Published in final edited form as:

Curr Nutr Rep. 2018 December ; 7(4): 235–258. doi:10.1007/s13668-018-0240-3.

Sleep, Diet, and Cardiometabolic Health Investigations: A Systematic Review of Analytic Strategies

Erica C. Jansen, PhD, MPH¹, Galit Levi Dunietz, PhD, MPH¹, Maria-Efstratia Tsimpanouli, PhD, MS¹, Heidi M. Guyer, PhD, MPH², Carol Shannon³, Shelley D. Hershner, MD¹, Louise M. O'Brien, PhD^{1,4,5}, and Ana Baylin, DrPH, MD^{6,7}

¹ Sleep Disorders Center, Department of Neurology, University of Michigan, Ann Arbor, MI, USA

² Survey Research Center, Institute for Social Research, University of Michigan, Ann Arbor, MI, USA

³ Health Sciences Library, University of Michigan, Ann Arbor, MI, USA

⁴ Department of Obstetrics & Gynecology, University of Michigan, Ann Arbor, MI, USA

⁵ Department of Oral & Maxillofacial Surgery, University of Michigan, Ann Arbor, MI, USA

⁶ Department of Nutritional Sciences, School of Public Health, University of Michigan, Ann Arbor, MI, USA

⁷ Department of Epidemiology, School of Public Health, University of Michigan, Ann Arbor, MI, USA

Abstract

Purpose of review: Poor sleep is a risk factor for cardiometabolic morbidity. The relationship of sleep and cardiometabolic health could be confounded, mediated, or modified by diet, yet the incorporation of diet in sleep-cardiometabolic health studies is inconsistent. This rapid systematic literature review evaluates the conceptualization of diet as a confounder, mediator, or effect modifier within sleep-cardiometabolic health investigations and the statistical approaches utilized.

Recent findings: Of 4,692 studies identified, 60 were retained (28 adult, 32 pediatric). Most studies included diet patterns, quality, or energy intake as a confounder, while a few examined these dietary variables as a mediator or an effect modifier. There was some evidence, mostly in pediatric studies, that inclusion of diet altered sleep-cardiometabolic health associations.

Address for correspondence: Erica C. Jansen, Sleep Disorders Center, Department of Neurology, University of Michigan, 1500 E. Medical Center Drive, C728 Med Inn Building, Ann Arbor, MI, USA, 48109; janerica@umich.edu.

Compliance with Ethics Guidelines

Conflict of Interest

Erica C. Jansen, Galit Levi Dunietz, Maria-Efstratia Tsimpanouli, Heidi M. Guyer, Carol Shannon, Shelley D. Hershner, Louise M. O'Brien, and Ana Baylin declare they have no conflict of interest.

Human and Animal Rights and Informed Consent

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Summary: Diet plays a diverse role within sleep-cardiometabolic health associations. Investigators should carefully consider the conceptualization of diet variables in these relationships and utilize contemporary statistical approaches when applicable.

Keywords

nutrition; diet; total energy intake; dietary quality; sleep; sleep quality; sleep duration; cardiometabolic health; obesity; body mass index; confounding; mediation; effect modification

INTRODUCTION

Cardiometabolic syndrome consists of metabolic dysfunction characterized by insulin resistance and impaired glucose tolerance, atherogenic dyslipidemia, hypertension and intra-abdominal adiposity, and is linked to cardiovascular morbidity and mortality [1, 2]. Despite significant progress in diagnosis and treatment, the public health burden of cardiovascular diseases and diabetes is increasing globally [3, 4].

A myriad of studies have associated diet - dietary quality, dietary patterns, total energy intake, intake of specific foods, macronutrients and micronutrients - with the development and prevention of cardiometabolic morbidity [5–7]. Recently, poor sleep quality and short sleep duration have also been related to cardiometabolic health [8–10].

Despite their reported independent associations with cardiometabolic health, sleep and diet are in fact strongly interrelated. Moreover, their relationship is likely bidirectional; short sleep duration may lead to higher total energy intake and consumption of less-healthy foods [11, 12], while at the same time diet could alter sleep duration and quality [13, 14]. However, only the impact of sleep on diet has been consistently investigated. Robust experimental evidence has shown that poor sleep alters key appetite regulators, leptin and ghrelin, that in turn lead to dysregulated diet [15]. Poor sleep quality has been shown to impact leptin and ghrelin, key appetite regulators.

The observed bidirectional associations between sleep and diet presents a challenge for analysis and interpretation of current studies. Analyses should differ if diet is hypothesized to be caused by or alternatively to cause poor sleep. With respect to cardiometabolic health, this bidirectionality suggests two possible scenarios (Figure 1). For example, experimental studies have demonstrated that restricted sleep increases dietary intake on the following day [12]. Here, diet would act as a likely mediator on the pathway of sleep and cardiometabolic health. In contrast, consumption of a high glycemic index carbohydrate meal before bedtime has been shown to shorten sleep onset [16], a scenario in which diet would act as a potential confounder. In addition to its potential role as a confounder or as a mediator, diet could act as an effect modifier of the sleep-cardiometabolic health association. For example, an association between short sleep and obesity may be more evident among those with low quality diets [17]. Furthermore, diet is a multifaceted behavior that could be measured as total energy intake, diet composition and meal timing patterns, among others. Each of these dietary measures could have a differential role in the association of sleep and cardiometabolic health.

Despite increasing evidence that link diet and sleep, prior studies have inconsistently included diet in the analysis of sleep and cardiometabolic health. This oversight may threaten internal and external validity of these studies. Importantly, the distinction of diet as a confounder or a mediator requires different analytic strategies; whereas confounders should be accounted for in some way (e.g. through adjusting for them in regression models), it is advised that mediators should not be adjusted for in the analysis. Adjusting for mediators- one form of over-adjustment-can lead to bias when certain assumptions are not met, in particular when there are unmeasured confounders of the mediator-outcome pathway [18]. The lack of consensus in the literature on the inclusion or exclusion of diet in the context of sleep and cardiometabolic health, coupled with the increasing evidence that diet and sleep are intertwined, has motivated this systematic review. Specifically, we aimed to 1) examine the incorporation of diet as a confounder, mediator, or effect modifier of the sleep-cardiometabolic health associations; and 2) to guide future analyses that plan to incorporate diet in the context of sleep and cardiometabolic health.

METHODS

We applied systematic review methodology to conduct a rapid systematic review to examine the role of diet in sleep and cardiometabolic health. Specifically, we performed a systematic search, appraisal, and synthesis of the literature published within the last 5 years, hence a rapid process compared to a traditional systematic review [19]. In addition to significantly decreasing the length of the process, rapid review provides a quick assessment of a focused research question to inform investigators and public health professionals. We used the 2009 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to specify the systematic literature search protocol. An experienced health sciences informationist (CS) applied this protocol to systematically search within PubMed, EMBASE (biomedical and pharmaceutical literature), PsycINFO (psychology and behavioural sciences), CINAHL Plus (Cumulative Index to Nursing and Allied Health Literature), and SCOPUS (Sciences, Engineering, Medicine, Social Sciences and some Arts) to identify peer-reviewed studies that examined sleep and diet in relation to cardiometabolic health within the last 5 years.

Search Strategy

The main search strategy, performed in PubMed and translated to other databases, was conducted by searching for selected keywords and medical subject headings in the titles/abstracts (tiab) and MeSH terms (mh) specific to sleep, diet and cardiometabolic health: sleep[mh] OR sleep[tiab] OR sleep wake disorders[mh] OR sleep wake disorders[tiab] OR sleep apnea syndromes[tiab] OR sleep quality OR sleep quantity[tiab]) AND (body mass index[mh] OR diet[mh] OR diet[tiab] OR dietary behavior[tiab] OR dietary pattern*[tiab] OR energy intake[mh] OR energy intake[tiab] OR feeding behavior[mh] OR feeding behavior[tiab] OR nutrition[mh] OR nutrition[tiab] OR nutritional status[mh] OR nutritional status[tiab]) AND (adiposity[mh] OR adiposity[tiab] OR cardiometabolic health[tiab] OR cardiovascular health[tiab] OR cardiovascular disease[mh] OR cardiovascular diseases[tiab] OR diabetes [mh] OR diabetes [tiab] OR metabolic syndrome[mh] OR metabolic syndrome[tiab] OR obesity[mh] OR obesity[tiab]). All searches were completed by 20

March 2018. The full search strategy is available upon request. Citations were imported into EndNote (Thomson-Reuters, New York, NY).

Selection Criteria

This systematic review included peer-reviewed studies of both children and adults that were published in English. The following exclusion criteria were applied: conference abstracts and duplicate publications; studies within a population with underlying morbidity, e.g. diabetes, obstructive sleep apnea; studies that did not consider both nutrition and sleep in relation to cardiometabolic health; or if sleep or diet were not the primary exposure; studies that considered alcohol or caffeinated beverages as their only dietary variables; or studies that did not evaluate cardiometabolic outcomes or included participants younger than 2 years. Four of the authors (ECJ, GLD, MET, HG) independently assessed the eligibility of the studies by the specified criteria in a two-step process. In the initial screening step, publications were evenly divided among the four authors and were screened based on their title and abstract. In the second step, full-text articles of retained abstracts were reviewed by 2 or more authors. Any disagreements were resolved through arbitration. At the end of the screening process, there was a full inter-rater agreement among all reviewers.

RESULTS

In total, 4,692 publications were identified. Following the first abstract review step, 711 articles were retained. A subsequent assessment of the 711 full-text by multiple authors yielded 60 articles (Figure 2). Of these, 44 used dietary variables strictly as a confounder or independent predictor, 10 studies considered diet strictly as a mediator, 4 studies considered diet only as an effect modifier; while one study examined diet both as a confounder and effect modifier and one study considered diet both as a mediator and effect modifier.

Diet as a confounder of the sleep and cardiometabolic health relationship

Ten longitudinal studies (Table 1) and thirty-five cross-sectional studies (Table 2) considered diet as a potential confounder in the relationship between sleep and cardiometabolic outcomes, or as an independent predictor of cardiometabolic outcomes. Of note, the majority of studies examined sleep duration, either continuously or defined as short sleep according to age-specific guidelines. Similarly, while the majority of cardiometabolic outcomes were a measure of adiposity or obesity. Of the prospective studies, half included children [20–24] while the remaining five studies included adults [25–28] or pregnant women [29].

The pediatric longitudinal studies included children aged 2–18 years [20–24] with mostly subjective measures of baseline sleep duration as the primary exposure. Only one study used actigraphy to analyze sleep duration. Of note, one study assessed the change in average sleep duration over time as the exposure [22]. In these studies, the primary cardiometabolic outcome was adiposity assessed at follow-up. Adiposity was measured as BMI for age z-scores, percent body fat (measured using bioelectrical impedance or dual-energy x-ray absorptiometry), waist-to-height ratio and/or waist circumference. A range of dietary variables were considered as potential confounders, including diet quality, total energy intake, dietary patterns, and intake of specific foods (e.g. fruits and vegetables, soda intake,

hamburgers/hotdogs). These measures were assessed at baseline with food frequency questionnaires [20, 21, 24] multiple 24-hour recalls [22, 23], or questions on specific foods or dietary habits [24].

A British study among 3-year old children found an association between shorter sleep duration and higher adiposity one year later [20], an association that remained unaltered by controlling for diet quality. However, other studies found no association between sleep and adiposity after adjusting for baseline dietary variables and other socio-demographic and behavioral confounders.

Studies in adult populations mostly focused on self-reported sleep duration [25–29]. In addition to sleep duration, one study included daytime napping [26]. The range of cardiometabolic outcomes assessed in adults included metabolic syndrome, gestational weight gain (in pregnant women), obesity, waist circumference, insulin resistance, and CVD events and mortality. The dietary confounders - measured concurrently with sleep - included total energy intake, dietary pattern intake, specific foods consumption or macronutrients (e.g. fish intake, unhealthy snacks, breads and grains, fruits and vegetables), and dietary habits (breakfast intake, snacking between meals). These studies found that short sleep duration was related to higher incidence of obesity and metabolic syndrome, even after accounting for dietary variables. Indeed, daily napping was associated with a lower probability of incident obesity after accounting for dietary confounders [26].

Among the 35 cross-sectional studies (21 in children and 14 in adults) [30–64], (Table 2) diet was incorporated as a confounder in the sleep-cardiometabolic health associations. As in the prospective studies, similar dietary confounders were included - total energy intake, dietary patterns, and intake of specific unhealthy or healthy foods. In contrast to findings in longitudinal pediatric studies, most cross-sectional reports suggested associations between sleep and adiposity or hypertension, [64] independent of dietary confounders. Regardless of study design, findings from adult populations were similar, as sleep duration was inversely associated with obesity and cardiometabolic risk after accounting for dietary confounders. Non-linear relations between sleep duration and cardiometabolic risk were examined in some studies that included a longer sleep duration category (e.g. >8 hours sleep duration) in addition to short sleep and sufficient sleep. A U-shape association was reported in 4 studies [49, 50, 52, 56], while one study found that only longer sleep (>8 hours) was associated with worse cardiometabolic outcomes compared to those with a 7 hour sleep duration [47].

Diet as a mediator of the sleep and cardiometabolic health relationship

Eleven studies evaluated diet as a potential mediator of the sleep-cardiometabolic health relationship, five of which were in pediatric populations [65–69] (Table 3). Within pediatric studies, four were longitudinal studies and one had a cross-sectional design. Sleep duration and sleep timing were examined as determinants of childhood obesity. With the exception of one study [67], sleep assessment of children and adolescents was subjective, either self-reported or parent-reported. Potential mediators included total energy intake, macronutrient intake, fast food consumption, diet quality, and food responsiveness (the degree to which a child expresses a desire for food, in particular for highly palatable food). [68] Evidence of partial mediation was observed in most studies. One study reported that energy intake or

macronutrient intake fully mediated the longitudinal association between shorter sleep duration and a subsequent BMI Z-score change in children aged 2–6 y old. Only two studies[67, 68] applied formal mediation analysis to examine direct and indirect pathways - through diet - between sleep and childhood adiposity, while the other four informally evaluated the change in effect estimates upon addition of the mediator/s into the statistical models.

Six adult studies[70–75], of which five were cross-sectional, examined sleep duration and quality with respect to adiposity or cardiometabolic health. Sleep duration and quality was self-reported in all but one study [74]. The range of cardiometabolic outcomes included BMI, metabolic syndrome, body fat and visceral adiposity. In these analyses, food groups (e.g. fruits, vegetables, fish, sugar-sweetened beverages), macronutrients, total energy intake, and micronutrients such as carotenoids were evaluated as potential mediators. Three of these studies reported no evidence of mediation by dietary factors, while three observed partial mediation. One study found that vitamins C and D partially mediated the sleep-obesity association, but only in women [71]. An Australian report suggested binge eating and night eating as partial mediators of short sleep and BMI association, [70]. Similarly, a Canadian study noted an attenuated association between decrease sleep duration over time and subsequent visceral adiposity gain upon adjustment for energy intake and physical activity [73]. None of these studies applied formal mediation analysis techniques.

Diet as an effect modifier of the sleep and cardiometabolic health relationship

Six studies evaluated diet as a potential effect modifier of the sleep-cardiometabolic health relationship in adults and children [62, 69, 76–79] (Table 4).

The pediatric studies[69, 62, 76] evaluated interactions between short sleep duration and diet in relation to BMI z-scores. Two longitudinal studies[69, 62] suggested that short sleep duration in combination with diet, either poor dietary quality or high starch intake at midday, were associated with higher than additive BMI z-scores. A Danish crossover study[76] examined whether short sleep in combination with school lunch change (adoption of a New Nordic Diet school lunch vs. usual packed lunch) would change adiposity. This study suggested that only children with short sleep had gains in adiposity after school lunch changes, while children with long sleep had no difference in adiposity following the dietary changes.

In adult populations, there were three studies that examined diet as an effect modifier of the association between sleep duration and cardiometabolic health in Korean adults [77–79]. Several authors were involved in all three analyses, and two of the studies used overlapping data from the Korean National Health and Nutrition Survey. Analysis included self-reported sleep duration as the exposure, while adiposity measures and cardiometabolic syndrome were outcomes. Macronutrient intakes, meal skipping patterns, and antioxidant intake were considered as effect modifiers. One of the studies conducted among men only showed that lower intake of antioxidants was associated with higher odds of obesity among short sleepers [78], while another one of the studies including both men and women showed that a higher intake of carbohydrates and a lower intake of fat was associated with lower odds of obesity among short sleepers. In the third study, researchers found that adults between the ages of 20

and 50 years who reported skipping breakfast in the previous two days and having either short sleep (defined as sleeping <6 hours) or long sleep (defined as >8 hours) had higher odds of metabolic syndrome compared to those in the same categories of sleep duration but who reported to have eaten breakfast in the last two days [79]. Nonetheless, in these studies the statistical methodology of the interaction analyses was unclear.

CONCLUSIONS

This unique systematic review performed a rigorous evaluation of the conceptualization and analytic approaches implemented to incorporate diet within sleep and cardiometabolic health investigations. This assessment showed that the majority (two-thirds) of studies considered dietary variables as potential confounders, while only a few assessed dietary variables as mediators or effect modifiers of the sleep and cardiometabolic health relationship. Considerable evidence- particularly in pediatric populations- suggested that diet mediates the sleep-cardiometabolic health pathway, raising the possibility that the dietary variables previously used as confounders were in fact mediators. Therefore, investigators should carefully consider the conceptualization of diet variables in sleep-cardiometabolic health relationships and utilize contemporary statistical approaches when applicable.

As confounder, the most common dietary variables considered were total energy intake, dietary quality scores or dietary patterns. Of note, these dietary variables are known to be affected by sleep [80], thus potentially mediate the pathway from sleep to cardiometabolic health. Adjusting for a mediator on the causal pathway could cause an attenuation of effect estimates, but not necessarily[18]. In the worst-case scenario, this overadjustment may lead to invalid study estimates. The results of this potential overadjustment were inconsistent in the studies identified; in some studies adjustment for diet and other potential cofounders attenuated effect estimates. Interestingly, the largest impact of dietary variables on sleep and cardiometabolic health associations were observed in prospective studies within pediatric populations. These results may represent age-related heterogeneity of sleep and diet associations.

Despite the suggested impact of diet on sleep and cardiometabolic health associations, the independent effect of dietary variables could not be separated from that of other confounders as most studies implemented simultaneous confounding adjustment strategies. In contrast, sequential adjustment of potential confounders would allow to disentangle the impact of each additional variable (or a set of variables) on the effect estimates of interest. Further, the concurrent measurement of sleep and dietary variables presents another major limitation as it hinders temporal assessment of the examined associations.

Eleven studies evaluated dietary variables as potential mediators in the pathway between sleep and cardiometabolic health, with mostly supportive evidence. Similar to confounding dietary variables, the most common mediating dietary variables included total energy intake and unhealthy dietary patterns. Further, the impact of mediating dietary variables on effect estimates was again stronger in pediatric populations compared with adult studies. Potential explanations for this observation are unknown, yet worth mentioning. In adults, additional mediators in the pathway of sleep and cardiometabolic health, such as physical activity or

altered metabolism [81], could exert a stronger indirect effect relative to dietary variables. Nonetheless, pediatric and adult study design heterogeneity may further explain the differential strength of dietary variables as mediators. Indeed, evidence from the pediatric populations was mostly obtained prospectively; while adult studies were mostly cross-sectional and thus subjected to reverse causation bias. In investigations of diet as a mediator, perhaps the main concern was the use of informal mediation analysis by most of these studies, which threatens internal validity of the reported results.

Finally, only 6 studies evaluated dietary variables as effect modifiers of sleep and cardiometabolic health associations. In children, associations between dietary variables and adiposity were more apparent among children with short sleep (based on age-specific recommendations). While adult studies echoed the pediatric findings, they lacked formal statistical tests of interaction, objective assessment of sleep, and temporal examination of sleep and cardiometabolic health. Although statistical interactions are not necessarily reflective of true biological interactions, underlying sleep-induced metabolic perturbations could alter the diet and cardiometabolic health associations. In support, experimental evidence showed that disrupted sleep schedules or a “cafeteria diet” alone in rats did not influence weight gain over a 12-week period; yet, the combination of disrupted sleep and a “cafeteria diet” caused weight gain and metabolic disruption in these rats [82].

Beyond the specific aforementioned analytical limitations, overarching methodological pitfalls could affect study validity regardless of the role of diet in these associations. First, measurement challenges pose a significant threat to internal validity, as sleep and diet were mostly self-reported, thus likely plagued by both random and systematic errors. Indeed, poor measurement of diet could explain the mild or null impact of dietary variables as confounders or mediators in some reports. Second, sleep and diet are multi-faceted behaviors with possible differential effects on cardiometabolic health. Yet, most studies focused on sleep duration but not sleep quality, timing, or weekday/weekend variability. Similarly, dietary variables mostly included measures of overall diet- e.g. total energy intake, diet patterns, diet quality- rather than meal timing or composition. Third, the majority of studies reported diet as either a confounder, mediator, or effect modifier in relation to sleep and cardiometabolic health. Certain aspects of diet may act as confounders (e.g. caffeinated beverages) while others (e.g. fast food consumption) could mediate the pathway from sleep to cardiometabolic health. Fourth, over the course of a longitudinal study diet is likely to change, however in none of the studies was diet evaluated as a time-varying confounder.

This systematic review fulfills a significant literature gap as it critically evaluates the incorporation of diet as a confounder, effect modifier, and mediator in sleep and cardiometabolic health associations. These findings will guide ongoing and future nutritional and epidemiological investigations. In particular, they may drive future investigations aimed to elucidate the complex associations between sleep, diet, and cardiometabolic health. As an additional strength, this rapid systematic review synthesizes the most recent studies, which ensures representation of the current knowledge and analytic techniques. Finally, careful attention was paid to causal inference implications. Namely, prospective studies were prioritized over cross-sectional, evaluation of the appropriateness of the statistical techniques and their applications was highlighted, and other important confounding factors such as age,

sex, and physical activity were considered. Nonetheless, some limitations remain: as part of the dietary factor evaluations, alcohol and caffeine intake were excluded, as were publications written in languages other than English.

As researchers continue to uncover the sleep-related determinants of cardiometabolic health, the essential role of diet should not be overlooked. In light of the increasing evidence that diet could mediate the causal pathway between sleep and cardiometabolic health, we caution against habitual adjustment of dietary variables and instead recommend a careful consideration of the diverse role that dietary variables play in these associations. In addition, to evaluate the independent role of diet on sleep-cardiometabolic health associations, crude study estimates should be shown first, followed by sequential adjustment for potential confounders and then dietary variables. Finally, the use of advanced statistical techniques, particularly formal mediation methods and the consideration of time-varying confounding, could help to shed light on the directionality of sleep and diet associations and their impact on cardiometabolic health. Ultimately, a more careful consideration of diet in the sleep-cardiometabolic health pathway is instrumental to the elucidation of pathways linking modifiable behaviors with cardiometabolic health.

REFERENCES

1. Huang PL. A comprehensive definition for metabolic syndrome. *Dis Model Mech* 2009; 2:231–7. doi: 10.1242/dmm.001180 [PubMed: 19407331]
2. McCullough AJ. Epidemiology of the metabolic syndrome in the USA. *J. Dig. Dis* 12:333–340 [PubMed: 21091931]
3. Ranasinghe P, Mathangasinghe Y, Jayawardena R, et al. Prevalence and trends of metabolic syndrome among adults in the Asia-Pacific region: A systematic review. *BMC Public Health* 2017; 17:. doi: 10.1186/s12889-017-4041-1
4. Shin D, Kongpakpaisarn K, Bohra C. Trends in the prevalence of metabolic syndrome and its components in the United States 2007–2014. *Int J Cardiol* 2018; 259:216–219. doi: 10.1016/j.ijcard.2018.01.139 [PubMed: 29472026]
5. Rimm EB, Appel LJ, Chiuve SE, et al. Seafood Long-Chain n-3 Polyunsaturated Fatty Acids and Cardiovascular Disease: A Science Advisory From the American Heart Association. *Circulation* 2018; CIR.0000000000000574. doi: 10.1161/CIR.0000000000000574
6. Shen J, Wilmut KA, Ghasemzadeh N, et al. Mediterranean Dietary Patterns and Cardiovascular Health. *Annu. Rev. Nutr* 35:425–449 [PubMed: 25974696]
7. World Health Organization (WHO) & Food and Agriculture Organization of the United Nations (FAO). Diet, nutrition and the prevention of chronic diseases
8. Shukla C, Basheer R. Metabolic signals in sleep regulation: Recent insights. *Nat. Sci. Sleep* 8:9–20 [PubMed: 26793010]
9. Xi B, He D, Zhang M, et al. Short sleep duration predicts risk of metabolic syndrome: A systematic review and meta-analysis. *Sleep Med Rev* 2014; 18:293–297. doi: 10.1016/j.smrv.2013.06.001 [PubMed: 23890470]
10. Knutson KL, Spiegel K, Penev P, Van Cauter E. The metabolic consequences of sleep deprivation. *Sleep Med. Rev.* 11:163–178 [PubMed: 17442599]
11. Hart CN, Carskadon MA, Considine R V, et al. Changes in children's sleep duration on food intake, weight, and leptin. *Pediatrics* 2013; 132:e1473–80. doi: 10.1542/peds.2013-1274 [PubMed: 24190680]
12. Mullins EN, Miller AL, Cherian SS, et al. Acute sleep restriction increases dietary intake in preschool-age children. *J Sleep Res* 2017; 26:48–54. doi: 10.1111/jsr.12450 [PubMed: 27641365]

13. Howatson G, Bell PG, Tallent J, et al. Effect of tart cherry juice (*Prunus cerasus*) on melatonin levels and enhanced sleep quality. *Eur J Nutr* 2012; 51:909–916. doi: 10.1007/s00394-011-0263-7 [PubMed: 22038497]
14. Peuhkuri K, Sihvola N, Korpela R. Dietary factors and fluctuating levels of melatonin. *Food Nutr Res* 2012; 56:1–9. doi: 10.3402/fnr.v56i0.17252
15. Spiegel K, Tasali E, Penev P, Van Cauter E. Brief communication: Sleep curtailment in healthy young men is associated with decreased leptin levels, elevated ghrelin levels, and increased hunger and appetite. *Ann Intern Med* 2004; 141:846–850. doi: 10.7326/00034819-141-11-200412070-00008 [PubMed: 15583226]
16. Afaghi A, O'Connor H, Chow CM. High-glycemic-index carbohydrate meals shorten sleep onset. *Am J Clin Nutr* 2007; 85:426–430. doi: 10.1093/ajcn/85.2.426 [PubMed: 17284739]
- 17 •. Cespedes EM, Hu FB, Redline S, et al. Chronic insufficient sleep and diet quality: Contributors to childhood obesity. *Obes (Silver Spring)* 2016; 24:184–190. doi: 10.1002/oby.21196.
This was a longitudinal study of US children with parent-reported sleep measures from age 6 months through 7 years. Investigators found that chronic insufficient sleep was associated with higher BMI z scores during mid-childhood, and they evaluated diet quality as a potential mediator and potential effect modifier, with partial evidence for both.
18. Schisterman EF, Cole SR, Platt RW. Overadjustment bias and unnecessary adjustment in epidemiologic studies. *Epidemiology* 2009; 20:488–495. doi: 10.1097/EDE.0b013e3181a819a1 [PubMed: 19525685]
19. Grant MJ, Booth A. A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Info. Libr. J* 26:91–108 [PubMed: 19490148]
20. Baird J, Hill CM, Harvey NC, et al. Duration of sleep at 3 years of age is associated with fat and fat-free mass at 4 years of age: the Southampton Women's Survey. *J Sleep Res* 2016; 25:412–418. doi: 10.1111/jsr.12389 [PubMed: 26909889]
- 21 ••. de Souza MC, Eisenmann JC, e Santos D V, et al. Modeling the dynamics of BMI changes during adolescence. The Oporto Growth, Health and Performance Study. *Int J Obes* 2015; 39:1063–1069. doi: 10.1038/ijo.2015.60.
Adolescents age 10–18 from the longitudinal Portuguese study Oporto Growth, Health and Performance Study were assessed over three years to determine changes in BMI during puberty. Weeknight sleep duration was not associated with BMI trajectories in fully adjusted models that included daily fruit and vegetable intake as dietary measures.
22. Lytle LA, Murray DM, Laska MN, et al. Examining the longitudinal relationship between change in sleep and obesity risk in adolescents. *Heal Educ Behav* 2013; 40:362–370. doi: 10.1177/1090198112451446
23. Shang L, O'Loughlin J, Tremblay A, Gray-Donald K. The association between food patterns and adiposity among Canadian children at risk of overweight. *Appl Physiol Nutr Metab* 2014; 39:195–201. doi: 10.1139/apnm-2012-0392 [PubMed: 24476475]
24. Fairley L, Santorelli G, Lawlor DA, et al. The relationship between early life modifiable risk factors for childhood obesity, ethnicity and body mass index at age 3 years: Findings from the Born in Bradford birth cohort study. *BMC Obes* 2015; 2:. doi: 10.1186/s40608-015-0037-5
- 25 •. Byrne DW, Rolando LA, Aliyu MH, et al. Modifiable Healthy Lifestyle Behaviors: 10-Year Health Outcomes From a Health Promotion Program. *Am J Prev Med* 2016; 51:1027–1037. doi: 10.1016/j.amepre.2016.09.012.
Frequency of sleeping 7–8 hours per night and dietary intake was assessed over time via self-report among university employees. Always sleeping 7–8 hours per night was associated with lower risk of cardiometabolic outcomes than never sleeping 7–8 hours per night after accounting for poor diet and additional covariates.

[PubMed: 27866595]

26. Sayon-Orea C, Bes-Rastrollo M, Carlos S, et al. Association between sleeping hours and siesta and the risk of obesity: the SUN Mediterranean Cohort. *Obes Facts* 2013; 6:337–347. doi: 10.1159/000354746 [PubMed: 23970143]
27. Hoevenaer-Blom MP, Spijkerman AM, Kromhout D, Verschuren WM. Sufficient sleep duration contributes to lower cardiovascular disease risk in addition to four traditional lifestyle factors: the MORGEN study. *Eur J Prev Cardiol* 2014; 21:1367–1375. doi: 10.1177/2047487313493057 [PubMed: 23823570]
28. Li Y, Sato Y, Yamaguchi N. Lifestyle factors as predictors of general cardiovascular disease: use for early self-screening. *Asia Pac J Public Heal* 2014; 26:414–424. doi: 10.1177/1010539511423067
29. Restall A, Taylor RS, Thompson JM, et al. Risk factors for excessive gestational weight gain in a healthy, nulliparous cohort. *J Obes* 2014; 2014:148391. doi: 10.1155/2014/148391 [PubMed: 24995130]
30. Arora T, Taheri S. Associations among late chronotype, body mass index and dietary behaviors in young adolescents. *Int J Obes* 2015; 39:39–44. doi: 10.1038/ijo.2014.157
31. Cao M, Zhu Y, He B, et al. Association between sleep duration and obesity is age- and gender-dependent in Chinese urban children aged 6–18 years: a cross-sectional study. *BMC Public Health* 2015; 15:1029. doi: 10.1186/s12889-015-2359-0 [PubMed: 26446623]
32. Carrillo-Larco RM, Bernabe-Ortiz A, Miranda JJ. Short sleep duration and childhood obesity: cross-sectional analysis in Peru and patterns in four developing countries. *PLoS One* 2014; 9:e112433. doi: 10.1371/journal.pone.0112433 [PubMed: 25393729]
33. D'Aniello R, Troisi J, D'Amico O, et al. Emerging pathomechanisms involved in obesity. *J Pediatr Gastroenterol Nutr* 2015; 60:113–119. doi: 10.1097/mpg.0000000000000559 [PubMed: 25199037]
34. Skidmore PM, Howe AS, Polak MA, et al. Sleep duration and adiposity in older adolescents from Otago, New Zealand: relationships differ between boys and girls and are independent of food choice. *Nutr J* 2013; 12:128. doi: 10.1186/1475-2891-12-128 [PubMed: 24034352]
35. Dev DA, McBride BA, Fiese BH, et al. Risk factors for overweight/obesity in preschool children: an ecological approach. *Child Obes* 2013; 9:399–408. doi: 10.1089/chi.2012.0150 [PubMed: 24020790]
36. Katzmarzyk PT, Barreira T V, Broyles ST, et al. Relationship between lifestyle behaviors and obesity in children ages 9–11: Results from a 12-country study. *Obes (Silver Spring)* 2015; 23:1696–1702. doi: 10.1002/oby.21152
37. Roman-Vinas B, Chaput JP, Katzmarzyk PT, et al. Proportion of children meeting recommendations for 24-hour movement guidelines and associations with adiposity in a 12-country study. *Int J Behav Nutr Phys Act* 2016; 13:123. doi: 10.1186/s12966-016-0449-8 [PubMed: 27887654]
38. Wilkie HJ, Standage M, Gillison FB, et al. Multiple lifestyle behaviours and overweight and obesity among children aged 9–11 years: results from the UK site of the International Study of Childhood Obesity, Lifestyle and the Environment. *BMJ Open* 2016; 6:e010677. doi: 10.1136/bmjopen-2015-010677
39. Zhang T, Cai L, Ma L, et al. The prevalence of obesity and influence of early life and behavioral factors on obesity in Chinese children in Guangzhou. *BMC Public Health* 2016; 16:954. doi: 10.1186/s12889-016-3599-3 [PubMed: 27613102]
40. Arora T, Hosseini-Araghi M, Bishop J, et al. The complexity of obesity in U.K. adolescents: relationships with quantity and type of technology, sleep duration and quality, academic performance and aspiration. *Pediatr Obes* 2013; 8:358–366. doi: 10.1111/j.2047-6310.2012.00119.x [PubMed: 23239604]
41. Labree W, van de Mheen D, Rutten F, et al. Differences in Overweight and Obesity among Children from Migrant and Native Origin: The Role of Physical Activity, Dietary Intake, and Sleep Duration. *PLoS One* 2015; 10:e0123672. doi: 10.1371/journal.pone.0123672 [PubMed: 26030064]
42. Santiago S, Zazpe I, Marti A, et al. Gender differences in lifestyle determinants of overweight prevalence in a sample of Southern European children. *Obes Res Clin Pr* 2013; 7:e391–400. doi: 10.1016/j.orcp.2012.07.001

43. Pileggi C, Lotito F, Bianco A, et al. Relationship between Chronic Short Sleep Duration and Childhood Body Mass Index: A School-Based Cross-Sectional Study. *PLoS One* 2013; 8:e66680. doi: 10.1371/journal.pone.0066680 [PubMed: 23805261]
44. Pengpid S, Peltzer K. Prevalence of overweight and underweight and its associated factors among male and female university students in Thailand. *Homo* 2015; 66:176–186. doi: 10.1016/j.jchb.2014.11.002 [PubMed: 25697745]
45. Jayawardana NW, Jayalath WA, Madhujith WM, et al. Lifestyle factors associated with obesity in a cohort of males in the central province of Sri Lanka: a cross-sectional descriptive study. *BMC Public Health* 2017; 17:27. doi: 10.1186/s12889-016-3963-3 [PubMed: 28056898]
46. Yan LX, Chen XR, Chen B, et al. Gender-specific Association of Sleep Duration with Body Mass Index, Waist Circumference, and Body Fat in Chinese Adults. *Biomed Env Sci* 2017; 30:157–169. doi: 10.3967/bes2017.023 [PubMed: 28427485]
47. Brocato J, Wu F, Chen Y, et al. Association between sleeping hours and cardiometabolic risk factors for metabolic syndrome in a Saudi Arabian population. *BMJ Open* 2015;
48. Japas C, Knutsen S, Dehom S, et al. Body mass index gain between ages 20 and 40 years and lifestyle characteristics of men at ages 40–60 years: the Adventist Health Study-2. *Obes Res Clin Pr* 2014; 8:e549–57. doi: 10.1016/j.orcp.2013.11.007
49. Grandner MA, Schopfer EA, Sands-Lincoln M, et al. Relationship between sleep duration and body mass index depends on age. *Obes (Silver Spring)* 2015; 23:2491–2498. doi: 10.1002/oby.21247
50. Buman MP, Winkler EA, Kurka JM, et al. Reallocating time to sleep, sedentary behaviors, or active behaviors: associations with cardiovascular disease risk biomarkers, NHANES 2005–2006. *Am J Epidemiol* 2014; 179:323–334. doi: 10.1093/aje/kwt292 [PubMed: 24318278]
51. Roos V, Elmstahl S, Ingelsson E, et al. Alterations in Multiple Lifestyle Factors in Subjects with the Metabolic Syndrome Independently of Obesity. *Metab Syndr Relat Disord* 2017; 15:118–123. doi: 10.1089/met.2016.0120 [PubMed: 28339343]
52. Yu S, Guo X, Yang H, et al. An update on the prevalence of metabolic syndrome and its associated factors in rural northeast China. *BMC Public Health* 2014; 14:877. doi: 10.1186/1471-2458-14-877 [PubMed: 25159694]
53. Parvaneh K, Poh BK, Hajifaraji M, Ismail MN. Sleep deprivation is related to obesity and low intake of energy and carbohydrates among working Iranian adults: a cross sectional study. *Asia Pac J Clin Nutr* 2014; 23:84–90. doi: 10.6133/apjcn.2014.23.1.02 [PubMed: 24561976]
54. Georgousopoulou EN, D’Cunha NM, Mellor DD, et al. The Association between Sleeping Time and Metabolic Syndrome Features, among Older Adults Living in Mediterranean Region: The MEDIS Study. *Metab Syndr Relat Disord* 2018; 16:. doi: 10.1089/met.2017.0113
55. Georgousopoulou EN, Naumovski N, Mellor DD, et al. Association between siesta (daytime sleep), dietary patterns and the presence of metabolic syndrome in elderly living in Mediterranean area (MEDIS study): The moderating effect of gender. *J Nutr Heal Aging* 2017; 21:1118–1124. doi: 10.1007/s12603-016-0865-0
56. Min H, Um YJ, Jang BS, et al. Association between Sleep Duration and Measurable Cardiometabolic Risk Factors in Healthy Korean Women: The Fourth and Fifth Korean National Health and Nutrition Examination Surveys (KNHANES IV and V). *Int J Endocrinol* 2016; 2016:. doi: 10.1155/2016/3784210
57. Kjartansdottir I, Arngrimsson SA, Bjarnason R, Olafsdottir AS. Cross-sectional study of randomly selected 18-year-old students showed that body mass index was only associated with sleep duration in girls. *Acta Paediatr Int J Paediatr* 2018; 107:1070–1076. doi: 10.1111/apa.14238
58. MacWana JJ, Mehta KG, Baxi RK. Predictors of overweight and obesity among school going adolescents of Vadodara city in Western India. *Int J Adolesc Med Health* 2017; 29:. doi: 10.1515/ijamh-2015-0078
59. Kelishadi R, Heidari Z, Kazemi I, et al. A hierarchical Bayesian tri-variate analysis on factors associated with anthropometric measures in a large sample of children and adolescents: The CASPIAN-IV study. *J Pediatr Endocrinol Metab* 2018; 31:443–449. doi: 10.1515/jpem-2017-0213 [PubMed: 29451860]

60. Chaput JP, Leduc G, Boyer C, et al. Objectively measured physical activity, sedentary time and sleep duration: Independent and combined associations with adiposity in canadian childre. *Nutr Diabetes* 2014; 4:. doi: 10.1038/nutd.2014.14
61. Magriplis E, Farajian P, Panagiotakos DB, et al. The relationship between behavioral factors, weight status and a dietary pattern in primary school aged children: The GRECO study. *Clin Nutr* doi: 10.1016/j.clnu.2018.01.015
62. Hunsberger M, Mehlig K, Bornhorst C, et al. Dietary Carbohydrate and Nocturnal Sleep Duration in Relation to Children's BMI: Findings from the IDEFICS Study in Eight European Countries. *Nutrients* 2015; 7:10223–10236. doi: 10.3390/nu7125529 [PubMed: 26670249]
63. Wijnhoven TM, van Raaij JM, Yngve A, et al. WHO European Childhood Obesity Surveillance Initiative: health-risk behaviours on nutrition and physical activity in 6–9-year-old schoolchildren. *Public Heal Nutr* 2015; 18:3108–3124. doi: 10.1017/s1368980015001937
- 64 •. Peach H, Gaultney JF, Reeve CL. Sleep characteristics, body mass index, and risk for hypertension in young adolescents. *J Youth Adolesc* 2015; 44:271–284. doi: 10.1007/s10964-014-0149-0.
- Among US sixth-graders, parent-reported sleep duration and daytime sleepiness was associated with BMI among boys whereas only daytime sleepiness was associated with BMI among girls. Daytime sleepiness had a direct effect on hypertension in boys and an indirect effect (through BMI) on hypertension in girls. Associations were independent of self-reported consumption of unhealthy foods such as soda, hotdogs, French fries and cookies.
- [PubMed: 25001215]
65. Rangan A, Zheng M, Olsen NJ, et al. Shorter sleep duration is associated with higher energy intake and an increase in BMI z-score in young children predisposed to overweight. *Int J Obes (Lond)*. doi: 10.1038/ijo.2017.216
66. Asarnow LD, McGlinchey E, Harvey AG. Evidence for a Possible Link between Bedtime and Change in Body Mass Index. *Sleep* 2015; 38:1523–1527. doi: 10.5665/sleep.5038 [PubMed: 26194568]
- 67 ••. He F, Bixler EO, Liao J, et al. Habitual sleep variability, mediated by nutrition intake, is associated with abdominal obesity in adolescents. *Sleep Med* 2015; 16:1489–94. doi: 10.1016/j.sleep.2015.07.028.
- This study of US adolescents found that actigraphyassessed sleep duration variability was associated with higher abdominal fat measured by dual X-ray absorptiometry (DXA). Further, they found evidence of partial mediation by total energy intake, measured by a food frequency questionnaire.
- [PubMed: 26611945]
68. McDonald L, Wardle J, Llewellyn CH, Fisher A. Nighttime sleep duration and hedonic eating in childhood. *Int J Obes* 2015; 39:1463–1466. doi: 10.1038/ijo.2015.132
69. Cespedes EM, Rifas-Shiman SL, Redline S, et al. Longitudinal associations of sleep curtailment with metabolic risk in mid-childhood. *Obes (Silver Spring)* 2014; 22:2586–2592. doi: 10.1002/oby.20894
70. Yeh SS, Brown RF. Disordered eating partly mediates the relationship between poor sleep quality and high body mass index. *Eat Behav* 2014; 15:291–297. doi: 10.1016/j.eatbeh.2014.03.014 [PubMed: 24854821]
- 71 •. Kanagasabai T, Arden CI. Contribution of Inflammation, Oxidative Stress, and Antioxidants to the Relationship between Sleep Duration and Cardiometabolic Health. *Sleep* 2015; 38:1905–1912. doi: 10.5665/sleep.5238.
- The association between vitamins and carotenoids and metabolic syndrome was assessed in a nationally-representative study of US adults. Carotenoids, vitamins C and D were modest mediators of the relationship between sleep duration and the metabolic syndrome among women.
- [PubMed: 26237775]

72. Mesas AE, Guallar-Castillon P, Lopez-Garcia E, et al. Sleep quality and the metabolic syndrome: the role of sleep duration and lifestyle. *Diabetes Metab Res Rev* 2014; 30:222–231. doi: 10.1002/dmrr.2480 [PubMed: 24123692]
 73. Chaput JP, Bouchard C, Tremblay A. Change in sleep duration and visceral fat accumulation over 6 years in adults. *Obes (Silver Spring)* 2014; 22:E9–12. doi: 10.1002/oby.20701
 74. Wirth MD, Hébert JR, Hand GA, et al. Association between actigraphic sleep metrics and body composition. *Ann Epidemiol* 2015; 25:773–778. doi: 10.1016/j.annepidem.2015.05.001 [PubMed: 26071309]
 - 75 •. Timmermans M, Mackenbach JD, Charreire H, et al. Exploring the mediating role of energy balance-related behaviours in the association between sleep duration and obesity in European adults. The SPOTLIGHT project. *Prev Med (Baltim)* 2017; 100:25–32. doi: 10.1016/j.ypmed.2017.03.021.
- Mediation of the association between longer sleeping (≥ 9 hours) and obesity by dietary intake behaviors was assessed in urban-dwelling European adults. Longer sleep duration was associated with a lower likelihood of obesity than short sleep duration (<7 hours), but there was no evidence of mediation by diet.
- 76 ••. Hjorth MF, Sjödin A, Dalskov SM, et al. Sleep duration modifies effects of free ad libitum school meals on adiposity and blood pressure. *Appl Physiol Nutr Metab* 2016; 41:33–40. doi: 10.1139/apnm-2015-0319.
- Children from Denmark were enrolled in a crossover trial, in which they were fed a New Nordic Diet (NND) lunch for 1 month and had usual packed lunches for one month. Among children with habitual short sleep (assessed with actigraphy), the NND resulted in fat mass gain compared usual lunch consumption.
- [PubMed: 26647154]
77. Doo H, Chun H, Doo M. Associations of daily sleep duration and dietary macronutrient consumption with obesity and dyslipidemia in Koreans: A cross-sectional study. *Med* 2016; 95:e5360. doi: 10.1097/md.00000000000005360
 78. Doo M, Kim Y. The Consumption of Dietary Antioxidant Vitamins Modifies the Risk of Obesity among Korean Men with Short Sleep Duration. *Nutrients* 2017; 9:E780 [PubMed: 28726758]
 79. Kim NH, Shin DH, Kim HT, et al. Associations between metabolic syndrome and inadequate sleep duration and skipping breakfast. *Korean J Fam Med* 2015; 36:273–277. doi: 10.4082/kjfm.2015.36.6.273 [PubMed: 26634092]
 80. Chaput J-P. Sleep patterns, diet quality and energy balance. *Physiol Behav* 2014; 134:86–91. doi: 10.1016/j.physbeh.2013.09.006 [PubMed: 24051052]
 81. Reutrakul S, Van Cauter E. Sleep influences on obesity, insulin resistance, and risk of type 2 diabetes. *Metabolism*.
 82. Espitia-Bautista E, Velasco-Ramos M, Osnaya-Ramírez I, et al. Social jet-lag potentiates obesity and metabolic syndrome when combined with cafeteria diet in rats. *Metabolism*. doi: 10.1016/j.metabol.2017.04.006
 83. National Cholesterol Education Program Expert Panel, National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III). Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III) final report. *Circulation* 2002; 106:3143–3421. doi: 10.1161/01.CIR.0000048067.86569 [PubMed: 12485966]

Figure 1.
Causal diagram illustrating the different roles of diet on the sleep-cardiometabolic health pathway

¹ One study examined diet as a confounder and an effect modifier, while another study examined diet both as a mediator and an effect modifier; thus, summing the number of studies in each nutrition category does not match the total number of studies retained (n=60)

Figure 2.
Selection of studies

Table 1.

Longitudinal studies with diet as a confounder or an independent risk factor

Author, Year, Country	Study population	Study design	Sleep Assessment	Confounder Assessment	Outcome Assessment ^{a,b}	Other Covariates	Statistical Analysis	Main findings
Children and adolescents								
Baird, 2016, UK [20]	587 children, aged 3 years at baseline	Population-based longitudinal study of mothers and children followed from preconception	Sleep duration, including nighttime sleep and daytime naps, at age 3; parent-report	Diet quality at age 3, Prudent diet z-score; FFQ	BMI (height and weight); body composition (fat and fat-free mass index by DXA scan) at age 4	Gestational age (GA), age at DXA, sex, pre-pregnancy maternal BMI, maternal education, prenatal smoking, parental SES, age last breastfed, activity level, TV watching time	Linear regression	Shorter sleep was associated with higher BMI, a greater fat mass index, and a greater fat-free mass index one year later; adjustment for confounders did not substantially alter estimates; diet was independently associated with adiposity
De Souza ^b , 2015, Portugal [21]	6,894 adolescents, aged 10–18 years at baseline	Longitudinal study, annual measurements for 3 years	Sleep duration during the week; self-report	Fruit and vegetable intake (dichotomous variable: every day vs. not every day); FFQ	BMI	Physical activity, physical fitness	Sex-stratified hierarchical linear models to model change in BMI	Sleep duration was not associated with BMI trajectories in fully adjusted models (crude association not reported)
Fairley ^b , 2015, UK [24]	987 participants, aged 3 years	Longitudinal multiethnic birth cohort	Sleep duration during day and night at 24 months; parent-report	Duration of any breastfeeding, age at weaning on to solids, infant's total energy intake per day, infant's total protein intake per day, caregivers feeding style; parent reported	BMI z-scores and child overweight; measured at the 36 month visit, based on the WHO 2006 growth standards	Ethnicity, infant sex, maternal age, maternal highest educational qualification, parity, birthweight, gestational age at delivery, mode of delivery	Linear regression models and Poisson regression models	No association between sleep duration and BMI-z scores (unadjusted analyses not shown). BMI z-scores were higher in children who breastfed between 1 day and 1 month (compared to those who never breastfed) and had an indulgent caregiver's feeding style; similar patterns for overweight
Shang, 2014, Canada [23]	613 children, aged 8–10 years	Longitudinal study of families	Sleep duration; 7-day actigraphy	3 dietary patterns (traditional, healthy fast food); total energy intake; 24-hr recalls	BMI, WC, fat mass %, obesity defined as 95th percentile for age and sex	Age, sex, screen time, mother's obesity, family income, daily steps; sweetened beverage intake	Multivariable logistic regressions	In fully adjusted multivariable models, fast food dietary pattern was associated with overweight

Author, Year, Country	Study population	Study design	Sleep Assessment	Confounder Assessment	Outcome Assessment ^{a,b}	Other Covariates	Statistical Analysis	Main findings
								and adiposity measures (BMI, WC, body fat mass %), sweetened beverage intake was associated with BMI and WC, but sleep duration was not significantly associated with adiposity (crude association not shown)
Lytle, 2013, USA [22]	723 adolescents, mean age 14.7 years at baseline	Longitudinal study; one follow-up visit 2 years after baseline	Change in average daily sleep duration over follow-up; self-report	Total energy intake; average daily calories from three 24-h recalls via phone (two weekdays and a weekend)	BMI and % body fat; body size via bioelectrical impedance and hydrodensitometry	Sex, grade level, depression, screen time/sedentary behavior, physical activity, puberty, race, SES, parental education, study	Random coefficient models to account for within-person correlation, all conducted separately for males and females	Change in sleep duration was not associated with change in adiposity measures over two years, neither in analysis adjusting only for sociodemographic characteristics nor in fully adjusted analysis.
Adults								
Byrne ^b 2016, USA [25]	10,248 employees of Vander bilt University, mean age 41 years	Longitudinal study, annual participation in health risk assessment	Sleep 7-8h per night (range from seldom or never to always); self-report	Dietary fat intake, unhealthy snacks, breads and grains, fruits and vegetables, regular breakfast; self-report	Cardiometabolic outcomes: hypercholesterolemia, hypertension, obesity, diabetes mellitus, heart disease, stroke; self-report	Age, sex, race/ethnicity, physical activity, smoking, strength exercising, baseline BMI and comorbidities	Multivariable Cox regression, excluding individuals with outcomes at baseline	“Always” sleeping 7–8h per night compared to “never” was associated with lower risk of obesity, heart disease, hypercholesterolemia, and stroke even after accounting for diet (largest effect estimate with high-fat diet) and other covariates
Hoevenaer-Blom, 2014, The Netherlands [27]	17,887 adults age 20-79 years	Longitudinal study, 10–14 year follow up	Sleep duration (sufficient (7 h) versus insufficient); self-report	Mediterranean diet intake; FFQ	CVD events and mortality	Age, sex, physical activity, smoking, education, BMI, blood pressure, alcohol	Cox proportional hazards, Preventable fraction calculated	Sufficient sleep in addition to the healthy lifestyle score significantly reduced the hazard of CVD deaths or events (unadjusted estimates not substantially

Author, Year, Country	Study population	Study design	Sleep Assessment	Confounder Assessment	Outcome Assessment ^{a,b}	Other Covariates	Statistical Analysis	Main findings
Li, 2014, Japan [28]	12,883 adults aged 20–79 year at baseline	Longitudinal study with a 10-year follow-up	Sleep duration (<6h vs. 6 h); self-report	3 dietary patterns: traditional, healthy, Western; FFQ	Diabetes mellitus, general CVD events and deaths	Occupation, age, current smoking, habitual drinking, regular physical activity, work intensity, BMI, systolic BP, total cholesterol, and fasting blood glucose	Cox proportional hazard regression and logistic regression to predict 10-year risk of CVD events	different from adjusted) Short sleep duration, traditional and Western diet were associated with CVD events after controlling for other lifestyle factors
Restall, 2014, multi-country: Australia, New Zealand, Ireland [29]	1,950 nulliparous women, mean age 29 years, 14–16 weeks pregnant with a singleton	Longitudinal, multi-center cohort study, 2004–2011	Nighttime sleep duration hours (<8h (reference), 8–9h, 10h); self-report	Fish/seafood (including oily fish such as tuna or salmon and shellfish or shrimps) weekly intake (<3 vs. 3 servings); self-report	Excessive gestational weight gain (yes vs. no) according to Institute of Medicine 2009 guidelines	Exercise, infertility, behavioral responses to illness, smoking, immigration status, birth weight	Logistic regression;	High fish/seafood intake and sleeping for 10h+ per night were each associated with higher risk for excessive weight gain in pregnancy (unadjusted associations not shown)
Sayon-Orea, 2013, Spain [26]	10,532 adults (n=9,470 for naps data), mean age 39 years at baseline	Longitudinal study, followed for median 6.5 years	Average night sleep duration (reference = 7–8 h) and average nap duration (reference=never/almost never nap); self report	Total energy intake, sugar-sweetened beverage intake, fast food intake, snacking between meals; FFQ	Incidence of obesity over follow-up period; self-reported height and weight	Age, sex, physical activity, smoking, sitting, regular snoring, insomnia, caffeine intake, alcohol intake, baseline BMI	Cox regression model	Sleeping <5 h per night was associated with higher risk of developing obesity and a nap of 30 min/day was associated with lower risk of developing obesity, accounting for potential confounders did not substantially alter estimates (except for adding baseline BMI).

BMI=Body Mass index; CDC=Centers for Disease Control; CHO=carbohydrate; FFQ= food frequency questionnaire; IOM=Institute of Medicine; IOTF=International Obesity Taskforce; MetS=metabolic syndrome; SES=socioeconomic status; TV=television; UK=United Kingdom; USA=United States of America; WC=waist circumference; WHO=World Health Organization

^aOverweight defined as BMI 25 and obesity defined as BMI 30, WC 40 in men, WC 35 in women unless otherwise specified

^bIndicates a study where sleep was one of many risk factors (including nutrition) considered for cardiometabolic outcome

Table 2.

Cross-sectional studies with diet as a confounder or an independent risk factor

Author, Year, Country	Study Population	Sleep Assessment	Confounder Assessment	Outcome Assessment ^{a,b}	Other Covariates	Statistical Analysis
Children and adolescents						
Kelishadi, 2018, Iran [59]	13,280 students, aged 6–18 years	Sleep duration as number of hours in a week; student and parent questionnaires	Intake of junk food, number of days eating breakfast in a week, breastfed	BMI, Waist-Height Ratio, WC	Provinces, Physical activity, family history of CVD, screen hours, smoking birth weight, psychological disorders, SES, age, sex	Bayesian multi-level regression
Magriplis, 2018, Greece [61]	4,434 children, aged 10–12 years	Sleep duration averaged for week nights and weekends; self-report	Non and potentially-obesogenic dietary patterns; self-report; 48-item FFQ	BMI, overweight based on IOTF	Age, sex, dietary pattern score, screen time, study hours	Logistic regression and excessive weight
Macwana ^c , 2016, India [58]	1,050 adolescents, aged 11–19 years old	Sleep duration (categories: up to 7h or more than 7h); self-report, in analysis as predicted independent variable	Specific food items-pulse, dal rice, cheese/butter/paneer, wafer/fry items, pizza/burger/fast food; vegetarian or mixed diet, preference for outside food, breakfast skipping, meal skipping; self-report	Overweight and obesity based on BMI-for-age WHO reference: triceps skin fold thickness; waist and hip circumferences	Age group, sex, language of instruction, family history of obesity, daytime activities	Multiple logistic regression
Roman-Vinās, 2016, multi-country [37]	6,128 children, aged 9–11 years	Sleep duration, dichotomous adherence to the recommended sleep duration (9–11 h/night), 7-day actigraphy	Unhealthy diet pattern (e.g. fast food, icecream, fried food); 23-item FFQ	Obesity; categorical and continuous BMI-for-age z based on WHO reference	Age, sex, parental education	Generalized linear model and linear regression. Adjusted or stratified
Wilkie ^c , 2016, UK [38]	374 children, aged 9–11 years	Sleep duration, 1 week hip worn actigraphy	Dietary patterns-health and unhealthy (from principal components analysis); FFQ	Overweight/obese, based on BMI-for-age WHO reference	Age, sex, SES	Multilevel multiple regression with school random effects; controlling for sleep duration
Zhang ^c , 2016, China [39]	3,766 children, aged 7–12 years	Average sleep duration (categories: <7h, 9–11h, and >11h); self-report	Average daily intake of fruits, vegetables, meat products, breakfast, sugar-sweetened beverages, high-energy snacks, fried food,	Overweight and obesity based on Working Group of Obesity in China criteria	Age, sex, only child, parental education, parental occupation, monthly	Multinomial logistic regression

Author, Year, Country	Study Population	Sleep Assessment	Confounder Assessment	Outcome Assessment ^{a,b}	Other Covariates	Statistical Analysis
			western fast food, eating speed		household income, sedentary time, physical activity	
Arora, 2015, UK [30]	511 children, aged 11–13 years	Sleep duration; 7-day actigraphy sub-sample n=236; sleep chronotype; self-report	Frequency of unhealthy foods/snacks (crisps, chocolate, biscuits, cake, sweets, etc.), daily intake of fruit and vegetables	BMI z-score (did not specify reference used)	Age, sex, school type, ethnicity, dietary behavior, parent obesity, depression, anxiety, daytime sleepiness, Confounder: intake of caffeinated beverages before bed	Linear regression
Cao, 2015, China [31]	8,760 children, aged 6–18 years	Sleep duration (categories: <7h, 7–9h, 9h); self-report, parent report for kids < 9 years	Daily food intake fruit, vegetables, meat, and sugar beverages; self-report, parent report for kids <9 years	Obesity, based on BMI z-scores by Chinese reference	Age, sex, dietary intake, physical activity, sedentary behavior	Logistic regression standard errors
D'Aniello ^c , 2015, Italy [33]	54 children, aged 4–15 years	Sleep duration; sleep quality/fragmentation; parent-report	Weekly fructose intake from sugar sweetened beverages and fruit juice	BMI percentiles from Italian reference	BPA, WC, BP	ANCOVA, Spearman correlations, logistic
Hunsberger, 2015, 12 countries (also found in effect modification) [62]	5,944 children at baseline	Sleep duration hours (categories: short sleep <10h vs. reference 10h);parent-report	Breakfast, CHO from sugar and starch in morning, midday or evening, total energy intake; 24-hour diet recall by parent and school staff Monday through Thursday	BMI, BMI z-score, according to IOTF criteria	Age, sex, highest parental education, country	Mutually adjusted linear regression
Katzmarzyk ^c , 2015, multicountry [36]	6,025 children, aged 9–11	Nocturnal sleep duration; 7-day actigraphy	Unhealthy and healthy dietary patterns; FFQ	Obesity based on BMI-for-age WHO reference	Age, sex, SES, moderate to vigorous physical	Generalized linear models to account

Author, Year, Country	Study Population	Sleep Assessment	Confounder Assessment	Outcome Assessment ^{a,b}	Other Covariates	Statistical Analysis
					activity, TV viewing	correlation within school
Labree ^c , 2015, The Netherlands [41]	1,943 parent-child dyads, children at baseline were 8–9 years	Sleep duration based on time went to bed and awoke on an average school day; reported by primary caregiver	Four food categories: fruit, vegetables, sugar-sweetened beverages, and energy-dense snacks intake; primary caregiver reported children's dietary intake with a FFQ	BMI and prevalence of overweight/obesity based on IOTF	Age, sex, parental educational level, and parental BMI	Linear regression
Peach, 2015, USA (cross-sectional analysis of longitudinal study) [64]	541 6 th grade students	Weekday sleep duration, weekend sleep duration from self-report; Daytime sleepiness; parent-report	Typical consumption habits of certain foods (soda, hotdogs/ham burgers, French fries, cookies/donuts); self-report	Hypertension, cutoffs determined by CDC sex, age, and height standards	Race/ethnicity, income, pubertal stage, depressive symptoms, physical activity, attention/behavioral problems, BMI	Structural equation BMI as mediator, and stratified by sex
Wijnhoven ^c , 2015, multicountry: Bulgaria, Lithuania, Portugal, Sweden, and Czech Republic [63]	15,643 children, aged 6–9 years	Usual amount of sleep each day (categories: <9h/day (yes/no)), parent-report	Breakfast intake frequency, usual intake of fresh fruit, 100% fruit juice, vegetables, foods like potato chips, foods like candy bars or chocolate, foods like biscuits and cakes, food like pizza and French fries, hamburgers, sausages, or meat pies	Obesity, based on BMI-for-age WHO reference	Physical activity, screen time, sex, age, urbanicity, parental education, parental occupation	Multilevel logistic accounting for correlation design
Carrillo-Larco, 2014, Peru [32]	1,929 children, mean age 7.9	Sleep duration as hours slept on a typical night (categories: <10h or 10–11h); self-report	Number of meals; self-report from previous day	BMI categorized into normal, overweight and obese by IOTF reference	Age, sex, urbanicity, birth weight, physical activity, parental education, maternal weight, wealth index	Generalized linear robust standard error account for cluster
Chaput ^c , 2014, Canada [60]	507 children, aged 9–11 years	Sleep duration; 7-day actigraphy	Fast food intake; self-reported frequency	% body fat (bioelectrical impedance), waist-to-height ratio	Age, sex, ethnicity, maturity offset, annual	Multivariable linear models

Author, Year, Country	Study Population	Sleep Assessment	Confounder Assessment	Outcome Assessment ^{a,b}	Other Covariates	Statistical Analysis
					household income, parental education, sedentary time and physical activity	
Arora, 2013, UK [40]	624 adolescents, aged 11–18 years	Weekday sleep duration, sleep onset latency, number of night-time awakening, sleep quality; self-report	Snacking before bedtime	Weight (kg) and height (cm), BMI z-score	Age, sex and ethnicity, quantity of weekday technology, snacking, activity, school, depression, potential OSA, bedroom sharing, morningness-eveningness and academic performance	Linear regression
Dev ^c , 2013, USA [35]	329 children, aged 2 years, from USA	Nighttime sleep duration (9h vs. 8h); parent-report	Mean intake/day of: milk, sugar beverages, juice, fresh fruits, French fries, vegetables, fast foods, candy sweets, salty snacks; sugar added to baby formula; perceived dietary quality	Overweight/obesity based on CDC reference	20 other potential risk factors for childhood obesity (e.g. sex, ethnicity, TV habits, parental characteristics, SES, parental feeding practices)	Logistic regression
Pileggi, 2013, Italy [43]	509 fifth graders, aged 10 years	Nighttime sleep duration, difference between weekday and weekend in hours of sleep; parent report; in analysis as continuous and dichotomous	Adequate intake calculated for key food groups including cereals, fruit and vegetables, milk, meat/fish and snacks based on Italian Institute of Nutrition age appropriate guidelines; self-report; FFQ	BMI percentile based on Italian Pediatrics Society of Diabetology and Endocrinology	Age, sex, physical activity, maternal BMI, parent's education, hours watching TV, hours playing video games, breastfed	Linear regression
Santiago, 2013, Spain [42]	2,814 children, aged 6–12 years	Sleep duration (categories: <9h vs. ≥9h), self-report to interviewer administered questionnaire	Eating patterns: number of meals, breakfast intake; from FFQ with daily/weekly intake assessed for recommended and not healthy food items	BMI classified as overweight/obese according to IOTF	Age, sex, physical activity, screen time	Logistic regression by sex

Author, Year, Country	Study Population	Sleep Assessment	Confounder Assessment	Outcome Assessment ^{a,b}	Other Covariates	Statistical Analysis
Skidmore, 2013, New Zealand [34]	685 adolescents, aged 15–18 years	Average sleep duration overall, on school nights and weekend nights; online questionnaire	Fruit and vegetable intake; self-report	BMI z-scores based on BMI-for-age WHO reference, Waist-to-height ratio, fat mass index, fat-free mass index (from bioelectrical impedance)	Sex, grade, ethnicity, number of screens in bedroom	GEE with robust standard errors, accounting for clustering within sample and stratification
Young adults						
Kjartansdottir, 2018, Iceland [57]	199 students, aged 18 years	Sleep duration based on weighted average of self-reported duration during weekend and weekdays (categories: < 7h or 7 h), sleep debt defined as weekend sleep 2 hrs more than weekday; self-report	Meal frequency; healthy eating score calculated based on eight food groups; unhealthy eating score calculated based on five food groups; 47-item FFQ	BMI and WC	VO ₂ max	Linear regression, sex
Pengpid, 2015, Thailand [44]	860 college students, aged 17–25	Sleep duration (reference category 7–8 hours), sleep disturbances; self-report	Weekly intake of fruits, vegetables, red meat, breakfast, snacks.	BMI categorized according to Asian guidelines for underweight, normal, overweight (>23) and obese (>25)	Perceived body size, belief in dietary benefits, physical activity, tobacco, alcohol, depression, PTSD, social support, religiousness, SES	Multinomial logistic regression stratified by sex
Adults						
Jayawardana, 2017, Sri Lanka [45]	2,469 males, aged 16–72 years	Sleep duration(categories: low (<6h), medium (7–8h), high (>8h)); self-reportduring an interviewer-administered interview	Average weekly intake of meat, fish, fruits, dairy, fried snacks and sweets, in last 6 months; FFQ	Obesity-WC, BMI (Asian cut-off values: underweight <18.5, normal 18.5–22.9, overweight 23–27.5 or obese >27.5)	Physical activity, smoking, alcohol, age, ethnicity, education, income	Multinomial logistic regression
Roos ^c , 2017, Sweden [51]	18,880 adults, aged 45–75 years	General sleep quality, self-reported questionnaire	Irregular eating habits (not having breakfast, lunch and dinner every day); self-reported questionnaire	MetS	Age, sex, and BMI or fat mass, or fat-free mass, or WC, or waist/hip ratio.	Logistic regression

Author, Year, Country	Study Population	Sleep Assessment	Confounder Assessment	Outcome Assessment ^{a,b}	Other Covariates	Statistical Analysis
Yan, 2017, China [46]	7,094 adults, aged 35–60 years	Sleep duration (categories: <6h, 6–7h, 7–8h (reference), 8–9h, 9h); self-report	Daily caloric intake, fat intake; FFQ (simplified)	BMI, WC; body fat (Bioelectrical Impedance Analysis) Obesity classified by BMI ≥28, WC ≥85 cm in men and ≥80 in women, body fat ≥25% in men and ≥35% in women	Age, education occupation, marital status smoking, alcohol sedentary behavior hypertension, diabetes, dietary intake, physical activity	Logistic regression, stratified
Min, 2016, South Korea [56]	8,505 women, aged 25–70 years	Average sleep duration per day (categories: short: 5h, short: 6h, reference: 7h, long: 8h, very long: 9h., self-report	Energy intake (kcal) 24-h recall method; self-report	MetS	BMI, smoking status, monthly income, alcohol intake, average physical activity per week, intense physical activity per week, education status.	Logistic regression
Brocato, 2015, Saudi Arabia [47]	2,686 adults, age not specified, from Saudi Arabia	Sleep duration (categories: <7h, 7h, 8h, >8h); self-report to interviewer administered questionnaire	Weekly intake of common food items, categorized as healthy (green leafy vegetables, fresh fruits, fish and green tea) and unhealthy (red meat, processed meat, pizza, croissants, ice cream, fried foods, soft drinks, etc.)	MetS components ^b	Age, education, physical activity, smoking,	Logistic regression

Author, Year, Country	Study Population	Sleep Assessment	Confounder Assessment	Outcome Assessment ^{a,b}	Other Covariates	Statistical Analysis
Grandner, 2015, USA [49]	5,607 participants, aged 16+ years	Sleep duration (categories: very short (< 4h), short (5–6h), average (7–8h), long (> 9h)) self-report; in analysis evaluated continuously and categorically	Total daily caloric intake and food variety; 24-h recalls	BMI; height and weight measured by trained research assistants	Sex, race/ethnicity, marital status, education level, income to poverty ratio, exercise, smoking, alcohol, and depression	Linear regression
Buman, 2014, USA [50]	2,185 adults (923 fasting subsample), aged 20+ years	Sleep duration; self-report	Total energy, saturated fat; 24-h dietary recalls	WC and systolic and diastolic BPs, HDL-cholesterol and C-reactive protein, LDL-cholesterol, fasting TGL, plasma glucose, and insulin, Homeostasis model assessment of insulin sensitivity (HOMA-S) and homeostasis model assessment of β -cell function (HOMA- β)	Age, sex, race/ethnicity, marital status, education, work status, ratio of family income to poverty level, smoking, caffeine intake, alcohol intake, depressive symptoms, a general health rating, previous diagnosis of cancer or malignancy, CVD, or diabetes, and current use of diabetic, antihypertensive, lipidemic, or other CVD medication	Single-variable and multivariable models, isotemporal substitution model analyses
Japas, 2014, USA and Canada [48]	9,864 males, aged 40–60 years	Sleep duration; self-report on self-administered questionnaire	Vegetarian status (vegan, lacto-ovo, semi- and non-vegetarian); FFQ	Change in BMI; BMI at 20, 30, 40 years of age and currently, based on retrospective self-report	Physical activity, income, education	Logistic regression

Author, Year, Country	Study Population	Sleep Assessment	Confounder Assessment	Outcome Assessment ^{a,b}	Other Covariates	Statistical Analysis
Parvaneh, 2014, Iran [53]	226 adults, aged 20–55 years	Bed time, wake time and sleep duration during weekends and weekdays; calculated average duration weighted for weekends and weekdays; self-report	24-hr food recall for 3 days (2 weekdays and 1 weekend), calculated servings and nutrients as mean values over 3 days; in analysis: mean intake values of energy, CHOs, protein and fat.	BMI (dichotomous normal or overweight/obese according to WHO criteria), height, weight, hip circumference, WC, and body fat %; all measured by trained research assistants	Age, sex, physical activity	Correlations of covariables; stepwise regression with obesity as the outcome
Yu, 2014, China [52]	11,496 adults, aged 35+ years	Average sleep duration (categories: 7h (reference), 7–8h, 8–9h, >9h); self-report obtained by trained research assistants	Weekly frequency of dietary intake of beans, bean products and tea; dietary score calculated based on food recall of average intake over the past year of vegetables and meat, fish and poultry.	MetS	Income, ethnicity, education, marital status, physical activity, smoking, alcohol, chronic diseases, sex, age	Logistic regression population and str
Older adults						
Georgousopoulou, 2018, Greece [54]	3,130 adults, aged 65–100 years	Sleep duration calculated from sleep and wake times on a typical day; self-report	Dietary habits; FFQ used and Mediterranean Diet score calculated	MetS and its components	Age, gender, BMI, daily walking, smoking	Linear regression each MetS component separate dependent
Georgousopoulou ^c , 2017, Greece [55]	1,369 men, aged 75±8 years and 1,380 women, aged 74±7 years	Siesta habit, considered as sleeping during the day for more than five days per week; self-report	Mean daily energy intake and mean percentage of total energy derived from dietary CHOs; from FFQ; level of adherence to the Mediterranean diet, from MedDietScore questionnaire	MetS	Age, sex, BMI, physical activity (daily walking time), smoking habits	Logistic regression

ANCOVA=Analysis of Covariance; BMI=Body Mass index; CDC=Centers for Disease Control; CHO=carbohydrate; CVD=Cardiovascular Disease; FFQ= food frequency questionnaire; HDL= high-density lipoprotein; IOM=Institute of Medicine; IOTF=International Obesity Taskforce; LDL= low-density lipoprotein; MetS=metabolic syndrome; MVPA=moderate-to-vigorous intensity physical activity; PSQI=Pittsburgh Sleep Quality Index; SES=socioeconomic status; TGL=triglycerides; TV=television; UK=United Kingdom; USA=United States of America; WC=waist circumference; WHO=World Health Organization

^aOverweight defined as BMI ≥25 and obesity defined as BMI ≥30, WC ≥40 in men, WC ≥35 in women unless otherwise specified

^bMetS defined with NCEP ATP III guidelines unless otherwise specified

^cIndicates a study where sleep was one of many risk factors (including nutrition) considered for cardiometabolic outcome

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Table 3.

Studies with diet as a mediator

Author Year	Study population	Study design	Exposure Assessment	Mediator Assessment	Outcome Assessment ^{1,2}	Other Covariates
Children and adolescents						
Rangan, 2018, Denmark [65]	368 children, aged 2–6 at baseline	1.3 year randomized controlled trial, intervening on diet, physical activity, sleep quality, and stress	Sleep duration and variability based on 6 nights; 7-day parent report; in analysis as continuous or quartiles	Total energy, macronutrients, added sugars; based on 4-day food record from Wednesday to Saturday; parent report	Change in BMI z-score by Danish reference BMI	Baseline age, baseline BMI-z score, sex, physical activity, overweight intervention, parental baseline BMI & education
Cespedes, 2016, USA (also found in effect modification) [17]	1,046 children, aged 6 months at baseline	Longitudinal study, reports by parents started when children's age 6 months and annually up to 7 years	Chronic insufficient sleep, quantified by a sleep score tallying the adequacy of parent- reported sleep duration, including naps and nighttime sleep, from infancy to mid-childhood according to National Sleep Foundation recommendations; in analysis continuous or categorical	Youth Healthy Eating Index (YHEI) score, and eating behaviors: fried foods outside the home, eating breakfast, and family dinner); parent report in mid-childhood	BMI z-score at mid-childhood according to CDC	Race/ethnicity, age, sex, maternal education and income, dietary factors at mid-childhood of an 18-item FFQ excluding YHEI factors
Asamow, 2015, USA [66]	3,342 adolescents, mean age 16 years at baseline	Nationally representative longitudinal study;	Workday bedtime; self-report	Fast food intake frequency; self-report	Change in BMI	Age, sex, race/ ethnicity, welfare status, pubertal status, wave II BMI, television viewing (mediator), exercise (mediator), workday total sleep time (mediator)
He, 2015, USA [67]	305 adolescents, mean age 16.7 years	Cross-sectional secondary analysis of a longitudinal study	Habitual sleep duration and variability; 7 nights of actigraphy and sleep diary	Daily total energy intake, total fat, protein, and CHO; Youth/Adolescent Questionnaire FFQ with 152 food items over 1 year	Abdominal obesity measures from DXA scans	Age, sex, race, BMI percentile according to CDC 2000 growth charts

Author Year	Study population	Study design	Exposure Assessment	Mediator Assessment	Outcome Assessment ^{1,2}	Other Covariates
McDonald, 2015, England and Wales [68]	1,008 children, each child from a twin pair, aged 5 years	Longitudinal twins study	Sleep duration (categories: shorter (<11), adequate (11–12), longer (>12)); parent-report	Appetite as food responsiveness (FR), measured using the 35-item Child Eating Behavior Questionnaire; parent-report	BMI, age- and sex-adjusted standard deviation scores according to UK 1990 reference data (n=494); height and weight parent-report	Age, sex, birthweight and maternal education
Adults						
Timmermans, 2017, multi-country: Belgium, France, Hungary, the Netherlands and the United Kingdom [75]	5,900 adults, mean age 52 years	Cross-sectional	Sleep duration during an average night (categories: short: < 7 h, normal: 7 < 9 h, long: 9 h); self-report; in analysis as continuous or categorical	Dietary habits: short common FFQ about frequency of intake of: fruits, vegetables, fish, sugar sweetened beverages, sweets and fast food. number of times per week eating breakfast and cooking a meal at home using bought ingredients, rather than eating ready or takeaway meals. Variables dichotomized using the median.	BMI (dichotomized according to WHO criteria into obesity and no obesity); self-reported weight and height	Covariates: age, gender, education, work type, alcohol intake, smoking, self-rated health, comorbidity, screen time, work hours; Effect modifiers: Age, gender, education and country; Other mediators: physical activity (leisure time and transport) and sedentary behaviors
Kanagasabai, 2015, USA [71]	2,079 adults, aged 20+ years	Cross-sectional study	Sleep duration per night on weekdays or workdays (categories 4, 5–6, 7–8, 9 h); self-report	Carotenoids, vitamins A, C, D, and E; laboratory measures from serum	MetS ^b ; number of MetS components, and individual MetS components	Other mediators: CRP, GGT, bilirubin, and uric acid Confounders: age, sex, ethnicity, income, education, alcohol intake, smoking history, and recreational physical activity (PA) adherence
Wirth, 2015, USA [74]	430 adults, aged 21 – 35 years	Cross-sectional analyses from an on-going longitudinal study	Nighttime sleep duration, Sleep/wake times, sleep efficiency, sleep latency, and wake after sleep onset (WASO), naps were removed; actigraphy	Dietary factors (i.e., calorie intake, percent calories from fat, and caffeine).	Body fat % measured by DXA; BMI	Total daily physical activity (also as potential mediator), smoking status, handedness, sex, age, height, and weight

Author	Year	Study population	Study design	Exposure Assessment	Mediator Assessment	Outcome Assessment ^{1,2}	Other Covariates
Chaput ^c , 2014, Canada [73]		293 adults aged 18–65 years	Longitudinal study, followed for a mean of 6.0 ± 0.9 years	Sleep duration at baseline and year 6; self-report; in analysis as continuous and categorical	Daily energy intake was assessed with a 3- day food record, including 2 week days and 1 weekend day	Visceral adipose tissue assessed using computed tomography	Age, sex, change in BMI, smoking habits, highest education level, total annual family income, and menopausal status, MVPA
Mesas, 2014, Spain [72]		10,342 adults, aged 18+ years	Cross-sectional study	Poor sleep quality, difficulty falling asleep, difficulty maintaining sleep and sleeping pill ingestion; self- report	Energy intake and adherence to a Mediterranean dietary pattern (Mediterranean Diet Adherence Screener); from FFQ based on previous year	MetS	Age, sex, education and occupation-based social class, tobacco, alcohol and coffee intake, diagnosed morbidity, sleep duration, energy spent in physical activity and time watching TV, drug treatments
Yeh, 2014, Australia [70]		330 adults, mean age 27 years	Community-based and snowball recruitment for online survey	Sleep duration, poor sleep quality (defined as >5 score on PSQI); self-report	Binge-eating (>26 score on Binge Eating Scale), night eating (>24 score on Night- Eating Questionnaire); self-report	BMI (>25); self-report	Depression, age, sex, education, relationship status, employment status

ANCOVA=Analysis of Covariance; BMI=Body Mass index; CDC=Centers for Disease Control; CHO=carbohydrate; CVD=Cardiovascular Disease; FFQ= food frequency questionnaire; HDL= high-density lipoprotein; IOM=Institute of Medicine; IOTF=International Obesity Taskforce; LDL= low-density lipoprotein; MetS=metabolic syndrome; MVPA=moderate-to-vigorous intensity physical activity; PSQI=Pittsburgh Sleep Quality Index; SES=socioeconomic status; TGL=triglycerides; TV=television; UK=United Kingdom; USA=United States of America; WC=waist circumference; WHO=World Health Organization

^aOverweight defined as BMI 25 and obesity defined as BMI 30, WC 40 in men, WC 35 in women unless otherwise specified

^bMetS defined with NCEP ATP III guidelines unless otherwise specified [83]

^cIndicates a study where sleep was one of many risk factors (including nutrition) considered for cardiometabolic outcome

Table 4.

Studies with diet as an effect modifier

Author Year	Study population	Study design	Exposure Assessment	Effect Modifier Assessment	Outcome Assessment	Other Covariates	Statistical Analysis
Children or Adolescents							
Cespedes, 2016, USA (also found in mediation) [17]	1,046 children, aged 6 months at baseline	Longitudinal study, reports by parents started when children aged 6-months and annually up to 7-years	Chronic insufficient sleep, from infancy to mid-childhood according to National Sleep Foundation recommendations; parent-report; in analysis dichotomous (≥ 11 h vs. <11 h, the median score)	Youth Healthy Eating Index (YHEI) and eating behaviors: fried foods outside the home, eating breakfast, and family dinner; parent report in mid-childhood; in analysis dichotomous (YHEI: ≥ 60 vs. <60 , the median score)	BMI z-score at mid-childhood according to CDC reference	Race/ethnicity, age, sex, maternal education and income	Multiple regression
Hjorth, 2015, Denmark [76]	834 children, 3 rd –4 th graders	Crossover trial, cluster-randomized, controlled,	Sleep duration in 7 consecutive days and 8 nights; accelerometer worn 7 consecutive days and 8 nights and sleep logs; sleep duration in tertiles	For 1 month children received school lunches based on Healthy New Nordic Diet (NND), for 1 month usual packed lunch from home	BMI z-score by WHO reference, total fat mass, abdominal fat mass, fat free mass, ratio of android from total fat and fat free mass, fat mass index	Age, sex, visit, order of dietary period (NND vs. packed lunch), height	Linear regression, accounting for year grade and sibling
Hunsberger, 2015, 12 countries (also found in confounder for cross-sectional analysis) [62]	5,944 children at baseline 4,301 at followup, aged 2–9 years at baseline	Longitudinal study	Sleep duration hours (categories: short sleep <10 h vs. reference ≥ 10 h);parent-report	Breakfast, CHO from sugar and starch in morning, midday or evening, total energy intake; 24-hour diet recall by parent and school staff Monday through Thursday	BMI, BMI z-score, according to IOTF criteria	Age, sex, highest parental education, country	Multiple regression, linear
Adults							
Doo, 2017, South Korea [78]	3,941 men, aged 40–69 years	Cross-sectional study	Sleep duration (categories: short sleep duration (≤ 6 h a day) and proper sleep duration (> 7 h a day)); self-report	Antioxidant Vitamins- vitamins A, C, E, retinol, carotene; FFQ	Obesity	Age, education, income, marital status, insomnia, smoking, drinking	Multiple regression

Author Year	Study population	Study design	Exposure Assessment	Effect Modifier Assessment	Outcome Assessment	Other Covariates	Statistical Analysis
Doo, 2016, South Korea [77]	14,680 adults, aged 19+ years	Cross sectional survey	Sleep duration per day (categories: <6h, 6–7h, 7–8h, 8+h), self-report	Total energy intake and the percentage of energy they obtained from protein, fat, and CHO; Dietary intake by a food frequency questionnaire with 63 food items	Body weight, height, WC, BMI, Systolic BPs, diastolic BPs, Venous blood samples collected after overnight fast. Fasting glucose (FG), total cholesterol, TGL, and HDL	Age, physical activity, current smoking, and alcohol drinking status	Multiple regression
Kim, 2015, South Korea [79]	12,999 adults, aged 20+ years	Cross-sectional study	Sleep duration per day (categories: <6h, 6–7h, 7–8h, 8+h), self-report	Eating every meal for the last 2 days (categories: (not skipping, skipping a meal in 1 day, skipping a meal both days); self-report	MetS	Age, sex, household income, education level, smoking status, alcohol sleep drinking, duration and physical eating activity, and total daily energy intake	Multiple regression

BMI=Body Mass index; CDC=Centers for Disease Control; CHO=carbohydrate; CVD=Cardiovascular Disease; DXA=dual-energy x-ray absorptiometry; FFQ= food frequency questionnaire; HDL= high-density lipoprotein; IOTF=International Obesity Taskforce; LDL= low-density lipoprotein; MetS=metabolic syndrome; TGL=triglycerides; TV=television; UK=United Kingdom; USA=United States of America; WC=waist circumference; WHO=World Health Organization

^a Overweight defined as BMI ≥ 25 and obesity defined as BMI ≥ 30, WC ≥ 40 in men, WC ≥ 35 in women unless otherwise specified

^b MetS defined with NCEP ATP III guidelines unless otherwise specified [83]

^c Indicates a study where sleep was one of many risk factors (including nutrition) considered for cardiometabolic outcome