and abstract of all studies identified in the systematic search were screened independently by two reviewers using Covidence. Potentially eligible studies were then retrieved and read in full. Only reviews that considered characteristics of sleep in terms of duration (total sleep time, sleep period time, time in bed), quality (subjective reports, sleep efficiency, number/duration of night time awakenings), timing (bedtime, wake-time, sleep mid-point) and day-to-day variability were included for review. Sleep problems, disorders, sleepiness and architecture were not considered. In cases where the review considered a variety of different characteristics, only findings relating to characteristics of interest were noted.

Papers were excluded if they were not written in English, were not systematic literature reviews of original studies, examined non-human participants or adults (≥19 y), exclusively examined clinical or special populations (e.g., children with a disability or known medical condition) and/or considered characteristics of sleep not for consideration in this review. Included references were imported and screened in Endnote [13].

Data extraction

All studies included for review were independently read in full by two reviewers (LM, CP), who undertook data extraction to determine key findings and limitations. A detailed summary of the data extraction process is reported in Appendix 2.

Associations between sleep characteristics and health were considered to be favourable if longer sleep duration, higher sleep quality, early sleep timing pattern (i.e., early to bed, early to rise), and low weekly sleep variability were associated with better health, and unfavourable if they were associated with poorer health. They were judged to be "mixed" if they varied by sub-group (e.g., if they were different for boys and girls) or if a non-linear association was found. Similar approaches to classifying findings have been applied in previous reviews [4,14,15]. Limitations reported within the discussion of each review were also documented.

All reported health outcome measures were considered and recorded. Health outcomes were assigned to one of five categories: cognitive, psychosocial, cardiometabolic, adiposity and 'other'. Similar categories have been reported in previous reviews [2,14].

Systematic review findings were synthesised for each health outcome examined. Systematic review findings were reported descriptively as an audit of results reported for the included individual studies (i.e., the number of studies within each review that reported favourable, unfavourable, mixed/null results).

It is important to note that some studies were included and reported by a number of systematic reviews included within this meta-review. We did not account for duplications of original studies as the key interest is understanding what has been conveyed within systematic reviews.

Results

As shown in Fig. 1, the systematic search identified 1159 different systematic reviews, of which 1086 were judged not to meet the inclusion criteria based on an examination of the abstracts. Of the remaining 73 potentially eligible systematic reviews, a further 38 were excluded as they did not meet the inclusion criteria when full-text versions were examined. Four additional studies were retrieved from pearling reference lists and searching in-press articles of sleep journals (*Sleep Medicine Reviews*, *Sleep*, *Sleep Medicine*, *Sleep Health*), resulting in a total of 39 different systematic reviews were included for review.

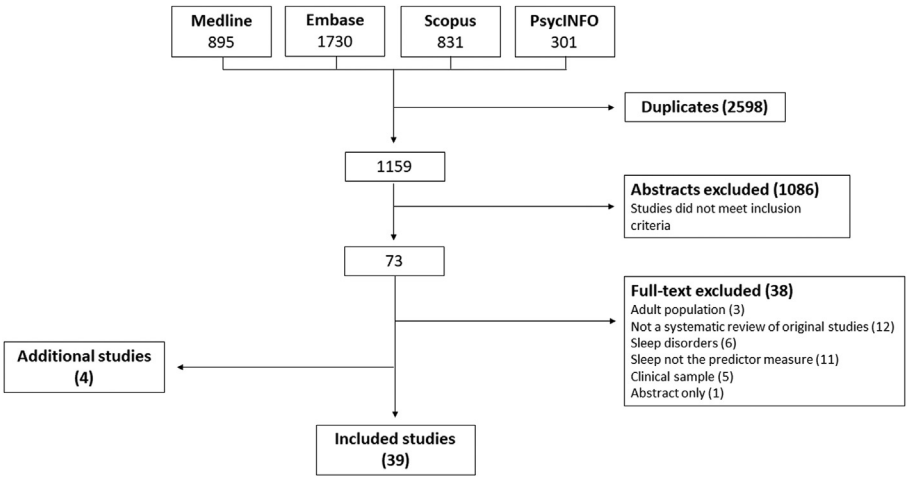

Fig. 1. Flow diagram of systematic search.

Table 1 presents a summary of the 39 included reviews [1–5,14,16–47]. Reviews varied considerably, particularly in terms of the number of studies included, sample size and study design. Few reviews exclusively examined studies of a specific study design (38%) or children within a narrow age range (e.g., less than six years) (10%). Most reviews examined studies that assessed subjectively-measured sleep, with only two reviews [1,23] that exclusively examined objectively-measured sleep, both of which included polysomnography and actigraphy-measured sleep characteristics.

Twenty four of the 39 systematic reviews reviewed the association between children's sleep and adiposity [2–4,14,15,18,21–23,25,27–29,31–36,39,40,42,43,47], eight considered cognition [1,3,5,14,15,20,24,30], eight psychosocial outcomes [3,14,15,17,26,30,38,44], twelve cardiometabolic outcomes [2–4,14,15,19,23,32,37,42,45,47] and five other health outcomes [2,14,16,41,46]. Table 2 provides a summary of the systematic reviews that examined the association between children's sleep and health, according to the different health subdomains and sleep characteristics. Most reviews exclusively examined the associations of sleep duration (72%). Although some reviews considered other characteristics of sleep in addition to duration, only one study [3] exclusively examined the role of a sleep characteristic other than duration (sleep variability). When reviews were considered in terms of the year of publication, a notable increase in the number of published reviews was observed, as was the number of studies that considered characteristics of sleep, other than duration (Fig. 2).

Fig. 3 presents the percentage of studies reporting favourable findings, according to the total number of studies examined. Sleep has been associated with many different health outcome measures, with most studies examining sleep duration and measures of adiposity and emotional well-being, yielding favourable results. In contrast, fewer studies have examined the association between sleep duration and quality with metabolic syndrome, inflammation, cardiovascular health and general well-being. Likewise, there are fewer favourable studies in these areas.

Cognition

Eight reviews [1,3,5,14,15,20,24,30] examined the association between children's sleep and cognition, assessed in terms of memory, global cognitive measures and school performance. Of these, three [1,14,15] examined sleep duration, three [5,20,24] examined both sleep duration and quality and one [30] considered sleep duration, quality and timing but noted most studies examined sleep duration. One review [3] examined sleep variability, which reported inconsistent results across individual studies. As shown in Table 3, 137 associations were reported, most associations reported on sleep duration, while no studies considered sleep timing.

Memory

Three reviews [1,5,24] examined the association between children's sleep and memory. Of these, one [24] provided a narrative review and two [1,5] provided results of a meta-analysis. Kopasz and colleagues [24], in a systematic narrative review of fourteen published studies, reported that relatively few studies have examined the sleep-memory link in children, with most studies supporting the notion that longer, good quality sleep is essential for declarative and non-declarative memory processes. This review also suggested that the memory task, as well as developmental stage and social aspects (e.g., ethnicity) may modulate the sleep-memory link in children. Later reviews that provided quantitative meta-analyses [1,5], however, reported no association for sleep duration [1,5] or sleep quality [5].

Global cognitive scores

Six reviews [1,3,5,14,15,30] examined the association between children's sleep and cognition. Of these, four [3,14,15,30] presented results descriptively and two [1,5] reported findings as a meta-analysis. Chaput and colleagues [14,15] published two reviews on the association between children's sleep duration and cognition. In 2016, Chaput [15] reviewed the evidence for school-aged children (5–17 y) and reported mixed (five of six studies) or no associations (one of six studies) across most studies. Similarly, in Chaput's [14] 2017 review of pre-school children, the majority of studies (63%) reported null (eight of 16 studies) or negative findings (two of 16 studies). Reynaud and colleagues [30] also examined the evidence for preschool children, but considered all characteristics of sleep. In this review, only studies on sleep duration and quality were identified (no studies were identified for sleep timing or variability), with an equal number of favourable (50%) and mixed/null findings

Table 1
Summary of included studies.

Ref	Study designs	Age range	k	n	Subjective reports	Sleep variable	Outcome domain
Astill [5]	CS; E	5–12	86	35,936	57%[a]	D, Q	Multiple outcomes
Chaput [15]	CS; L; RCT	5–17	141	592,215	79%	D	Multiple outcomes
Chaput [14]	CS; L; RCT	0–5	60	148,524	86%	D	Multiple outcomes
Becker [3]	NR	NR	36	NR	NR	V	Multiple outcomes
Reynaud [30]	CS; L	0–6	26	37,935	88%	D, Q, T	Multiple outcomes
Grgic [42]	CS; P	4–17	7	6198	14%	D	Multiple outcomes
Felso [23]	CS; P; RCT	3–16	27	16,177	0%	D	Multiple outcomes
Andreucci [16]	P	8–16	13	18,888	100%	D	Other (pain)
Short [41]	CS; L; E	13–17	26	579,380	88%	D	Other (risk taking)
Gao [46]	CS	6–18	7	21,132	100%	D	Other (injuries)
Dewald [20]	CS; L	8–18	33	28,830	85%	D, Q	Cognitive
Kopasz [24]	CS; E	6–18	11	1065	1%	D	Cognitive
Short [1]	CS; E	5–13	19	1760	0%	D	Cognitive
Lovato [26]	CS; L	12–20	23	96,645	44%	Q	Psychosocial
Lundahl [38]	E	0–18	13	NR	NR	D[a]	Psychosocial
Chiu [44]	CS; P	14–16	12	598,281	NR	D	Psychosocial
Cairns [17]	L	12–18	3	NR	100%	D	Psychosocial
De Azevedo [19]	CS; L	11–20	7	27,798	86%	D	Cardiometabolic
Dutil [37]	CS; L; RCT	0–19	23	16,106	48%	D, Q, T	Cardiometabolic
Fobian [47]	CS; L; RCT	5–19	27	39,280	78%	D	Cardiometabolic
Jiang [45]	CS	10–19	7	21,150	86	D	Cardiometabolic
Matthews [4]	CS; L	0–29	55	93,112	60%	D, Q	Cardiometabolic
Quist [2]	CS; L	3–20	75	187,877	61%	D,Q	Cardiometabolic
Kuzik [25]	L	3–5	1	1827	90%	D	Adiposity
Saunders [32]	CS; L	5–17	4	36,560	75%	D	Adiposity
Cappuccio[a] [36]	CS; L	2–20	12	30,002	100%	D	Adiposity
Chen [18]	CS; Co; CC	0–18	17	38,942	94%	D	Adiposity
Fatima [21]	L	0–18	11	24,821	77%	D	Adiposity
Fatima[a] [22]	CS; L; CC	0–34	18	32,799	83%	Q	Adiposity
Hart [39]	CS; L	0–18	38	91,669	92%	D, T	Adiposity
Magee[a] [27]	L	0–12	7	10,959	100%	D	Adiposity
Nielsen[a] [28]	P	0–32	8	13,117	100%	D	Adiposity
Patel[a] [29]	CS; P	3–18	13	35,381	69%	D	Adiposity
Ruan [31]	P	0–16	25	31,185	96%	D	Adiposity
Thind [33]	L	0–32	22	53,330	91%	D	Adiposity
Jansen [40]	CS; L	0–18	31	91,723	87%	D,T,Q,V	Adiposity
Woo [34]	L	0–18	4	NR	100%	D	Adiposity
Miller [43]	P	0–18	42	100,393	88%	D	Adiposity
Wu [35]	L	0–18	13	35,540	100%	D	Adiposity

k: number of studies relevant to the current review; n: sample size; CS: cross-sectional; L: longitudinal; CC: case-control; P: prospective; Co: cohort; RCT: randomised control trial; E: experimental; NR: not reported; D: sleep duration; T: sleep timing; V: sleep variability; Q: sleep quality.
[a] Indicates studies that examined both adults and children but only children were considered.

(50%) for sleep duration, and two non-significant associations reported for sleep quality. Becker and colleagues [3] reviewed the evidence for sleep variability and considered all age groups. In this review [3], a scarcity of studies was noted, with all eight studies reporting mixed or no association.

Two reviews [1,5] conducted a meta-analysis. Astill [5] reviewed 52 studies on sleep duration (mostly measured in terms of subjective reports) and ten studies on sleep quality (operationalised as objectively-measured sleep efficiency). This review revealed sleep duration ($r = 0.08$; 85% CI 0.06, 0.10), but not sleep quality ($r = 0.12$; 85% CI 0.013, 0.21) is significantly associated with cognition in school-aged children. Short and colleagues [1] reviewed the association between objectively-measured sleep and cognitive outcome measures in comparable school-aged children. In this meta-analysis, of nineteen studies, a small, but significant association was found between children's sleep duration and cognition ($r = 0.06$, 95% CI: 0.01, 0.12).

School performance

Four studies [3,5,15,20] reported on the association between children's sleep and school performance. Of these, two [3,15] provided a narrative review for a specific sleep characteristic, while the other two reviews [5,20] reported on a meta-analysis that considered multiple sleep characteristics. In 2016, Chaput and colleagues [15] reviewed the association between school-aged children's sleep duration and school performance within a larger review that considered all health outcome measures. In this review, seventeen cross-sectional and four longitudinal studies were identified for school performance. Of these, most (11 of the 17 cross-sectional and three of the four of the longitudinal studies) reported favourable effects of longer sleep durations, with only one cross-sectional study reporting an unfavourable association. However, the evidence was considered to be of very low methodological quality, predominantly due to the use of subjective sleep measures with no psychometric properties reported and the use of self-reported grades. In 2017, Becker and colleagues [3] considered the association between sleep variability and school performance. This review identified only one study in adolescents, which found no association.

Two earlier reviews [5,20] pooled individual study results in a meta-analysis to determine the association between children's sleep (duration and quality) and academic performance. In 2012, Astill and colleagues [5] reviewed twenty studies on sleep duration and three studies on sleep quality (defined as objectively-measured sleep efficiency) and revealed a significant association for sleep duration ($r = 0.09$, 85% CI: 0.06, 0.12), but not sleep quality ($r = 0.15$, 85% CI 0.02, 0.28) in children aged 5–12 y. In a similar 2010 review on older children (aged 8–18 y), Dewald and colleagues [20] considered both subjective and objective measures of sleep

Table 2
Summary of studies that examined each health domain and sleep characteristic.

Health domain	Sub-domain	Duration	Quality	Timing	Variability
Cognition	Academic	Chaput [15]			
		Dewald [20]	Dewald [20]		
		Astill [5]	Astill [5]		
					Becker [3]
	Memory	Kopasz [24]			
		Short [1]			
		Astill [5]	Astill [5]		
	Cognition	Chaput [15]			
		Chaput [14]			
		Short [1]			
		Astill [5]	Astill [5]		
		Reynauds [30]	Reynauds [30]	Reynauds [30]	
					Becker [3]
Psychosocial	Depression	Cairns [17]			
		Chiu [44]			
		Lovato [26]	Lovato [26]		
					Becker [3]
	Emotional	Chaput [15]			
		Chaput [14]			
		Lundahl [38]			
		Reynauds [30]	Reynauds [30]	Reynauds [30]	
					Becker [3]
Other	Quality of life	Chaput [15]			
		Chaput [14]			
	Harms/injury	Chaput [15]			
		Chaput [14]			
		Short [41]			
	Pain	Gao [46]	Gao [46]		
		Andreucci [16]	Andreucci [16]		
Cardiometabolic	Metabolic	Chaput [15]			
		Chaput [14]			
		Saunders [32]			
		Grgic [42]			
		Matthews [4]	Matthews [4]		
					Becker [3]
	Lipid	De Avezedo [19]			
		Fobian [47]			
		Matthews [4]	Matthews [4]		
		Quist [2]	Quist [2]	Quist [2]	Quist [2]
	Glucose	Felso [23]			
		Quist [2]	Quist [2]	Quist [2]	Quist [2]
		Matthews [4]	Matthews [4]		
		Fobian [47]	Fobian [47]	Fobian [47]	
		Dutil [37]	Dutil [37]	Dutil [37]	
	Blood pressure	Chaput [15]			
		Jiang [45]			
		Quist [2]	Quist [2]		
		Fobian [47]	Fobian [47]		
		Matthews [4]	Matthews [4]		
	Inflammation	Fobian [47]			
		Chaput [15]			
		Quist [2]	Quist [2]		
Adiposity	Adiposity	Chaput [15]			
		Chaput [14]			
		Cappuccio [36]			
		Chen [18]			
		Patel [29]			
		Felso [23]			
		Matthews [4]			
		Maggee [27]			
		Thind [33]			
		Neilsen [28]			
		Woo [34]			
		Ruan [31]			
		Wu [35]			
		Fatima [21]			
		Kuzik [25]			
		Miller [43]			

Table 2 (*continued*)

Health domain	Sub-domain	Duration	Quality	Timing	Variability
		Grgic [42]			
		Saunders [32]			
		Jansen [40]	Jansen [40]	Jansen [40]	Jansen [40]
		Fobian [47]	Fobian [47]	Fobian [47]	
		Quist [2]	Quist [2]		
		Fatima [22]	Fatima [22]		
		Hart [39]		Hart [39]	Hart [39]
					Becker [3]

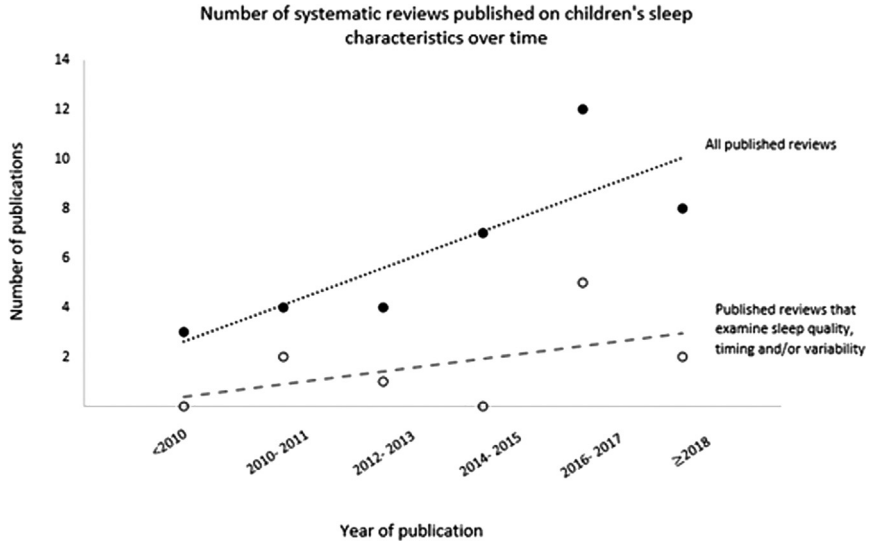

Fig. 2. Year of systematic review publication and characteristic of sleep examined. *solid circles* indicate the total number of reviews that examine the sleep health link in children, with consideration of sleep characteristics other then duration (i.e., sleep quality, timing, variability).

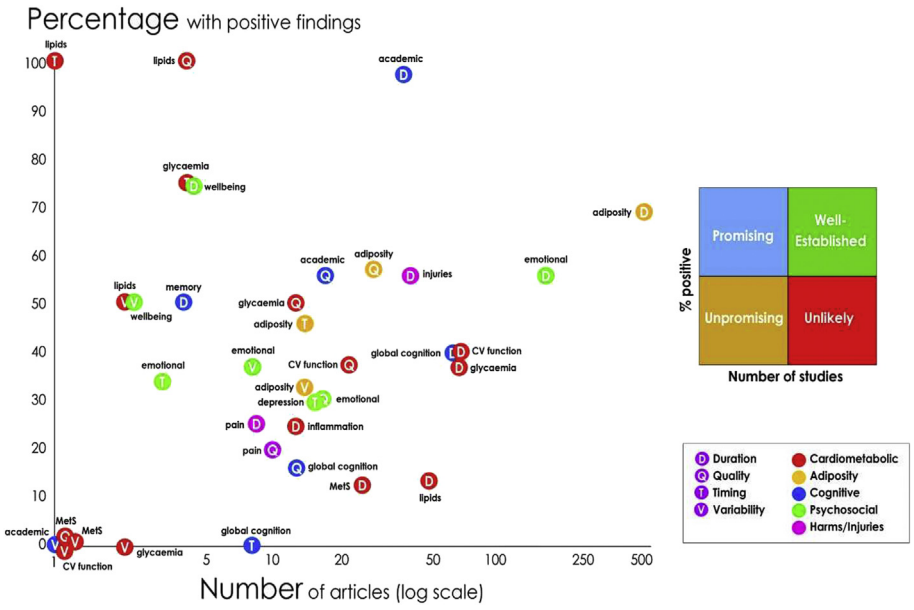

Fig. 3. Percentage of studies finding favourable associations with specific health outcomes (Y-axis), plotted against the overall number of studies reported across all reviews (X-axis). D = sleep duration; Q = sleep quality; T = sleep Timing; V = sleep variability. Health outcomes categories are colour-coded. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Summary of the number of associations reported across reviews that examined the association between children's sleep and cognition.

	Favourable	Mixed/Null	Unfavourable	Total
Duration	50 (36%)	46 (34%)	4 (3%)	100
Quality	11 (8%)	17 (12%)	0	28
Variability	0	9 (7%)	0	9
Total	61	72	4	137

Table 4
Summary of the number of associations reported across reviews that examined the association between children's sleep and psychosocial health.

	Favourable	Mixed/Null	Unfavourable	Total
Duration	101 (47%)	68 (31%)	11 (5%)	180
Quality	5 (2%)	11 (5%)	0	16
Variability	7 (3%)	11 (5%)	0	18
Timing	1 (1%)	2 (1%)	0	3
Total	114	92	11	217

quality. In this review [20] of sixteen studies on sleep quality and seventeen studies on sleep duration, a significant association was reported for both sleep duration ($z = 0.071$; 95% CI: 0.055, 0.087) and sleep quality ($z = 0.100$; 95% CI: 0.083, 0.117), with larger effects for younger children compared to older children and a significant age-gender interaction. The authors of this review suggested that sleep quality and duration may have different contributions to the sleep-school performance association, with age and gender as important moderators [20].

Overall, reviews tend to suggest sleep may be important for children's cognitive abilities, although the current body of evidence consists of a limited number of studies and predominantly focuses on sleep duration, with variability in how cognition is defined and measured across studies. For school performance, sleep duration [5,20] appears important, although effect sizes are small and the methodological quality of studies is low, particularly due to a failure to consider potential confounders and mostly self-report measures of sleep [14,15,30], while the evidence for sleep quality [5,20] appears mixed, although this may reflect different definitions of sleep quality (i.e., subjective vs. objective measures) and the evidence for sleep variability [3] is scarce and not convincing. For memory, the limited available evidence suggesting no association for sleep duration or quality [1,5,24]. Inconsistent and limited evidence was also reported for global cognitive score. All reviews that reported on multiple sleep characteristics did so by considering characteristics in isolation. The interaction between sleep characteristics therefore remains unclear. Several reviews examined the role of potential moderators. Children's age, sex and method of assessing sleep were most commonly examined, however reviews reported different findings. For example, Dewald [20] reported a larger effect on school performance for younger children, while Lundahl [38] reported a larger effect on attention for older children and Astill [5] reported age had no effect on cognition or behaviour.

Psychosocial health

Eight reviews examined the association between children's sleep and psychosocial health, assessed in terms of depression/suicidality, emotional-behavioural regulation and quality of life. Of these, five [14,15,17,38,44] examined sleep duration, one [26] examined sleep duration and quality, one [3] examined sleep variability, one [30] examined sleep duration, quality and timing. As shown in Table 4, most associations reported on sleep duration.

Depression

Three reviews [3,17,26] examined the association between children's sleep and depression in adolescents or older children. Lovato and colleagues [26] explored the bidirectional relationship of sleep disturbances (defined in terms of sleep duration and quality) and depression in adolescents, while Cairns and colleagues [17] reviewed the literature for potential modifiable lifestyle behaviours (including sleep duration) which may be associated with future depression. Becker [3] descriptively reported on the role of sleep.

Lovato and colleagues [26] reviewed twenty-three studies in an effort to quantify a directional relationship between sleep and depression in adolescents aged 12–20 y. Of the identified studies, 13 examined the cross-sectional association between sleep and depression, seven examined the prospective role of sleep in the development of depression and three examined the prospective role of adolescent depression in the development of sleep disturbances (i.e., poor sleep quality and short sleep duration). Overall, it was found that adolescents with depression experience significantly poorer sleep quality. Poor sleep quality, considered in terms of sleep efficiency ($d = -0.51$, 95% CI: −0.98 to −0.30) and wake after sleep onset ($d = -0.58$, 95% CI: 0.28 to 0.88), but not sleep duration ($d = -0.52$, 95% CI: −1.36 to 0.32), was also found to act as a precursor for the development of depression. Little support was found for a predictive role of depressive symptoms in the development of poor sleep ($d = -0.06$, 95% CI: −0.58 to 0.46).

Chiu and colleagues [44] reviewed twelve studies to determine whether a dose-response association exists between adolescent sleep duration and suicidality. In this systematic review, a strong curvilinear dose-response relationship was identified for sleep duration and risk of suicide ideation and attempt, with the lowest risk occurring at 8–9 h of sleep duration. A linear dose-response relationship was found for sleep duration and suicide plans (OR 0.89, 95% CI: 0.88, 0.90), with authors suggesting that the risk of suicide plans statistically decreased by 11% for every 1 h increase in sleep duration. Depression and other characteristics of sleep were not found to be significant moderators in any subgroup analyses.

Cairns and colleagues [17] reviewed the literature to determine modifiable lifestyle behaviours for the development of depression in adolescents. In this review of 113 longitudinal studies, covering adolescents aged 12–18 y, three studies, yielding positive findings were identified. The authors of this review suggested sleep duration is a modifiable lifestyle behaviour that should be considered in health education campaigns or self-help prevention interventions targeting adolescent depression. It was however, noted that the relative importance of all lifestyle behaviours could not be quantified through meta-analyses and results may not be generalisable across cultures and different age groups.

Becker and colleagues [3] reviewed the evidence for an association between sleep variability and anxiety/depressive symptoms in children. Eight studies were identified, covering children aged four to nineteen years. Of these studies, three reported favourable findings and five reported mixed findings/null findings. The authors of this review concluded that the current body of evidence conveys mixed findings for a relationship between sleep variability and anxiety/depressive symptoms in children.

Emotional-behavioural regulation

Five reviews [3,14,15,30,38] examined the cross-sectional association between children's sleep and emotional-behavioural regulation. Of these, three [14,15,38] examined sleep duration and two examined other characteristics of sleep, including sleep variability [32] and multiple characteristics [30].

Of the three reviews [14,15,38] that examined the association between sleep duration and emotional regulation, two [14,15] presented a narrative review of study findings and one [38] presented findings of a meta-analysis. Chaput and colleagues [15] reviewed sixty-two studies and reported most studies (79%) suggest longer sleep in school-aged children is associated with better emotion regulation. In a similar review of preschool children, Chaput [14] found that just over half of studies (52%) report positive findings for sleep duration. Both reviews noted two studies that reported unfavourable results, whereby longer sleep was associated with poorer emotional regulation, and that studies were of varying methodological quality (low to very high). Lundahl and colleagues [38] conducted a meta-analysis to determine the association between sleep deprivation and children's attention and hyperactivity. In this review of 13 experimental studies, sleep restriction was significantly associated with poorer levels of attention compared to baseline sleep ($r = -0.19$; 95% CI: −0.34, −0.03) and extended sleep conditions ($r = -0.37$; 95% CI: −0.55, −0.19), while sleep restriction was significantly associated with greater levels of hyperactivity, compared to extended sleep conditions ($r = -0.35$; 95% CI: −0.71, −0.003), but not baseline sleep conditions ($r = -0.001$; 95% CI: −0.34, 0.33). Age and sex were significant moderators for sleep extension/restriction and attention analysis, with the negative effect of sleep restriction being greater for older children and for boys.

Two reviews [3,30] examined characteristics other than sleep duration. Becker and colleagues [3] reviewed six studies on the association between sleep variability and behavioural functioning. Of these, three reported favourable findings (i.e., more consistent sleep patterns are associated with better emotional regulation) and three mixed/null findings. The authors of this review concluded that studies generally report an association between sleep variability and social functioning. Similarly, Reynaud and colleagues [30], in a review of twenty-three studies of preschool children, report studies tend to suggest an association between sleep and (internalising and externalising) behaviour. However, most studies in this review also had small sample sizes, relatively weak effect sizes and different types and means of measuring both sleep characteristics and behaviour measures. Further, most studies either did not, or only partially controlled for potential confounders. All sleep characteristics were considered independent of each other.

Quality of life

Two reviews [14,15] examined the evidence for an association between sleep and quality of life. Both reviews, one on school-aged children [15] and the other on preschool children [14], identified only a small number of studies (three and one study, respectively). For school-aged children, two of the three studies reported a favourable association (i.e., longer sleep is associated with better quality of life), while no association was found for preschool children. In both reviews, the studies were of very low methodological quality.

Overall, reviews tend to suggest sleep may be important for psychosocial health in children, but are limited by studies on relatively small sample sizes on select age-groups. Reviews [14,15] tend to suggest sleep duration and quality may play a predictive role in the development of anxiety/depressive symptoms in older children, while the role of other sleep characteristics, such as variability and timing remain unclear, with few or no available reviews, respectively. Reviews [14,15] also appear to suggest an association between children's sleep and emotional regulation, with experimental evidence [38] to suggest sleep restriction, compared to baseline and extended sleep, is detrimental. The role of other characteristics of sleep appear possible, but are less clear, with about 33% of studies finding favourable associations. Reviews [14,15] suggest very few studies of low methodological quality have examined the association between children's sleep and quality of life. The role of potential confounders and mediators were not extensively examined in any of the reviews. All reviews that reported on multiple sleep characteristics did so by considering characteristics in isolation. The interaction between sleep characteristics therefore remains unclear.

Cardiometabolic health (excluding adiposity)

Twelve reviews [2–4,14,15,19,23,32,37,42,45,47] set out to determine the association between children's sleep and cardiometabolic health. Of these, seven [14,15,19,23,32,42,45] examined sleep duration, three [2,4,37] examined sleep duration and quality, one [47] examined sleep duration, quality and timing and one [3] examined sleep variability. As shown in Table 5, most associations reported on sleep duration, with very few reporting on sleep variability or timing.

Cardiometabolic health was examined in terms of a composite cardiometabolic risk score [4,32], multiple cardiometabolic risk factors [3,14,15] or as individual cardiometabolic risk factors (i.e., lipid profile, glycaemic control, inflammation and cardiovascular function) [2,4,19,23,37,42,45,47].

Cardiometabolic risk

Six reviews [3,4,14,15,32,42] examined the association between children's sleep and cardiometabolic risk. Of these, three [14,15,32] reviewed the evidence for sleep duration. Two [14,15] considered cardiometabolic health as part of a larger study that considered all health outcome measures in pre- and school-aged children, while two studies [32,42] reviewed the evidence for sleep duration as a component of 24-h movement-based behaviours. Two reviews [3,4] examined other characteristics of sleep (i.e., sleep quality and variability). All reviews were descriptive in nature.

The association between children's sleep duration and cardiometabolic risk was examined in four reviews [14,15,32,42]. Chaput and colleagues [15] reviewed the evidence for school-aged children and reported most studies (17 of 19) reveal mixed or non-significant results and are of very low to low methodological quality. In a similar review [14] for preschool children, no studies were identified. Saunders and colleagues [32] and Grgic and colleagues [42] examined the association between sleep duration and cardiometabolic risk, but adopted a different approach. Here, authors aimed to determine whether sleep, as a component of the 24-h d, is associated with cardiometabolic risk. In the review by Saunders and Colleagues [32], only one study was identified, where it was noted that activity compositions characterised by higher sleep, lower sedentary time and higher moderate-vigorous physical activity (MVPA) resulted in a greater improvement in metabolic syndrome after a 200-d follow up, when compared to daily

Table 5
Summary of the number of associations reported across reviews that examined the association between children's sleep and cardiometabolic health (excluding adiposity).

	Favourable	Mixed/Null	Unfavourable	Total
Duration	66 (23%)	156 (54%)	15 (5%)	237
Quality	21 (7%)	16 (6%)	3 (1%)	40
Variability	1 (0.5%)	5 (2%)	0	6
Timing	4 (1%)	1 (0.5%)	0	5
Total	92	178	18	288

compositions characterised by low sleep, high sedentary time and lower MVPA. Grgic and colleagues [42] reported on two isotemporal substitution studies and reported findings were unclear or insignificant.

Two reviews [3,4] considered characteristics of sleep other than sleep duration only. Becker [3] reviewed the evidence for sleep variability and reported on only one study, which revealed no association between sleep duration variability and metabolic markers (glucose, cholesterol), but a significant association with triglycerides in obese children. Few studies were also identified in the review by Matthews and colleagues [4], who set out to determine the evidence for an association between sleep characteristics (duration, quality and continuity) and cardiometabolic risk. Although the authors noted that the evidence for an association between children's sleep characteristics and metabolic syndrome is weak, it was also noted that the results tend to be more positive for studies that use objective sleep assessment and suggest future studies should preferentially use objective measures of sleep.

Lipid profiles

Five studies [2,4,15,19,47] reviewed the evidence for an association between sleep and lipid profile. Of these, three [15,19,47] considered the role of sleep duration and two [2,4] considered the role of multiple sleep characteristics.

De Azevedo and colleagues [19], in the first attempt to review the evidence for an association between children's sleep duration and blood lipid profile, identified seven studies. Of these, only three reported an association, two suggested short sleep is associated with poor lipid profiles (i.e., higher total cholesterol and LDL-cholesterol) and the other suggested longer sleep is associated with higher triglyceride levels. The authors of this review [19] reported a lack of consistent evidence to support an association and noted important methodological limitations, including heterogeneity in assessing sleep and blood lipid profiles. Limited and inconsistent findings were also reported in more recent reviews by Chaput and colleagues [15], who reported on five studies and Fobian and colleagues [47], who reported on eight studies.

Reviews that examined the association between multiple sleep characteristics and blood lipid profiles maintained that sleep duration may not play an important role, although other characteristics may. Matthews and colleagues [4], noted that the evidence does not support an association between sleep characteristics and blood lipids in children, however, it must be noted that most studies focused on sleep duration, with relatively few studies on sleep quality, all of which indicate a favourable association. Similarly, Quist and colleagues [2], noted no association between children's sleep duration and blood lipid profile across most studies identified, but a positive association across the few available studies on sleep disturbances/quality, timing and variability. Quist [2] also noted that positive associations were more often reported in girls and that detailed information about potential confounders and mediators is lacking.

Glycaemic control

Five reviews [2,4,23,37,47] examined the association between children's sleep and glycaemic control. With the exception of one review [23], which examined the association between objectively-measured sleep duration and glycaemic control, all reviews considered the role of multiple sleep characteristics (i.e., duration, quality, timing, variability), assessed in a variety of ways (i.e., subjectively and objectively).

All five reviews [2,4,23,37,47] considered the role of sleep duration on glycaemic control in children. In the earliest review, Matthews and colleagues [4], identified thirteen cross-sectional studies, with just over half (62%) reporting short sleep is associated with poorer glycaemic control in children aged 3–26 y. Inconsistent results were also reported by Fobian and colleagues [47], where five of the ten studies identified reported mixed or null findings. Dutil and colleagues [37] identified twenty-three relevant studies (21 observational and 2 experimental) covering children aged up to 19 y of age. Of these, 10 cross-sectional studies reported no association for sleep duration, while both longitudinal studies reported significant associations. The authors of this review [37] noted findings were often attenuated by adiposity, maturity, sex and age. Felso and colleague [23] reviewed the association between objectively-measured sleep duration and glycaemic control in children aged 8–19 y. Of the four studies identified, mixed findings were reported. Specifically, a negative or U-shaped association was found for HOMA (Homeostatic Model Assessment, a method for assessing insulin resistance), while a positive association was found for insulin sensitivity (Matshuda index). Non-significant or mixed findings were also reported in most studies (15 of 21) reviewed by Quist and colleagues [2]. Non-significant findings were also reported in the meta-analysis by Quist and colleagues [2] to determine the association between sleep duration and HOMA-IR ($r = 0.01$, 95% CI −0.03, 0.05).

The role of sleep characteristics, other than sleep duration, were examined by four reviews [2,4,37,47]. Matthews and colleagues [4] identified two studies that reported poor sleep continuity was associated with poorer blood glucose profiles across both studies identified. Similarly, Fobian and colleagues [47] reported sleep quality (two of three studies) and timing (one of one study) was favourably associated with glucose control and insulin sensitivity in the very few studies identified. Dutil and colleagues [37] identified a favourable association for most studies (five of six) that examined the role of sleep quality and architecture while Quist and colleagues [2] identified that while there are some studies to suggest sleep timing may be favourably associated with blood glucose regulation, few studies exist, each of which consider different measures of glucose control. Quist also noted the importance of considering potential confounders and mediators, noting most studies report that adiposity mediates the association between sleep duration and insulin resistance/hyperglycaemia. Although age was considered by most studies, puberty stage and physical activity was rarely examined.

Inflammation

Three studies [2,15,47] reviewed the association between sleep and inflammation. Chaput and colleagues [15] considered the role of sleep duration in school-aged children and identified one study, which found mixed results, depending on the different inflammatory biomarkers. Fobian and colleagues [47] identified two studies that examined the association between night-time sleep duration and inflammation (measured in terms of C-reactive protein) and reported mixed results. Quist and colleagues [2] identified nine relevant studies, with notable differences reported according to sex in some studies. While Quist and colleagues [2] noted some evidence exists to support an association in the hypothesised direction, the authors could not draw a solid conclusion due to the limited number of studies and heterogeneity in biomarkers considered.

Blood pressure

The association between sleep and blood pressure was reviewed by five papers [2,4,15,45,47]. Of these, four [2,4,15,45] considered sleep duration and two [2,4] considered sleep quality and timing.

Chaput and colleagues [15] reviewed the evidence for an association between school-aged (5–17 y) children's sleep duration and blood pressure. Of the seven studies identified, only one reported a favourable association, with most studies (five of seven) reporting mixed/null findings. Matthews and colleagues [4] considered a wider age range of children (3–19 y) and identified 21 different studies that examined the association between characteristics of children's sleep and blood pressure. Of the 22 associations reported for sleep duration, eight were favourable and 12 were mixed or non-significant. Mixed results were also reported by Fobian and colleagues [47], where four of the eight studies identified reported favourable results and the other half reported mixed/null findings. Similar mixed results were reported by Quist and colleagues [2] in a review of 30 different studies, albeit a modest yet beneficial effect of long sleep duration was identified from meta-analyses (systolic blood pressure $\beta = -0.33$ mmHg per 1hr longer sleep duration, 95% CI $= -0.57, -0.09$, $p = 0.009$; diastolic blood pressure $\beta = -0.21$ mmHg per 1hr longer sleep duration, 95% CI $= -0.33, -0.10$, $p = 0.002$). In another, more recent review and meta-analysis by Jiang and colleagues [45], short sleep duration was significantly associated with an increased risk of high blood pressure (OR 1.51, 95% CI 1.04, −2.19), while long sleep duration was not (OR 1.04, 95% CI 0.78, −1.38). Subgroup analyses revealed short sleep duration presented a greater risk in males compared to females.

Mixed results were reported for characteristics other than sleep duration. Matthews and colleagues [4] did not find any favourable associations for sleep quality or continuity across the six associations reported, while Quist and colleagues [2] reported mixed results in three of the six studies identified as examining the association between children's sleep quality and blood pressure.

Overall, reviews fail to provide compelling evidence for an association between children's sleep and cardiometabolic health. Reviews [2,4] indicate most studies concentrate on the role of sleep duration, with few studies on sleep quality and even fewer studies on sleep timing and variability. With the exception of blood pressure, where a small significant association was reported [2], most reviews reported mixed or no association between children's sleep duration and cardiometabolic outcomes. Limited available studies on other characteristics of sleep were suggest to have a potentially important role on children's cardiometabolic health [2,4]. Although Quist [2] noted association were at time independent of sleep duration, reviews largely considered the different sleep characteristics in isolation of each other. There was also considerable variation in the inclusion of potential confounders across studies. In general, adiposity, puberty stage, sex and age were considered important. Though the role of physical activity was perhaps underexplored, it was acknowledged as important in a number of reviews [2,4,32]. Indeed, one review considering sleep as a component of the 24-h d, alongside physical activity and sedentary time.

Adiposity

Most papers (62%) reviewed the sleep-obesity link in children. Of these, all but six reviews [2,3,22,39,40,47] considered sleep characteristics other than duration. Of these, two [2,22] considered sleep duration and quality, two [39,47] considered sleep duration in addition to two other sleep characteristics, one [40] considered all four characteristics and one [3] considered sleep variability. As shown in Table 6, most associations reported on sleep duration.

Six papers [2,18,23,29,36,39] reviewed the cross-sectional association between children's sleep and adiposity. Patel and colleagues [29] identified eleven studies and reported a consistent and strong association between short sleep in children. Consistent findings were reported by Hart [39] and Felso [23]. Unlike other reviews, Felso colleagues [23] exclusively examined studies that objectively measured children's sleep duration. Cappuccio and colleagues [36] conducted a meta-analysis of identified studies and reported an association between children's sleep duration and obesity (OR 1.89, 95% CI 1.46, 2.43). Similar results (OR 1.58, 95% CI 1.26, 1.98) were reported in a meta-analysis by Chen and colleagues [18] who also revealed that children with sleep durations less than recommended values ($\geq$11 h for children <5 y; $\geq$10 h for children 5–10 y; $\geq$9 h for children $\geq$10 y) had a significantly higher odds of OW/OB (OR 1.60, 95% CI 1.22, 2.10). Unlike other reviews, which examined adiposity in terms of body mass index, Quist and colleagues [2] reviewed the association between children's sleep duration and waist circumference. In this review, eight cross-sectional studies, consisting of sixteen data-analyses, were meta-analysed to reveal short sleep in children is associated with an increased waist circumference ($\beta = -1.34$ cm per 1hr longer sleep duration, 95% CI −1.83, −0.85).

Table 6
Summary of the number of associations reported across reviews that examined the association between children's sleep and adiposity.

	Favourable	Mixed/Null	Unfavourable	Total
Duration	299 (61%)	140 (29%)	4 (1%)	443
Quality	15 (3%)	11 (2%)	0	26
Variability	2 (0.4%)	8 (1.6%)	0	10
Timing	4 (1%)	4 (1%)	0	8
Total	320	163	4	487

Five papers [4,27–29,33] reviewed the longitudinal association between children's sleep and obesity. Patel and colleagues [29], in the earliest review identified two longitudinal studies, both of which supported a favourable association. Since this review, Magee and colleagues [27] identified seven studies, of which all but one reported that short sleep predicts future obesity. Likewise, reviews by Thind [33] and Nielsen [28] also reported short sleep was associated with future obesity risk in most studies. These reviews also discussed important methodological considerations. Of particular note, Magee [27] identified variation in the selection of potential confounding variables across studies and raised concerns about the inclusion of appropriate confounding and moderating variables. Specifically, sleep problems, time-varying covariates and media use were identified as important covariates to consider. Similarly, Thind and colleagues [33] also noted a large number of studies (seven of 22 studies) did not report an association between children's sleep and obesity, after controlling for baseline body composition. Methodological issues were further reviewed by Nielsen and colleagues [28], who discussed measurement issues beyond the need to utilise objective assessment tools, such as the potential importance of considering characteristics of sleep other than just duration. Matthews and colleagues reviewed longitudinal studies of children's sleep and obesity published after 2011 and that were not included in previous reviews. This review identified 16 studies of relevance, of these, only two reported non-significant differences, while eight suggested a positive relationship and six reported relationships varied according to age, sex, and adiposity measure.

Meta-analyses of longitudinal studies appeared to support descriptive findings. Wu and colleagues [35] reviewed thirteen longitudinal studies covering 35,540 children aged 0–18 y and found short sleep duration in children to be significantly associated with the odds of future obesity (OR, 1.71; CI: 1.36–2.14). In a similar, larger study, Ruan and colleagues [31] reviewed the longitudinal relationship between children's sleep duration and risk of overweight/obesity across 25 different studies, covering 56,584 children from 10 different countries, but predominantly the US, with an

average follow up period of 3.4 y. The findings of this review were consistent with aforementioned studies, that short sleep is a risk factor for obesity (OR 1.76, 95% CI: 1.39, 2.23), with the odds of overweight/obesity 21% lower with every 1 h/d sleep duration increment. In terms of annual body mass index (BMI) gain, Ruan and colleagues [31] revealed children with short sleep duration had a significantly greater annual BMI gain (β coefficient 0.13, 95% CI 0.01, 0.25), with every 1 h/d sleep duration increment decreasing BMI gain by 0.05 kg/m^2. Likewise, Fatima and colleagues [21], in a meta-review of eleven longitudinal studies, covering 24,821 children, found that the odds of overweight/obesity were twice as likely in children with short sleep durations compared to children with long sleep durations (OR 2.15, 95% CI 1.64–2.81). Similarly, Miller and colleagues [43] in a systematic review and meta-analysis of prospective studies, reported sleep is an important risk factor in the development of obesity in infants ($k = 7$; $n = 14{,}738$; RR 1.40, 95% CI 1.19, 1.65, $p < 0.001$), early childhood ($k = 8$; $n = 31{,}104$; RR 1.57, 95% CI 1.40, 1.76, $p < 0.001$), middle childhood ($k = 3$; $n = 3005$; RR 2.23, 95% CI 2.18, 2.27, $p < 0.001$), and adolescents ($k = 3$; $n = 26{,}652$; RR 1.30, 95% CI 1.11, 1.53, $p < 0.002$).

Subgroup analyses for sex and age were conducted across a number of meta-reviews. Chen and colleagues [18] reported a two-fold increase in obesity among boys compared to girls across cross-sectional studies, while Ruan reported no longitudinal difference according to sex. Three meta-reviews [18,31,35] examined the effect of age. Chen and colleagues [18] in a review of cross-sectional studies revealed a stronger association for children aged 10 y and older compared to younger children (OR 1.62 vs. 1.51). In contrast, a stronger association was reported for younger children (aged <5y) in a review of longitudinal studies by Wu and colleagues [35], while Ruan and colleagues [31] reported no age differences in their review of longitudinal studies.

Four reviews [25,32,34] considered sleep duration within the context of time-use and lifestyle factors. Kuzik [25] and Saunders [32] examined the combined effect of sleep, physical activity and sedentary behaviours of childhood obesity. Although few studies examined the complete activity profile (sleep, physical activity and sedentary time), higher sleep profiles (i.e., longer sleep duration) were associated with lower risk of overweight/obesity in most of the available studies. Grgic and colleagues [42] reviewed isotemporal substitution studies to determine the interplay between sleep, physical and sedentary behaviours. Although this review identified twelve relevant studies, discussion of study findings focused on substituting sedentary behaviours with physical activity, with the role of sleep largely not assessed. Woo and colleagues [34] reviewed risk factors for childhood obesity in the first 1000 d of life. Here, sleep was noted as an important risk factor, although only four studies were identified.

Jansen and colleagues [40] reviewed the literature to determine the association between sleep, diet and cardiometabolic health. Specifically, whether the association between sleep and cardiometabolic health is confounded, mediated or modified by diet. In this review, 31 paediatric studies were identified, of which, all but one examined adiposity. The authors of this review suggested that the current available evidence suggests diet mediated the sleep-adiposity pathway. This suggests that adjusting for dietary variables when examining the association between sleep and adiposity may attenuate effect estimates.

Seven reviews [2,3,22,39,40,47] reviewed characteristics of sleep other than sleep duration, all of which noted limited available evidence. Hart and colleagues [39] identified eight studies, most of which reported positive ($k = 4$) or mixed findings ($k = 3$). In contrast, Becker and colleagues [3] in a review of sleep variability, identified only eight studies on adiposity, most of which reported non-significant associations. Limited and mixed results were also reported by Fobian [47], Jansen [40] and Quist and colleagues [2], while Fatima and colleagues [22] conducted a meta-analysis on eighteen studies (mostly cross-sectional) and noted poor sleep quality was associated with obesity in children, adolescents and young adults (OR 1.46, 95% CI 1.24–1.72), independent of sleep duration.

Overall, systematic reviews strongly support a cross-sectional and longitudinal association between children's sleep duration and obesity, with differences according to age and sex. The reviews also identify the need to consider potential confounding and mediating variables, such as baseline adiposity, when considering longitudinal associations. The importance of considering other known predictors of childhood obesity (physical activity and sedentary behaviours) was also acknowledged. Indeed, two reviews explored the combined effects of sleep, activity and sedentary time. Few studies appear to have examined the association between children's activity profile and adiposity, though this may reflect the way in which considering sleep as a component of time use is a relatively new concept [10]. Compared to sleep duration, relatively few studies have examined the role of sleep quality, timing and variability. These reviews suggest characteristics other than duration may also be important independent predictors of adiposity.

Other health outcomes

Other health outcome measures considered for review include musculoskeletal pain, risk of harms/injuries and risk-taking behaviours (Table 7). Andreucci and colleagues [16] reviewed the association between children's sleep problems, defined in terms of duration, quality and tiredness, with musculoskeletal pain. Of the thirteen papers included for review, eight reported on sleep duration and ten reported on sleep quality, with only two studies reporting positive findings for each. Given that most studies reported mixed or no associations, the authors concluded that the current available evidence does not suggest that sleep problems are risk factors for musculoskeletal pain in children and adolescents. Three reviews [14,15,46] examined the evidence for an association between children's sleep duration and the risk of harms/injuries. One review [15] identified four studies on school-aged children, most (three of the four) reported mixed or no associations, while the other [14] identified three studies on school-aged children, most (two of the three) reporting a favourable association. In another review by Gao and colleagues [46], seven studies were identified. Of these, three were included in a meta-analysis, revealing children with short sleep were more likely to be injured (OR 1.58, 95% CI 1.05, 2.37). Short and Colleagues [41] reviewed the evidence examining the association between children's sleep and risk-taking behaviours. Of the twenty-six studies included for review, twenty-four were included in a meta-analysis, which revealed insufficient sleep was significantly associated with a greater likelihood of risk-taking behaviours (OR 1.43, 95% CI 1.26, 1.63).

Table 7
Summary of the number of associations reported across reviews that examined the association between children's sleep and musculoskeletal pain, harms/injury, risk taking behaviours.

	Favourable	Mixed/Null	Unfavourable	Total
Duration	25 (42%)	23 (39%)	1 (2%)	49
Quality	2 (3%)	8 (14%)	0	10
Total	27	31	1	59

Limitations

Table 8 presents a summary of the limitations reported in each of the reviews. Limitations considered study methodology, sleep measurement issues and issues around conceptualising sleep.

Study methodology

As presented, most reviews (79%) reported that the available body of evidence is limited by self-reported measures of sleep, which are prone recall and social desirability bias. A large proportion of reviews (49%) also commented on the limitation that most studies reviewed were of a cross-sectional study designs, from which causation cannot be concluded due to the correlational nature of such studies. The need for experimental and randomised controlled trials (involving sleep restriction and extension) and careful consideration around potentially confounding variables was also suggested in 38% and 67% or reviews, respectively. Methodological issues around the quality, robustness (study size and number of studies) as well as generalisability of studies included for review were also acknowledged as important issues. Reviews also noted various methodological issues relating to the outcome measure assessed.

Reviews identified covariates varied across studies [4,27,28,30]. While the effects of age and sex were explored in some reviews [5,18,20,31], other covariates, such as puberty status, socioeconomic status, adiposity and physical activity were not explicitly examined but acknowledged by a number of reviews [2,4].

Sleep measurement issues

A notable proportion of reviews (23%) commented that sleep characteristics are often inconsistently defined and/or conceptualised. For example, Lovato and colleagues [26] noted that the definition of 'poor' sleep varied across studies, while a number of reviews [29,35,39] noted that studies applied different reference values to categorise sleep length (i.e., sleep period time [sleep onset to sleep offset] vs sleep duration [sleep onset to sleep offset minus wake after sleep onset]). Similarly, De Azevedo [19] and colleagues noted that characteristics of sleep may be derived and operationalised in a number of ways. For example, questionnaires may enquire about 'usual night-time sleep' or operationalise sleep duration based on responses to questions regarding bedtime, wake-time and/or night-time awakenings. Given that sleep usually varies across school and non-school nights, different measures may not be commensurable. There

Table 8
Summary of limitations noted in each review.

Study	Self-report (sleep)	Mostly cross-sectional	Need for experimental studies	External validity	Robustness	Study quality	Sleep reference values	Defining sleep characteristics	Confounding variable	Sleep as a component of time	Multiple sleep characteristics
Astill [5]	x	x	x		x						
Chaput [14]	x	x			x	x			x		x
Chaput [15]	x	x	x			x				x	x
Saunders [32]	x	x	x			x			x	x	
Dewald [20]	x	x	x						x		x
Lundahl [38]				x							x
Kopasz [24]	x		x						x		x
Lovato [26]		x						x	x		
Cairns [17]											
De Azevedo [19]	x	x		x			x	x	x		
Matthews [4]	x	x	x						x		x
Cappuccio [36]	x	x		x					x		
Chen [18]	x	x	x						x	x	
Fatima [21]	x										x
Fatima [22]	x	x						x	x		x
Hart [39]	x	x	x				x		x	x	x
Magee [27]	x	x							x	x	x
Nielsen [28]	x		x						x		x
Patel [29]	x	x					x		x	x	x
Ruan [31]	x						x		x	x	x
Thind [33]	x								x	x	x
Woo [34]	x	x									x
Wu [35]	x			x			x				
Becker [3]	x		x	x	x			x			x
Felso [23]			x	x	x				x	x	
Andreucci [16]	x			x		x		x	x		
Kuzik [25]	x				x	x		x		x	
Reynaud [30]	x	x	x	x	x			x	x		x
Dutil [37]					x				x	x	x
Quist [2]	x	x					x	x	x		
Short [1]			x		x				x		x
Chiu [44]	x	x		x							
Miller [43]	x										
Short [41]	x		x	x			x		x		
Gao [46]					x			x			
Fobian [47]	x		x						x		x
Miller [43]	x								x		
Grgic [42]		x							x	x	
Jansen [40]	x										x
TOTAL	**31**	**19**	**15**	**10**	**9**	**5**	**7**	**9**	**26**	**12**	**21**

'x' denotes limitation identified in each review.

also appears to be confusion and inconsistencies in how sleep characteristics are conceptualised. For example, Fatima and colleagues [22] identified 'considerable variation across studies in defining key terms [used to describe characteristics of children's sleep]' and noted '…inconsistency in defining sleep quality, or the vague use of terminology is an important source of variability…' the authors concluded that 'these findings highlight the complexity of sleep quality and the importance of understanding the different constructs' and acknowledged that objectively assessed indicators are relatively less explored.

Conceptualising sleep

Rethinking sleep, beyond traditional approaches that examine an isolated sleep characteristic and a given health outcome, was also noted in a number of reviews. In line with our narrative review [10], the need to consider sleep as a component of the 24-h d (e.g., consider sleep alongside physical activity and sedentary behaviour) and as a multidimensional construct (i.e., characteristics other than duration) was acknowledged in 31% and 54% of reviews, respectively. Given that sleep characteristics occur simultaneously and are a component of the 24-h d, empirical analyses that conceptualise sleep in this way may add to our understanding of how sleep contributes to health [10].

None of the reviews examined the evidence for an association between sleep, as a multidimensional construct, and health. Although ten studies [2,4,5,16,20,22,26,30,37,39] examined multiple characteristics of children's sleep, all adopted traditional methods of reporting associations for individual characteristics.

Only three reviews [25,32,42] examined the evidence for an association between sleep, as a component of the 24-h d, and health. Overall, few studies were identified, most of which considering only two components of time (e.g., physical activity and sedentary time), with little focus on sleep as the main predictor.

Discussion

Principal findings

To our knowledge, this is the first meta-review to examine the evidence for an association between children's sleep and health. A total of 39 different systematic reviews were identified, covering areas of cognitive, psychosocial and cardiometabolic health. In line with the emergence of poor sleep as a serious health concern, a notable increase in the number of reviews published was observed, particularly over the last three years. Overall, sleep was identified as important for children's health and well-being. There is substantial and consistent evidence relating sleep duration to adiposity and emotional outcomes. The relationships between sleep quality and timing and blood lipids and glycaemic control merit further research. Links between sleep and metabolic syndrome in children appear to be weak and inconsistent.

Strengths and weaknesses

This study provides an overview of findings reported in systematic reviews that examine the sleep-health link in children. Synthesis of systematic literature reviews are able to provide a summary of the best available evidence and identifies key areas in need of further research. Given the growing body of sleep-health literature, this review provides valuable insight into our current understanding, areas of interest and aspects in need of further research. This review may help guide future studies, particularly in addressing deficits and limitations identified, thereby enhancing our understanding of the health-related consequences of children's sleep.

Despite the strengths of this study, there are also limitations. It must firstly be acknowledged that this review does not provide an overview of the entire body of literature, only a summary of findings from systematic reviews, not individual studies or meta-reviews. It must therefore be noted that there may be an overlap of primary studies, with a potential to bias summary table results. This is a common limitation of meta-reviews and has been noted previously [48]. Few reviews provided a quality appraisal of individual studies. Similar to other previously published meta-reviews [49], we did not provide a quality appraisal of systematic reviews as the aim of this meta-review was to provide an overview of findings and limitations reported by available systematic reviews. It is also important to note that it may be possible that the large number of positive findings reported may have arisen as a result of publication bias [50] and results may need to be viewed with caution. A review of individual studies is unlikely to overcome this limitation. It is important to note, however, that some studies have been reported in several reviews. Only sleep characteristics, including sleep duration, quality, timing and variability, were considered. Studies that examined sleep disorders and sleep architecture were not considered for review. We applied a broad search strategy to identify all available reviews, however, as reviews identified, the language used to describe sleep characteristics are not consistent and it may be possible that reviews may have been missed because of this. Lastly, only studies written in English were considered.

Unanswered questions and future research

Our meta-review suggests sleep is important for children's health. Of the 1196 associations reported, 614 were positive. Sleep duration was the focus of most reviews, with limited evidence for sleep quality, timing and variability. Given that most studies were observational in nature and different statistical approaches were applied, with a range of different outcome variables for a given outcome measures, we used a Bayesian approach to help evaluate the evidence. Applying this theorem (see Fig. 3), synthesised results suggest sleep duration is likely to be associated with children's adiposity, cognition and psychosocial health but less likely to be associated with children's cardiometabolic health, although other characteristics such as sleep timing, may be. It remains unclear whether there is an association for other sleep characteristics and health outcomes.

In order to better understand the sleep-health link in children, results of this meta-review suggest further research is needed. In addition to studies that examine areas of health with limited research (e.g., health-related quality of life and inflammation), further research is needed on characteristics of sleep other than duration, such as sleep quality, timing and variability. It would also be of interest to understand the interaction of sleep characteristics [10]. There is also a need for more studies that apply reliable and valid methods of assessing children's sleep are needed. Indeed, the sleep-health association may differ depending on whether sleep is objectively assessed, with larger effect sizes reported for objectively-measured sleep characteristics in some [4], but not all instances [5,20]. As noted in a number of reviews [27,28], there is great diversity in the inclusion of potential confounders between studies, which poses questions regarding possible residual confounding. For children, putative confounders for the sleep-adiposity link appear to be age, sex, measures of socioeconomic status and aspects of time-use (e.g., physical activity and media use) and baseline adiposity [27]. Reviews examining other health outcomes, also made note of these potential confounders.

As previously discussed [10], sleep is a component of the 24-h d, co-occurring with other lifestyle behaviours, such as physical activity and sedentary time, which are also known to affect health. Adopting this view, it is important to consider sleep as part of the entire 24-h activity profile rather than as an isolated behaviour. Given that behaviours (sleep, physical activity, and sedentary time) are co-dependent, the use of compositional data analysis (CoDA) is gaining interest in place of traditional statistical linear regression models, which are unable to handle the multicollinear nature of time-use data [10]. While our meta-review indicates interest in understanding how sleep, as a component of time, influences health, the three systematic reviews [25,32,42] that explored this concept identified very few studies, none of which applied CoDA techniques.

Conclusion

This is the first meta-review to examine the sleep-health link in children. Meta-reviews are important in providing an overall synthesis of findings derived from systematic reviews, which are considered one of the highest level of available evidence [51]. In synthesising these findings, were able to identify key findings, trends, limitations and areas in need of further work. Further, this study design allowed us to compare evidence available across different types of health outcomes and sleep variables, which may not be possible under a single systematic review. This is an important task for the field of Sleep Medicine, where sleep is fast evolving as an important component of population health. Overall, sleep appears important for children's health and well-being, however, further research is needed, particularly in areas other than adiposity and sleep duration. There is also a clear need to better understand the role of sleep duration with a 24-h activity profile and the role of sleep characteristics, such as sleep quality, timing and variability, and their interaction with sleep duration.

Practice points

- Sleep is important for children's health and well-being.
- Compelling evidence suggests sleep duration is associated with adiposity in children.
- Sleep quality, timing and variability also appear important for children's health, but further research is needed.
- Current available evidence is primarily cross-sectional and relies on self-report sleep data.

Research agenda

- Further research is needed to determine the association between objectively measured sleep and children's health, particularly health outcomes other than adiposity
- While the evidence suggests sleep quality, timing and variability may be important for children's health and well-being, further research is needed.
- Sleep is a multidimensional construct (involving duration, timing, quality and variability), as well as component of the 24-h d. Further research is needed to better understand the sleep-health link, when conceptualised in this way.

Conflicts of interest

The authors do not have any conflicts of interest to disclose.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.smrv.2019.04.011.

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