Background

Sleep is essential for healthy cognitive, psychosocial, and physical health [1, 2]. Healthy sleep is generally defined by adequate duration, appropriate timing, good quality, and the absence of sleep disturbances or disorders [3]. Sleep-wake regulation and sleep states evolve rapidly during the first year of life, with continued maturation across childhood [4]. For example, newborns (0–3 months) do not have an established circadian rhythm [5]; this begins to emerge at around 10–12 weeks of age, with sleep becoming more nocturnal between ages 4–12 months [6]. Children continue to take daytime naps between 1 and 4 years of age, and night wakings are common in infancy and early childhood [7]. By age 5, daytime napping typically ceases and overnight sleep duration gradually declines throughout childhood, in part due to a shift to later bedtimes and unchanged wake times [7].

Sleep patterns can vary between individuals and are explained by a complex interplay between genetic, environmental, behavioural, and social factors. For example, factors such as parenting practices and expectations, family routines, cultural preferences, and daycare schedules can all influence sleep [4]. Findings from a recent systematic review of 69,542 infants, toddlers, and preschoolers from 18 countries showed mean reference values and ranges (± 1.96 SD) of 12.8 h/day (9.7–15.9) for infants (< 2 years), and 11.9 h/day (9.9–13.8) for toddlers/preschoolers (ages 2–5 years) [8]. These international normative data can help to determine the normative distribution of sleep duration, but cannot identify duration associated with health benefits.

Although many studies have confirmed the importance of sleep duration for individual health outcomes, to our knowledge no study has attempted to systematically and comprehensively examine the literature on the associations between sleep duration and a broad range of health indicators in children aged 0–4 years. A systematic review can help to determine whether the available evidence supports existing sleep duration recommendations. The National Sleep Foundation recommends that for every 24-h cycle, newborns (0–3 months) obtain 14–17 h of sleep, infants (4–11 months) obtain 12–15 h of sleep, toddlers (1–2 years) obtain 11–14 h of sleep, and preschoolers (3–5 years) obtain 10–13 h of sleep [9]. Similarlw507(450(T1_d4(,)-)Tj97(a)13e3(9.9)]cabos7aTJT*)14-12al4 normaobtain 11

Outcomes (health indicators)

Ten health indicators were chosen based on the literature, expert input and consensus, and recognition of the importance of including a broad range of health indicators. Five health indicators were identified as critical (primary outcomes) by expert agreement: (1) adiposity (e.g., overweight, obesity, body mass index, skinfold thickness, body fat); (2) emotional regulation (e.g., mood, social-emotional problems, stress, hyperactivity/impulsivity); (3) cognitive development (e.g., learning, memory, attention, concentration, language development); (4) motor development (e.g., gross motor skills, fine motor skills, locomotor and object control); and (5) growth. Five health indicators were identified as important (secondary outcomes) by expert agreement: (1) cardiometabolic health (e.g., blood pressure, blood lipids, glucose, insulin); (2) sedentary behaviour (e.g., screen time); (3) physical activity (e.g., moderate- to vigorous-intensity physical activity); (4) quality of life/well-being; and (5) risks/injuries.

Study designs

All study designs, except case studies, were eligible for inclusion in this systematic review. In longitudinal studies, any follow-up length was allowed; however, the exposure had to be assessed at least once during the identified age range. There were no sample size restrictions for studies included in this systematic review. Published peer-reviewed original manuscripts and "in press" articles were eligible for inclusion, as were studies with results posted to a trial registry. Grey literature, book chapters, disseresg(i)17ov2/7ov2/a(n)14(su)e2(g(i)17/)24(gi)22(nt)12(i)1173(rs,ent)12(i)1ce istracts

Inform ion sources and search strategy

A research librarian wit expertise in ystematic review searching created the eleinic search strategy. A second researc librarian peer-reviewed it. See [redacted] adiposity [redacted] able S2). Among th [redacted] ted that shorter sleep duration [redacted] posity gain [17–26], 2 reported nu [redacted] d 1 reported that longer [redacted] sity gain [redacted]

Table 1 Association between sleep duration and adiposity in children aged 0–4 years

No of studies	Design	Quality Assessment					No of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
Mean age ranged between 0 and 4.9 years. Data were collected cross-sectionally and up to 9.5 years of follow-up. Sleep duration was assessed by actigraphy or parent report. Adiposity was assessed objectively as body weight, body mass index (absolute, z-score or percentile), waist-for-length ratio, weight status (different definitions for underweight, normal weight, overweight, obese) or % body fat/fat mass/fat mass index (bioelectrical impedance, dual-energy X-ray absorptiometry, skinfolds).									
13	Longitudinal study[a]	No serious risk of bias	No serious inconsistency	No serious indirectness	No serious imprecision	None	31,482	Out of 13 longitudinal analyses, 10 reported a significant association between shorter sleep duration and adiposity gain [17–26], 2 reported null findings [27, 28], and 1 reported that longer sleep duration predicted adiposity gain [29].	LOW
18	Cross-sectional study[b]	No serious risk of bias	No serious inconsistency	No serious indirectness	No serious imprecision	None	30,829	Out of 18 cross-sectional analyses, 10 reported a significant association between shorter sleep duration and adiposity [23, 26, 30–37], 7 reported null findings [24, 25, 27, 28, 38–40], and 1 reported that sleep duration was positively associated with BMI z-scores [41].	LOW

Due to heterogeneity in the measurement of sleep and adiposity, a meta-analysis was not possible
[a]Includes 13 longitudinal studies [17–29]
[b]Includes 18 cross-sectional studies [23–28, 30–41]

evidence remained at "low" for the longitudinal studies. Among the 18 cross-sectional studies, 10 reported a significant association between shorter sleep duration and adiposity [23, 26, 30–37], 7 reported null findings [24, 25, 27, 28, 38–40], and 1 reported that sleep duration was unfavourably associated with adiposity [41]. The quality of evidence remained at "low" for the cross-sectional studies.

Emotional regulation

A total of 25 studies examined the association between sleep duration and emotional regulation (Table 2 and Additional file 2: Table S2). The 2 randomized studies (both randomized cross-over trials) showed better self-regulation strategies and emotional responses in the routine sleep versus the sleep restriction condition [42, 43]. The quality of evidence remained at "high" for the randomized trials. There was also 1 non-randomized trial showing a reduced morning cortisol awakening response after sleep restriction [44]. The quality of evidence was downgraded from "low" to "very low" because of a serious risk of imprecision. Among the 5 longitudinal studies, 2 reported that shorter sleep duration was associated with poorer emotional regulation at follow-up [45, 46], while 3 reported null findings [47–49]. The quality of evidence remained at "low" for the longitudinal studies. Among the 17 cross-sectional studies, 8 reported that shorter sleep duration was associated with poorer emotional regulation [50–57], 7 reported null findings [38, 49, 58–62], and 2 reported opposite associations [63, 64]. The quality of evidence was downgraded from "low" to "very low" due to a serious inconsistency in the findings.

Cognitive development

A total of 16 studies examined the association between sleep duration and cognitive development (Table 3 and Additional file 2: Table S2). One randomized trial examined this association [65] and found that the number of correct answers in an explicit recognition task was significantly higher in the nap condition compared to the wake (sleep restriction) condition; however, implicit memory (priming task) did not differ between conditions. The quality of evidence remained at "high" for this randomized trial. The 4 longitudinal studies that examined the relationships between sleep duration and cognitive development provided mixed findings, although they had mainly favourable associations or null findings [66–69]. The quality of evidence for longitudinal studies remained at "low". Finally, of 11 cross-sectional studies, 7 reported null findings [38, 51, 55, 70–73], 3 reported that shorter sleep duration was associated with poorer cognitive function [57, 74, 75], and 1 reported opposite associations [76]. The quality of evidence remained at "low" for the cross-sectional studies.

Motor development

Two cross-sectional studies examined the association between sleep duration and motor development (Table 4 and Additional file 2: Table S2). Both studies reported no associations between sleep duration, and gross and fine motor skills [38, 51]. The quality of evidence remained at "low" for the cross-sectional studies.

Growth

Two studies examined the relationship between sleep duration and linear growth (Table 5 and Additional file 2: Table S2). The longitudinal study by Lampl et al. [29] showed that higher total daily sleep hours and number of sleep bouts were significantly associated with growth in infant length. The quality of evidence was downgraded from "low" to "very low" for this study because of a serious risk of bias. In the cross-sectional study [77], sleep was assessed both objectively and subjectively in 6-month-old infants. The authors reported that shorter actigraphy-measured sleep duration was associated with higher weight-for-length ratio in girls only. The results also showed that, in the total sample, shorter night sleep duration (as reported by parents) was associated with higher weight-for-length ratio and weight above the expected weight for length. The quality of evidence was downgraded from "low" to "very low" due to a serious risk of imprecision.

Cardiometabolic health

No studies examined the association between sleep duration and cardiometabolic biomarkers in children aged 0–4 years.

Sedentary behaviour

A total of 5 studies (1 longitudinal study and 4 cross-

Table 3 Association between sleep duration and cognitive development in children aged 0–4 years

No of studies	Design	Quality Assessment					No of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
Mean age ranged between 6 months and 4.9 years. Data were collected cross-sectionally and up to 3 years of follow-up. Sleep duration was assessed by actigraphy or parent report. Cognition was measured by various instruments including memory tasks, imitation tasks, neuropsychological tests, interviews, scales of intelligence or questionnaires.									
1	Randomized trial[a]	No serious risk of bias	No serious inconsistency	No serious indirectness	No serious imprecision	None	23	The number of correct answers in an explicit recognition task was significantly higher in the nap (control) compared to the wake (sleep-restricted) condition, whereas implicit memory (priming task) did not differ between conditions [65].	HIGH
4	Longitudinal study[b]	No serious risk of bias	No serious inconsistency	No serious indirectness	No serious imprecision	None	438	Children getting higher proportions of their sleep at night as infants (i.e. 1 year) were found to perform better on executive functions, but did not show better general cognition [66]. Higher proportions of total sleep occurring at night time, at both 12 and 18 months, were associated with better performance on executive tasks, especially those involving a strong impulse control component. However, the total sleep duration at 12 and 18 months was not associated with executive functioning at 18 and 26 months. Sleep duration at 12 months was not correlated with 18 month working memory ($r = -0.11$, $p > 0.05$), 26 month conflict executive functioning ($r = -0.10$, $p > 0.05$) or 26 month impulse control ($r = -0.06$, $p > 0.05$). Sleep duration at 18 months was not correlated with 18 month working memory ($r = -0.16$, $p > 0.05$), 26 month conflict executive functioning ($r = 0.09$, $p > 0.05$) or 26 month impulse control ($r = -0.16$, $p > 0.05$) [67]. The number of daytimenaps was positively associated with both predicted expressive ($p = 0.062$) and receptive vocabulary growth ($p = 0.006$), whereas the length of nighttime sleep was negatively associated with rate of predicted expressive vocabulary growth ($p = 0.045$) [68]. Children who had 8 h or more of sleep had significantly higher General Conceptual Ability (GCA) scores than those with 7 h or less of sleep by 35.53 points at age 3. Children with more than 10 h of sleep had higher GCA scores at age 3 compared to children with 8–998(to)sasof) sco5.9(neg)evs.oca203.92,ocaGCAhec-299(n=)-194645) [	

evidence was downgraded from "low" to "very low" due to a serious risk of bias. The 3 cross-sectional studies [30, 31, 81] showed either favourable (i.e., longer sleep duration was associated with more physical activity) or null findings. The quality of evidence remained at "low" for the cross-sectional studies.

Quality of life/well-being

Only 1 study examined the association between sleep duration and quality of life/well-being (Table 8 and Additional file 2: Table S2). This longitudinal study found that short sleep duration at 3 years of age (< 10 h versus > 11 h) was not associated with poor quality of life at ~13 years of age [82]. The quality of evidence was downgraded from "low" to "very low" because of a serious risk of bias.

Risks/injuries

Three cross-sectional studies examined the association between sleep duration and risks/injuries in children aged 0–4 years (Table 9 and Additional file 2: Table S2). Koulouglioti et al. [83] reported that children with shorter sleep duration sustained a higher number of medically attended injuries. Likewise, Boto et al. [84] reported that a sleep duration shorter than 8 h per day was associated with an increased risk of accidental falls. In contrast, Owens et al. [85] did not find an association between sleep duration and injury risk. The quality of evidence remained at "low" for the cross-sectional studies.

Summary of findings

A high-level summary of findings by health outcome can be found in Table 10. Overall, studies tended to show

Table 5 Association between sleep duration and growth in children aged 0–4 years

No of studies	Design	Quality Assessment					No of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
Mean age ranged between 4 months and 17 months. Data were collected cross-sectionally and up to 13 months. Sleep duration was assessed by actigraphy or parent report. Growth was assessed using the maximum stretch technique and using weight above the expected weight for length.									
1	Longitudinal study[a]	Serious risk of bias[b]	No serious inconsistency	No serious indirectness	No serious imprecision	None	23	Saltatory length growth was associated with increased total daily sleep hours ($p < 0.001$) and number of sleep bouts ($p = 0.001$). Subject-specific probabilities of a growth saltation associated with sleep included a mean odds ratio of 1.20 for each additional hour of sleep ($n = 8$, 95% CI 1.15–1.29) and 1.43 for each additional sleep bout ($n = 12$, 95% CI 1.21–2.03) [29].	VERY LOW
1	Cross-sectional study[c]	No serious risk of bias	No serious inconsistency	No serious indirectness	Serious imprecision[d]	None	139,305	Using actigraphy, sleep duration was associated with weight-to-length ratio ($r = -0.47$, $p < 0.01$) in girls only. Using the questionnaire, night sleep duration was associated with weight-to-length ratio ($r = -0.26$, $p < 0.05$) and weight above the expected weight for length ($r = -0.25$, $p < 0.05$) in the total sample [77].	VERY LOW

[a]Includes 1 longitudinal study [29]
[b]

Table 6 Association between sleep duration and sedentary behaviour in children aged 0–4 years

No of studies	Design	Quality Assessment					No of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
Mean age ranged between 6 months and 4.5 years. Data were collected cross-sectionally and up to 4 years. Sleep duration was assessed by parent report. Sedentary behaviors (screen time) were assessed using time-use diaries or questionnaires.									
1	Longitudinal study[a]	Serious risk of bias[b]	No serious inconsistency	No serious indirectness	No serious imprecision	None	2984	Sleep duration at 4 years of age was inversely associated with television viewing ($\beta = -0.07$, $p = 0.003$) and computer use ($\beta = -0.04$, $p = 0.001$) at 6 years of age [22].	VERY LOW
4	Cross-sectional study[c]	Serious risk of bias[d]	No serious inconsistency	No serious indirectness	No serious imprecision	None	42,751	Short sleep duration was associated with time spent watching TV (OR: 1.65, 95% CI 1.23–2.21 per additional hour/24 h) in boys. In girls, the association was not significant ($p = 0.75$) [31]. Infants who were exposed to screen media in the evening at 12 months of age had a 28-min lower nighttime sleep duration on weekdays. Moreover, infants who were exposed to screen media in the evening at age 6 months and 12 months had shorter 12-month nighttime sleep duration compared with those who were not exposed to screen media after 7 pm at both ages [78]. Watching more than an hour of TV in the evening was associated with short sleep duration (OR = 1.89, 95% CI 1.26–2.84). However, the association was not significant20.1385151.0299.000d[(=)-293s98-1.127Td[(Watch)6(ing0-1.127TD98(hour)-295(of)	

Table 7 Association between sleep duration and physical activity in children aged 0–4 years

No of studies	Design	Quality Assessment					No of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
Mean age ranged between 20 months and 4.5 years. Data were collected cross-sectionally and up to 4 years. Sleep duration was assessed by parent report. Physical activity was assessed using accelerometers, time-use diaries or questionnaires.									
1	Longitudinal study[a]	Serious risk of bias[b]	No serious inconsistency	No serious indirectness	No serious imprecision	None	2984	Sleep duration at 4 years of age was not associated with physical activity at 6 years of age (β = −0.02, 95% CI −0.09-0.03) [22].	VERY LOW
3	Cross-sectional study[c]	No serious risk of bias	No serious inconsistency	No serious indirectness	No serious imprecision	None	2272	Longer nighttime sleep duration was associated with more physical activity (MVPA min/day: r = 0.19, p = 0.012; activity counts: r = 0.21, p = 0.006). In multivariable models, nighttime sleep duration was positively associated with physical activity (β = 0.332, p = 0.017) [30]. Sleep duration was not associated with physical activity in either boys (p = 0.89) or girls (p = 0.41) [31]. Total daily sleep duration was positively associated with physical activity in boys only (OR = 1.04, 95% CI 1.02–1.07) [81].	LOW

Due to heterogeneity in the measurement of sleep and physical activity, a meta-analysis was not possible
[a]Includes 1 longitudinal study [22]
[b]

favourable associations between sleep duration and adiposity (20/31 studies), emotional regulation (13/25 studies), growth (2/2 studies), screen time (5/5 studies), and risks/injuries (2/3 studies). However, no association was found between sleep duration and motor development (only 2 studies) and quality of life (only 1 study), and the evidence was mixed for cognitive development and physical activity indicators. It is difficult to establish the optimal amount of sleep associated with favourable health outcomes based on the available evidence. Most of the evidence was correlational in nature or compared groups with different cut-points for short and long sleep duration. However, longer sleep durations, when compared to shorter sleep durations, were generally associated with better outcomes in the studies synthesized herein, and the pattern of associations did not differ by the age group examined (i.e., infants, toddlers, and preschoolers).

Discussion

This systematic review synthesized peer-reviewed scientific evidence from 69 articles/studies examining the relationships between sleep duration and key health indicators in children aged 0–4 years. The overall quality of evidence ranged from "very low" to "high" across study designs and health indicators. Collectively, shorter sleep duration was generally associated with higher adiposity, poorer emotional regulation, impaired growth, more screen time, and higher risk of injuries. However, the evidence was mixed for cognitive development and physical activity, and null findings were reported for motor development and quality of life. Also, no studies

Table 8 Association between sleep duration and quality of life/well-being in children aged 0–4 years

No of studies	Design	Quality Assessment					No of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
Children were 3 years of age and followed until first-year junior high school (approximately 13 years old). Data were collected longitudinally (approximately a 10-year follow-up period). Sleep duration was assessed by parent report. Quality of life was assessed using the Dartmouth Primary Care Cooperative Project (COOP) charts.									
1	Longitudinal study[a]	Serious risk of bias[b]	No serious inconsistency	No serious indirectness	No serious imprecision	None	9674	Short sleep duration at 3 years of age (< 10 h vs. > 11 h) was not associated with quality of life at age ~13 years (OR = 1.15, 95% CI 0.99–1.33, p = 0.06) [82].	VERY LOW

Due to the fact that only one study was published on sleep duration and quality of life/well-being, a meta-analysis was not possible
[a]Includes 1 longitudinal study [82]
[b]Sleep duration was parent-reported with no psychometric properties reported. Therefore, the quality of evidence was downgraded from "low" to "very low"

Table 9 Association between sleep duration and risks/injuries in children aged 0–4 years

No of studies	Design	Quality Assessment					No of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
Mean age ranged between 18 months and 4.9 years. Data were collected cross-sectionally only. Sleep duration was assessed by parent report.									

examined the association between sleep duration and cardiometabolic biomarkers in this population. Overall, this comprehensive assessment of available evidence should encourage efforts aimed at promoting the importance of sleep duration for overall health in children aged 0–4 years.

Adiposity ($n = 31$ studies) and emotional regulation ($n = 25$ studies) were the health indicators with the highest number of studies in the present systematic review. This is in agreement with our previous systematic review examining the associations between sleep duration and health indicators in school-aged children and youth [2]. However, the findings from these two health indicators in the current paper are more mixed than those found in the children and youth review. Potential reasons to explain this difference include: (1) differences in measurement tools used to assess sleep duration and health outcomes; (2) differences in confounding factors; (3) differences in development stages; (4) differences in the robustness of study designs; and (5) the likelihood that it is more difficult to find associations with adverse health indicators in a younger and healthier population of children, as the outcomes explored in this review are likely to manifest over time if short sleep duration is prolonged .

Many tools have been used to assess emotional regulation in the studies reviewed herein. These included video-recording, various questionnaires, and even cortisol response. It is debatable whether cortisol awakening response (CAR) is an emotional regulation indicator, but it fit our inclusion/exclusion criteria as a stress marker. The non-randomized intervention that examined CAR after sleep restriction [44] showed that CAR was robust after nighttime sleep, diminished after sleep restriction, this field of research—it is clear that, currently, the evidence being used to inform sleep duration recommendations in the early years is weak, suggesting that expert opinion is needed until more and better research is conducted. There is an urgent need for higher-quality studies that can help to better inform recommendations for sleep duration in this population. For example, the available evidence relies heavily on cross-sectional studies that use parent-reported sleep durations. Multiple age groups were also grouped together, despite obvious differences in development. Most importantly, the current evidence is largely correlational in nature, and there is a clear need for dose-response curves with multiple time points of sleep duration that can provide a better idea of optimal sleep duration ranges. In an experimental context, this means examining how health indicators change in response to sleep restriction/extension interventions. In observational studies, this means comparing several categories of sleep duration in relation to health indicators rather than using continuous data in order to have a better sense of dose-response gradient. Ideally, results would be reported for narrower age groups that are aligned with the current sleep duration recommendations (i.e., newborns [0–3 months], infants [4–11 months], toddlers [1–2 years], preschoolers [3–5 years]); development progresses rapidly in the early years and many factors can confound the associations (e.g., growth, eating habits, environment, locomotion).

The National Sleep Foundation in the USA recommends that in each 24-h cycle, newborns (0–3 months) obtain 14–17 h of sleep, infants (4–11 months) obtain 12–15 h of sleep, toddlers (1–2 years) obtain 11–14 h of sleep, and preschoolers (3–5 years) obtain 10–13 h of across studies precluded conducting meta-analyses, and all studies were weighted equally. Second, the present systematic review included only articles published in English or French, meaning any relevant studies published in other languages were excluded. Third, the risk of publication bias (i.e., an over-representation of studies with sig-

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