Sleep duration and obesity in adulthood: An updated systematic review and meta-analysis

Sleep Duration and Obesity in Adulthood: An Updated Systematic Review and Meta-Analysis

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Abstract: Short and long sleep duration have been associated with risk of obesity in children and adolescents. Evidence in adults is more mixed, with biological and psychosocial factors underlying these relationships mostly unknown. This review aimed at qualitatively and quantitatively summarizing previous studies on sleep duration as a predictor of obesity in adults in order to provide an update of the state of art in this field and clarify these relationships. Odds ratios at 95% Confidence Intervals (CI) were estimated using random-effects models. Heterogeneity of effects distribution and publication bias were tested. Twelve articles were selected for short sleep (n=154936) and eight for long sleep duration (n=152192). Results indicated that short sleep duration (OR: 1.412; 95% CI: 1.177-1.694) was significantly associated with the risk of future obesity, and that long sleep duration (OR: 0.995; 95% CI: 0.889-1.114) was not associated. Heterogeneity was high and lowered to non-significant values when considering gender and extremes of short/long sleep duration. Results seem to confirm a potential role of short sleep duration in predicting but results on long sleep are still mixed. Future investigations on potential mediators of such relationships are needed.

Keywords: Obesity; Adults; Sleep duration; Systematic Review; Meta-analysis

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1. Introduction

World Health Organization declared obesity as a global epidemic [1]. The worldwide prevalence of overweight and obesity combined has risen by 27.5% for adults between1980 and 2013, with 2.1 billion having a body mass index (BMI, i.e., weight/height^2) $\geq$ 25 Kg/m^2 [2]. Obesity has been associated with a higher risk of cancer [3], cardiovascular diseases, and mortality [4]. Besides, obesity is associated with critical economic costs (related to preventive, diagnostic and treatment services) and negative psychosocial consequences such as social stigma and depression [5,6]. Several factors contribute to obesity in adults, including excessive energy consumption not only in portion sizes but also in the number of processed food items [7] and decreased physical activity that leads to decreased number of expended calories [8].

Simultaneously, sleep duration has dramatically shortened in the last century [9], despite recent evidence on objective sleep reporting contrasting results [10]. Currently, the National Sleep Foundation guidelines recommend 7–9 h of sleep per night for adults aged 18–64 years and states that 6 h or less and 10 hours or more may have a negative impact on health and well-being [11]. Nevertheless, Youngstedt and colleagues recently suggested that objectively measured ideal sleep duration is closer to 6.5 – 7.5 hours per night [10]. Thus, different interpretations have been given of what is considerable "healthy" sleep duration.

Poor sleep quality and quantity has been associated with higher mortality risk [12] and cardiovascular disease [13]. Moreover, both obesity and poor sleep are often associated with increased risk of mental disorders [14,15]. Also, previous studies found a longitudinal association of short sleep duration with

greater risk of obesity [16], hypertension [17], diabetes [18], cardiovascular disease [19], and all-cause mortality [20]. Interestingly, long sleep duration, generally defined as more than 9 hours per night, has also been considered as a predictor of higher mortality, cardiovascular comorbidity, and obesity [21,22].

Several factors have been hypothesized to be involved in sleep-obesity relationships, including endocrine [23], neurochemical [24], behavioral [25], and psychophysiological [26] variables. Meta-analytic evaluations of findings in children, adults and elderly demonstrated a longitudinal association between sleep duration and obesity [16, 27-29]. Moreover, a recent meta-analysis by Liu et al. found a significant association between long sleep duration (considered as > 9 hours per night) and the risk of future obesity in the adult population [22]. However, evidence regarding adult samples yielded mixed results [30-36], which are likely due to methodological heterogeneity such as variability in sleep assessment, lack of objective or validated subjective measures, differences in considering potential confounders and differences in the characteristics of study populations. With this background, it appears utmost important to better delineate the longitudinal relationships between sleep duration and obesity risk and the potential moderators of this relationship. Therefore, the present systematic review and meta-analysis aimed at summarizing qualitatively and quantitatively the longitudinal evidence on short and long sleep duration as a predictor of obesity in adults, providing an update of the recent literature on this topic.

2. Materials and Methods

2.1 Literature search and study selection

This study was performed according to the meta-analysis of observational studies in epidemiology (MOOSE) [37] and the preferred reporting items for systematic reviews and meta-analyses (PRISMA; see Document S1 in supplemental material) [38] guidelines and registered on PROSPERO

(ID: CRD42017059540). Pubmed, PsychINFO and Medline were searched from inception up to May 2019 using the following terms: ((sleep [Title/Abstract]) AND (obesity [Title/Abstract] OR (BMI [Title/Abstract])). Search strategies did not use language or year publication restrictions. First and second author performed the title and abstract screening on Citavi 6 software (https://www.citavi.com). Reference lists of the original retrieved articles and relevant reviews and meta-analysis [16, 22, 27, 39] were hand-searched for additional relevant studies. Full-texts were screened by two independent researchers (first and third author) against inclusion criteria. Finally, in order to collect data from non-published studies, first author screened published conference proceedings from major sleep journals from 2014 to 2019 and contacted recognized expert authors in the field to obtain further data.

2.2 Inclusion criteria

Studies were included if they were based on longitudinal data, reported baseline mean sleep duration (either objective or subjective) or sleep duration category as the exposure variable, study subjects were adults (≥18 years old) and BMI was the outcome. Only studies written in English were considered. Moreover, only studies reporting odds ratios (OR) and confidence intervals (CI) for short and/or long sleep duration compared to normal sleep duration, or values that allowed to derive OR were included.

2.3 Data extraction

For each study, the following information was extracted: sample size, age of population at baseline, gender of population, number of follow-up years, country under investigation, sleep duration categories and type of assessment of sleep duration. For the meta-analytic calculations, adjusted OR at 95% CI for short and long sleep duration compared to normal duration were extracted. Adjusted values were preferred in order to have the highest degree of control for potential confounders following the procedure of similar and preceding meta-analysis [19, 27]. When the necessary data were not provided in the eligible articles, corresponding authors were contacted.

2.4 Quality assessment

Two reviewers (first and fourth author) independently assessed the methodological quality and level of evidence of included studies and resolved disagreements through discussion. We used the Newcastle-Ottawa Scale (NOS) for Assessing the Quality of Nonrandomized Studies in Meta-Analysis (cohort version) [40]. The NOS consists of eight multiple-choice questions that address subject selection and comparability of cohorts and the assessment of the exposure. High-quality responses earn a star, totaling up to nine stars (the comparability question earns up to two stars). The results of the application of the NOS have been conveyed in a summary score equal to the number of stars earned by each study. Furthermore, the level of evidence of included studies were assessed with the Critical Appraisal Skills Program (CASP) Cohort Study Checklist [41] (A detailed explanation of this tool is provided in supplemental material document S2).

2.5 Statistical analysis

Analyses were performed using Comprehensive Meta-Analysis Software (CMA, version 3). In order to estimate the quantitative relation between short and long sleep duration and obesity, we obtained an estimate from each study of the OR with 95% CI. As we could not assume that effect sizes of original studies were identical in magnitude due to substantial variability between populations, countries, age and sleep duration categories, a random-effects model was preferred. To test the heterogeneity of effects distribution, Cochran's Q and Higgins's I^2 were estimated. Significant values of Q indicate a high level of heterogeneity between effects that need to be further investigated. Low percentages of I^2 are indicative of low heterogeneity, while percentages over 75% represent considerable levels of heterogeneity [42]. To investigate the potential sources of heterogeneity, sensitivity analyses were conducted by selecting groups of studies depending on possible confounding variables. Specifically, a subset of analyses was conducted considering studies that included either males or females, regional groupings, extreme sleep categories exclusively, objective

or subjective sleep duration assessment and participants' mean age (> 50 years or < 50 years) . Furthermore, to test publication bias, i.e., the tendency to publish studies with positive results rather than those with negative or non-significant results, funnel plots of effect sizes against standard errors were computed, and Egger's linear regression was performed to quantify the bias captured by the funnel plot [43]. In the Egger test, the standard normal deviate is regressed on precision, defined as the inverse of the standard error. The intercept in this regression corresponds to the slope in a weighted regression of the effect size on the standard error, and significant Egger's test reflects presence of publication bias [44].

3. Results

3.1 Study selection

Figure 1 illustrates the detailed flow chart of the selection process. Literature research yielded 2062 papers (PubMed: n = 1738; PsycINFO: n = 88; Medline: n = 236), out of which 315 were duplicates. After removing duplicates, a total of 1747 papers remained. Titles and abstracts were examined for relevance, and 1705 were excluded. Forty-two records were scrutinized, and 31 papers were excluded for the following reasons: not sleep duration as criteria (n = 1), not having a prospective design (n = 11), not having the BMI as outcome (n = 14) and 5 due to overlapping population with more recent studies. Reference lists of the original retrieved articles provided one more included record. A total of 12 studies met the inclusion criteria and were therefore reviewed (See Fig.1 for PRISMA flow chart).

Please insert here Figure 1

3.2 Study characteristics and quality

A detailed description of the studies is reported in Table 1. Sample size at the follow-up ranged from 151 [45] to 35219 [46]. Age of the participants ranged from 34 [47] to 57.8 years [36]. Five studies were conducted in the eastern countries (all in Japan) [48-52], while seven studies in western

countries [36, 45-49, 53-555]. Results from three articles [46, 48, 52] were presented separately for males and females. The study by Nishiura et al. [51] was conducted on a male sample, and the study by Theorell-Haglow et al. [54] was conducted on a female sample. Years of follow-up ranged from 1 [52] to 12 [50]. All the included studies assessed sleep duration through self-reported measures, except for the study by Vgontzas et al. (2013) [55] that also used polysomnography. Two studies [47,53], calculated sleep duration as time in bed minus sleep onset latency, without considering nocturnal waking, and only four studies [36,46,51,54] asked participants to report their average sleep duration specifying during the night period. Only one study [46] asked to participants to report nap time and considered it in the analyses. Furthermore, only two studies [36, 52] specified to participants to report their sleep duration during weekdays. In each study we identified the reference category, that was for the majority of studies between 7 and 8 hours [45,46,49,51,52] or 7 hours [36,47,50,53]. Furthermore, six studies categorized short sleep duration as ≤ 6 hours per night; six studies as ≤ 5 hours and only one study [53] as ≤ 6.5 hours; long sleep duration was categorized as ≥ 9 by five studies, as ≥ 8 by two studies and only from one study [48] as > 7.

Please insert here Table 1

In Table 2 is reported the qualitative assessment of the included studies. Total score ranges from "poor quality" to "good quality". Specifically, only one study scored "fair quality" [45] for low scores in the selection section; and two studies scored "poor quality" because of the low scores in outcome section [45, 52]. Results from the CASP confirmed that included studies presented overall good quality scores. Despite that, in almost all the studies there it emerged evidence for a potential bias due to the exposure and/or outcome measurement (see Document S2 in supplemental material for detailed judgments).

Please insert here Table 2

3.3 Short sleep duration as a predictor of obesity

Twelve prospective studies involving 154936 participants were included in the analysis comparing short sleep and normal sleep. The overall result indicated that short sleep duration was significantly associated with risk of future obesity (OR: 1.412; 95% CI: 1.177-1.694, p< 0.001; see Figure 2). Heterogeneity statistics were high and significant (Q = 71.956, df = 14, p < 0.001; I2 = 80.544%). Visual investigation of the funnel plot (see Figure 3) suggested a low risk of publication bias, and this was statistically confirmed by a non-significant Egger test (b = 0.806, 95% CI: 1.211-2.823, p =.201).

We replicated this analysis excluding the study by Bo et al. [53], that was the only one with short sleep duration of ≤ 6.5 hours and not < 6 hours. The result indicated that short sleep duration was significantly associated with risk of future obesity (OR: 1.500, 95% CI:1.293-1.740). Heterogeneity statistics were high and significant (Q = 35.416, df = 13; p < 0.001, I2 = 63.293 %).

To investigate the potential sources of heterogeneity, we ran a series of sensitivity analyses considering sex, country, sleep duration, sleep assessment and participants' age. First, we repeated the analyses separately for males (n = 69398, [46, 48, 51, 52]) and females (n = 41016, [46, 48, 51, 53]. Results showed a significant effect both in males (OR: 1.582, 95% CI: 1.171-2.138) and in females (OR: 1.464 ,95% CI: 1.182-1.812). Results were heterogeneous for males (Q =13.010, df = 3, p = 0.005; I2 = 76.940%) but homogeneous for females (Q = 2.961, df = 3, p = 0.398; I2 = 0.000%). Second, we repeated the analyses considering the countries where the studies were conducted, selecting western (n = 78777) and eastern (n = 76159) studies. Results were significant in both western [35, 45-49 ,53-55], (OR: 1.403, 95% CI: 0.963-2.044), and eastern countries [48-52] (OR: 1.452, 95% CI: 1.202-1.754). However, heterogeneity statistics were high and significant in both

subgroups (western: Q = 46.021, df = 7, p < 0.001; I2 = 84.789%; eastern: Q = 21.027, df = 6, p = 0.002; I2 = 71.465). Furthermore, we repeated the analysis considering duration of follow-up, selecting studies with follow-up ≥ 7 years (n= 92043, [46-48, 50, 54, 55]) and < 7 years (n = 62246, [35, 45, 49, 51-53]). Results were significant both in studies with follow-up ≥ 7 years (OR: 1.586, 95% CI: 1.208-2.083) and in those with follow-up < 7 years (OR: 1.358, 95% CI: 1.073-1.720). Results were heterogeneous for studies with follow-up < 7 years (Q = 49.033, df = 9, p < 0.001, I2 = 81.645%), but homogeneous for studies with follow-up ≥ 7 years (Q = 8.487, df = 4, p = 0.075, I2 = 52.868%). We also repeated the analysis excluding the only study that used objectively sleep assessment [55]. Results were significant (OR: 1.427, 95% CI: 1.183-1.720) and heterogeneity statistics were high and significant (Q = 71.782, df = 13, p = 0.000; I2 = 81. 890%). Furthermore, we repeated the analysis considering studies with participants > 50 years [36,46,50,53] and < 50 years [44,47-49,51,52,54,55]. Results were not significant for studies with participants > 50 years (OR: 1.088, 95% CI: 0.785-1.509) and significant for studies with participants < 50 years (OR: 1.746, 95% CI: 1.291-2.361). Nevertheless, both these results presented high heterogeneity (respectively, Q = 22.287, df = 4, p = 0.000; I2 = 82. 052% and (Q = 30.150, df = 8, p = 0.000; I2 = 73. 466%).

Finally, we considered extreme short sleep duration, repeating the analysis on studies that considered ≤ 5 hours of sleep as short sleep duration ([35, 46, 48, 50, 52, 55], n= 48311). Results were significant (OR: 1.322, 95% CI: 1.148-1.523) and homogeneous (Q = 12.504, df = 8, p = .130; I2 = 36.019%).

Please insert here Figure 2 and Figure 3

3.4 Long sleep duration as a predictor of obesity

Eight prospective studies comparing long sleep and normal sleep and including 152192 participants were selected for the analysis. The overall result indicated that long sleep duration was not associated with the risk of future obesity (OR: 0.995; 95% CI: 0.889-1.114, p=0.936; see Figure 4). Moreover,

heterogeneity statistics were not significant ($Q = 5.051$, df = 8, $p = 0.752$; $I^2 = 0.000\%$). Again, visual examination of the funnel plot suggested a low risk of publication bias, and this was statistically confirmed by non-significant Egger test ($b = 0.806$, 95% CI: 1.211- 2.823, $p = .201$).

Please insert here Figure 4

4. Discussion

The present systematic review and meta-analysis aimed to replicate and provide further evidence regarding the relationships between sleep duration and obesity in adulthood. Findings revealed that only short sleep duration was significantly associated with increased risk of future obesity in adults when compared to normal sleep duration. Results from this meta-analysis extend previous results in children and adolescents [e.g. 16, 56] to adulthood. On the other hand, long sleep duration was not associated with risk of future obesity, and this confirms some previous meta analytic result [28] and at the same time disconfirm other previous results [23].

Previous studies provided several potential mechanisms accounting for the associations between short sleep and increased risk of obesity [57]. At first, chronic sleep restriction may induce alterations in hormones that regulate appetite as leptin and ghrelin, which may lead to increased appetite and increased food intake [25]. However, in a meta-analysis by Capers and colleagues no overall effect emerged on ghrelin and leptin levels due to sleep restriction, with a large heterogeneity among studies as a potential explanation for such inconsistent findings [58]. Moreover, it is clear that those who sleep less have augmented opportunity to eat [59] and often report fatigue, with consequent reduction in physical activity [60].

Mixed and heterogeneous results found both in the present and previous meta-analyses about long sleep duration and its association with the risk of obesity may be explained in different ways. Short sleep is associated with a slight increase in total daily energy expenditure, likely due to prolonged wakefulness but with inadequate nutrients intake [61]. On the other hand, long sleep could affect

energy expenditure due to the decline in metabolic rate in normal sleep [62]; we may assume that in case of prolonged sleep duration, a marked reduction in metabolic rate can contribute to decreased 24-h total energy expenditure, favoring weight gain. Although most of the studies reported results adjusted for the presence of psychopathology and level of physical activity, they also adjusted for the effects of other variables (e.g. smoking habits, alcohol consumption, sex, BMI at baseline, age) and this did not allow to accurately measure the unique contribution of some variables of interest on the results. It is therefore utmost important for future studies to clearly define the mental and physical status of the included sample, in order to reduce heterogeneity and control for confounding effects of comorbidity. Furthermore, more studies are needed in order to assess the differential effects of long sleep on different outcome variables (e.g. weight gain, BMI change).

Several factors were hypothesized to account for heterogeneity and were therefore statistically investigated in sensitivity analyses. As aforementioned, international medical organizations such as the National Sleep Foundation [11] and the Sleep Health Foundation [63], recommend a specific amount of sleep duration for adults. Specifically, they suggest between 7 and 9 hours as "normal" sleep duration, and more than 10 hours and less than 6 hours as "not recommended" sleep duration. However, we were limited in adopting these categorizations since none of our studies used 10 hours as long sleep category and 6 hours to 8 hours as "normal sleep duration" category, and only one study used less than 6.5 hours as "short sleep duration" category [53]. For instance [51], it happened that similar sleep durations overlapped different sleep categories. Also, most of the included studies that investigated long sleep duration used > 9 hours' categorization [64], with consequent difficulties for investigating this specific category. Thus, it is necessary for future studies to standardize sleep duration categories in order to limit heterogeneity and consolidate results. Finally, although we investigated a small sample of studies, analyses were run on a large number of participants, and this increased statistical power and generalizability of the results compared to single studies.

4.1 **Limitations**

This study has several limitations to be acknowledged. First, since the aim of our meta-analysis was to investigate the longitudinal relationship between sleep duration and obesity risk, it was beyond our aims to investigate the impact of sleep on other obesity-relevant parameters, such as weight gain, BMI change and waist circumference. This approach increased the specificity of our results but reduced the number of papers considered in the meta-analysis and the amount of evidence reviewed. Although BMI is a commonly used, easy to measure, and inexpensive measure of obesity, future studies on adults would provide a more comprehensive picture of the relationship between sleep and obesity by considering other parameters alongside BMI, such as waist circumference. Moreover, since the majority of the included studies used self-report measures both for sleep duration and BMI, we were limited in considering differences between subjective and objective parameters. This would be an essential advance in the field since there is evidence that people are inclined to under-report both sleep duration [65] and weight [66]. Furthermore, self-reported sleep duration did not allow (unless explicitly built as additional questions) to differentiate time asleep from time in bed or to estimate the number and duration of daily naps. Only two studies asked specifically to report sleep duration during weekdays (workdays), this may induce reporting bias since it is well known that adult rend to sleep longer in weekend or non-working days. Thus, our results would need further confirmation from studies using objective measures both for sleep duration and BMI. Finally, future studies should take into account other aspects of sleep that could affect obesity, such as daytime napping [67], perceived sleep quality[68], and respiratory sleep disorders, i.e., obstructive sleep apnea (OSA) [69].

5. Conclusions

Results of this systematic review and meta-analysis support the potential role of short sleep duration in predicting obesity risk in adults and confirm mixing results for the role of long sleep duration. For future research, we suggest exploring the effect of both poor sleep quality and sleep duration on risk of obesity, using both physiological and accurate self-reported measures. Moreover, future studies should differentiate between young adults, adults and the elderly because sleep duration and quality could change in these age groups. Furthermore, in the present meta-analysis, most of the included studies reported results adjusted for some self-reported variables that could be potential moderators. Future studies should examine these potential moderators with appropriate and valid questionnaires and providing information about the unique contribution of these variables on the association between sleep duration and obesity. Finally, future longitudinal studies that measure both qualitative and quantitative aspects of sleep with subjective and objective measures of sleep, BMI and potential confounders measures, could help to better understand the causal nature of the association between sleep and obesity in adults.

Abbreviations:

ANS: Autonomic Nervous System

BMI: Body Mass Index

CASP: Critical Appraisal Skills Program

CI: Confidence Interval

F: Female

M: Male

MOOSE: Meta-analysis Of Observational Studies in Epidemiology

NOS: Newcastle-Ottawa Scale

OR: Odd Ratio

OSA: Obstructive Sleep Apnea

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

Author Contributions:

V.B., A.B., C.L Conceptualization, V.B., A.B., S.C., M.V. Methodology, V.B., A.B., F.L.

Formal Analysis, V.B., A.B., S.C., E.P, L.D Writing—Original Draft Preparation, V.B., A.B., S.C., M.C., E.P., L.D., F.L., C.L. Writing—Review & Editing, C.L., F.L., L.D. Visualization and supervision

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Table 1: Study characteristics

Study	Sample size (n)	Mean age ± Standard deviation (years)	Sex	Mean BMI (at baseline)	Follow-up (years)	Country	Mean sleep duration (hours)	Short sleep category	Referent sleep category	Long sleep category	Assessment of sleep duration
Bo et al. 2011 [53]	1282	54.8 ± 6.1	M/F	28.4±2.0	6	Italy	6.3±1.4	≤ 6.5	7	n/a	Self reported, question in ad hoc questionnaire: "self-reported time in bed (calculated from bedtime to rise time) min us sleep latency."
Chaput et al. 2010 [44]	151	38.4 ± 14	M/F	26.8±7.1	6	Canada	n/a	< 6	7-8	n/a	Self reported, question in ad hoc questionnaire: "How many hours do you sleep per day?"
Hasler et al. 2004 [47]	496	34 ± n/a	M/F	22.5±3.4	7	Switzerland	F: 7.6 ± 0.9 M: 7±0.9	< 6	7	n/a	Self reported, question in ad hoc questionnaire: "Sleep duration

											was calculated as duration spent in bed (a, b) minus time needed to fall asleep (c)."
Itani et al. 2011 [48]	M= 11424 F= 899	29-50*	M/F	n/a	7	Japan	n/a	<5	5-7	>7	Self reported, question in ad hoc questionnaire: "What was your daily average sleep duration?''
Kobayashi et al. 2017 [49]	31830	< 6= 43.7 ± 10. 8 6-7= 46.9 ± 11.5 7-8=50.2 ± 12. 6 >8 = 53.5 ± 14. 3	M/F	< 6= 22.6 ± 3.5 6-7= 22.4 ±3.3 7-8=22.3 ± 3.1 >8 = 22.2 ± 3.2	4	Japan	n/a	< 6	7-8	> 8	Self reported, question in ad hoc questionnaire: "Sleep duration … hours"
Nagai et al. 2013 [50]	6162	≤ 5= 57.5 ± 9.7 7= 56.2 ± 9.3 ≥ 9= 61.9 ± 8.5	M/F	≤ 5= 23.6 ±3.3 7= 23.7 ± 3 ≥ 9= 23.7 ± 3-6	12	Japan	n/a	≤ 5	7	≥ 9	Self reported, question in ad hoc questionnaire: "How many hours on average do you sleep per day ?"

Nishiura et al. 2010 [51]	2632	<6= 47.8 ± 5.6 7-7.9= 47.9 ± 5.3 ≥ 8= 48.6 ± 5.6	M	<6= 22.7 ± 1.6 7-7.9= 22.5 ± 1.8 ≥ 8= 22.3 ± 1.9	4	Japan	n/a	< 6	7-8	≥ 8	Self reported, question in ad hoc questionnaire: "How many hours, on average, do you sleep during the night?"
Stranges et al. 2008 [36]	3786	≤ 5=54.5 ± 5.5 7=55.5 ± 6.1 ≥ 9= 57.8 ± 5.3	M/F	≤ 5=27 ± 4.1 7=25.9 ± 3.4 ≥ 9= 25.7 ± 3.3	4	England	n/a	≤ 5	7	≥ 9	Self reported, question in ad hoc questionnaire: "How many hours of sleep do you have on an average week night?"
Theorell-Haglow et al. 2014 [54]	4903	43.9 ± 15.2	F	24.2 ± 4.2	10	Sweden	6.9 ± 1.2	< 6	6-9	≥ 9	Self reported, question in ad hoc questionnaire: "How many hours do you sleep on average during the night?"
Vgontzas et al. 2013 [55]	815	48.9 ± 13.4	M/F	24.6 ± 2.8	7.5	United States of America	7.0±1.2	≤ 5	6-7	n/a	Polysomnography

Watanabe et al. 2010 [52]	M= 20023 F=3189	< 5= M= 39.4 ± 8.9 F= 41.5 ± 8.9 7 – 8= M= 40.6 ± 10.1 F= 35.8 ± 9.5 ≥ 9= M= 42 ± 11.2 F=36.3 ± 8	M/F	< 5= M= 24.4 ± 3.7 F= 21.9 ± 3.6 7 – 8= M= 23.6 ± 3.2 F= 20.7 ± 3.1 ≥ 9= M= 23.5 ± 3.5 F=21.7 ± 5.7	1	Japan	n/a	<5	7-8	≥ 9	Self reported, question in ad hoc questionnaire: “how many hours do you sleep on weekdays (workdays)?"
Xiao et al. 2013 [46]	M=3531 F= 32025	51-72 *	M/F	n/a	7.5	United States of America	n/a	<5	7-8	≥ 9	Self reported, question in ad hoc questionnaire: "amount of time they slept at night in a typical 24-hour period over the past 12 months."

Legend: *age range of participants was reported if mean age and standard deviation was not specified ; M=Males, F= Females.

Table 2: Risk of bias assessment

Studies	**Selection**	**Comparability**	**Outcome**	**Total score**
Bo et al., 2011 [53]	***	**	***	**Good quality**
Chaput et al.,2010 [45]	**	**	**	**Fair quality**
Hasler et al.,2004 [47]	****	**	**	**Good quality**
Itani et al.,2011 [48]	***	**	***	**Good quality**
Kobayashi et al.,2017 [49]	***	**	***	**Good quality**
Nagai et al.,2013 [50]	***	**	**	**Good quality**
Nishiura et al.,2010 [51]	***	**	***	**Good quality**
Stranges et al.,2008 [36]	***	**	**	**Good quality**
Theorell-Haglow et al.,2014 [54]	***	**	**	**Good quality**
Vgontzas et al.,2013 [55]	****	**	***	**Good quality**
Watanabe et al.,2010 [52]	***	**	*	**Poor quality**
Xiao et al.,2013 [46]	***	**	*	**Poor quality**

Notes: In order to be rated as “good quality”, studies should have 3 or 4 stars in selection domain; 1 or 2 stars in comparability domain and 2 or 3 stars in outcome/exposure domain. For “fair quality” judgment: 2 stars in selection domain; 1 or 2 stars in comparability domain and 2 or 3 stars in outcome/exposure domain. For “poor quality”: 0 or 1 star in selection domain or 0 stars in comparability domain or 0 or 1 stars in outcome/exposure domain.

Supplementary material:

Document S1: PRISMA checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	4-5
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	5-6
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	5
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	6
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	5-6
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	5

Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	6
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	6-7
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	9
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	7
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	7-8
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	7-8

Document S2: Risk of bias assessment from CASP tool

	Section A: Are the results of the study valid?								**Section B: What are the results?**			**Section C: Will the results help locally?**			
Studies	Did the study address a clearly focused issue?	Was the cohort recruited in an acceptable way?	Was the exposure accurately measured to minimise bias?	Was the outcome accurately measured to minimise bias?	Have the authors identified all important confounding factors?	Have they taken account of the confoundin g factors in the design and/or analysis?	Was the follow up of subjects complete enough?	Was the follow up of subjects long enough?	What are the results of this study?	How precise are the results?	Do you believe the results?	Can the results be applied to the local populatio n?	Do the results of this study fit with other available evidence?	What are the implications of this study for practice?	Totale
Bo et al., 2011 [50]	1	1	0	1	1	1	1	1	OR	Precise	1	1	1	1	11
Chaput et al.,2010 [42]	1	1	0	1	1	1	1	1	OR	Precise	1	1	1	1	11
Hasler et al.,2004 [44]	1	1	0	0	1	1	1	1	OR	Precise	1	1	1	1	10
Itani et al.,2011 [45]	1	1	0	1	1	1	1	1	OR	Precise	1	1	1	1	11
Kobayashi et al.,2017 [46]	1	1	0	1	1	1	1	1	OR	Precise	1	1	1	1	11
Nagai et al.,2013 [47]	1	1	0	1	1	1	1	1	OR	Precise	1	1	1	1	11
Nishiura et al.,2010 [48]	1	1	0	1	1	1	1	1	OR	Precise	1	1	1	1	11
Stranges et al.,2008 [34]	1	1	0	1	1	1	1	1	OR	Precise	1	1	1	1	11
Theorell-Haglow et al.,2014 [51]	1	1	0	0	1	1	1	1	OR	Precise	1	1	1	1	10
Vgontzas et al.,2013 [52]	1	1	1	0	1	1	1	1	OR	Precise	1	1	1	1	11
Watanabe et al.,2010 [49]	1	1	0	1	1	1	1	1	OR	Precise	1	1	1	1	11
Xiao et al.,2013 [43]	1	1	0	0	1	1	1	1	OR	Precise	1	1	1	1	10

The CASP tool encompasses a systematic approach based on 12 specific criteria: (a) study issue is clearly focused; (b) cohort is recruited in an acceptable way; (c) exposure (caries) is accurately measured; (d) outcome (incidence of caries) is accurately measured; (e) confounding factors are addressed; (f) follow up is long and complete; (g) results are clear; (h) results are precise; (i) results are credible; (j) results can be applied to the local population; (k) results t with available evidence; and (l) there are important clinical implications. Each criterion was given a response of either “yes” (1) , “no” (2), or “cannot tell”. Each study could have a maximum score of 12.