A systematic review of the bidirectional association between consumption of ultra-processed food and sleep parameters among adults

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Statements and Declarations

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Abbreviations

BMI: Body mass index

CI: Confidence interval

CVD: Cardiovascular diseases

FFQ: Food Frequency Questionnaire

NIH: National Institutes of Health

OR: Odds ratio

PR: Prevalence ratio

PSQI: Pittsburgh Sleep Quality Index

T2D: Type 2 diabetes

UPF: Ultra-processed food (and beverages)

Abstract

Objectives: Sleep contributes to cardiometabolic health; sleep restriction leads to increased intakes of high-carbohydrate/high-fat foods, a profile representative of ultra-processed food (UPF). We summarized research on the bidirectional association between UPF and sleep.

Methods: This systematic review covers the association of UPF intake, as an exposure or an outcome, and sleep. UPF was defined as NOVA Group 4. MEDLINE and EMBASE were searched through February 2023 for epidemiological studies with general-population adult samples.

Results: Fourteen studies met the inclusion criteria; all were cross-sectional, published between 2016 and 2023, with samples from Brazil (n=8), Spain (n=2), Italy (n=1), Paraguay (n=1), Iran (n=1) and China (n=1). Twelve studies examined UPF intake as the exposure whereas two tested UPF intake as the outcome. UPF intakes were determined using food frequency questionnaires (78%) or 24-h recalls (22%). Two studies assessed sleep via accelerometry; the remaining studies relied on self-reports of sleep quality, duration, anxiety-induced insomnia, and napping, with >50% using a single question. Six of the 12 studies that examined UPF consumption as the exposure revealed inverse associations with sleep outcomes in adjusted (n=5) or bivariate (n=1) analyses. Both studies addressing UPF consumption as the outcome and sleep as the exposure also showed significant inverse associations. The average methodological quality across the studies was deemed “fair”.

Conclusion: There is accumulating evidence for a UPF - sleep association, although sleep assessment limitations are apparent. This review can provide impetus for research using comprehensive and validated sleep measures and nudge policymakers towards refining dietary guidelines worldwide.

Keywords: general population; NOVA classification; observational studies; review; sleep quality; ultra-processed food

Introduction

Diet quality is a known contributor to chronic health and disease [1, 2]. All major health organizations recommend higher intakes of fruits and vegetables, whole grains and legumes, and lower intakes of animal protein and fat to reduce the risk of cardiovascular diseases (CVD), type 2 diabetes (T2D), obesity, and cancer [1, 3, 4]. A dietary profile comprised of more complex carbohydrates and unsaturated fats and less refined carbohydrates and saturated fats has been associated with reduced incidence of CVD, T2D, and mortality [5-7]. Beyond the nutritive components of diet, more recently, the degree of food processing has come under scrutiny as a potential contributor to cardiometabolic risk associated with a Western diet [8].

Globalization of the food systems and technological progress have led to a high prevalence of consumption of industrially manufactured products [9], referred to as ultra-processed foods and beverages (UPF), across age, sex, ethnicity, and socioeconomic strata [10]. A product is regarded as UPF if it has been produced by means of extensive physical and chemical modifications of its basic ingredients, includes substantial amounts of sugar, fat, or salt, and contains colorants, flavorings, or other additives [11]. Such products are ready-to-eat, palatable, attractively packaged, easy to locate on supermarket shelves, well marketed, affordable for consumers and profitable for manufacturers [12]. Although the potential health risks associated with UPF intake were first evoked in 2009 [8], a review of representative studies published since 2016 revealed that UPF consumption contributes up to 25.4% of daily caloric intake in Brazil, 31.1% in France, 56.8% in the UK, and 57.9% in the US [13]. Cross-sectional and prospective studies almost consistently link UPF consumption with an increased risk of T2D, metabolic syndrome, overweight, obesity, dyslipidemia, eating disorders, irritable bowel syndrome, Crohn's disease/ulcerative colitis, non-alcoholic fatty liver disease, depressive symptoms, CVD, hypertension, asthma/wheezing, frailty, cancer, and mortality [10, 13-18].

Sleep has recently been noted as contributing to cardiometabolic health [19] and studies show that sleep restriction leads to increased energy intakes, particularly from snacks, high-carbohydrate, and high-fat foods [20], a profile representative of UPF. Interestingly, diet quality has also emerged as a potential

contributor to sleep quality [21]. Despite these associations, none of the existing literature reviews focused on multiple chronic outcomes has examined the associations of UPF consumption with sleep. To our knowledge, only one meta-analysis of cross-sectional studies carried out among children, adolescents and adults has synthesized the evidence for the association between consumption of any type of processed food (e.g., fast food, processed meat, instant noodles, salty snacks, confectionary, soft drinks, energy drinks, etc.) and sleep quality/duration, reporting significant results across age [22].

Therefore, the objective of the present systematic review was to synthesize and evaluate the available epidemiological evidence regarding the bidirectional association between UPF intake, using a uniform measure, and sleep parameters among adults.

Methods

This review covers observational epidemiological studies assessing the association of UPF intake, as an exposure or as an outcome, and sleep. UPF intake was defined using the 4-level NOVA classification [12]. Accounting for the extent and purpose of processing, NOVA assigns unprocessed and minimally processed food that does not contain added substances to Group 1 (e.g., fruit, eggs, plain yogurt); processed culinary ingredients to Group 2 (e.g., butter, honey, vinegar); processed food containing few ingredients to Group 3 (e.g., cheese, fresh bread, canned fish); and UPF containing multiple ingredients including substances not commonly used in culinary preparations to Group 4 (e.g., ice-cream, hot dogs, instant soups, carbonated drinks, energy bars) [12].

We searched MEDLINE/PubMed and EMBASE using the following selection criteria: publication in any language through February 2023; cross-sectional or prospective design; general population or non-clinical sample of adults aged ≥18 y. Studies based on mixed adolescent-adult samples were retained if participants aged ≥18 y constituted ≥10% of the sample. The diet-related terms "processed food", "NOVA", and "ultra-processed food" were crossed with each of the following sleep-related keywords: sleep, insomnia, sleep apnea, sleep disorders, sleep quality, sleep duration, napping, sleep variability, circadian rhythm, daytime sleepiness, social jetlag, hypersomnolence, sleep-related breathing disorders, sleep-wake disorders, sleep disturbances, and parasomnia. The following MeSH

terms were also applied: sleep; sleep deprivation; sleep initiation and maintenance disorders; sleep apnea syndromes; sleep apnea, obstructive; sleep wake disorders; sleep disorders, circadian rhythm; sleep quality; dyssomnias. The reference lists of pertinent articles were manually searched. From a total of 158 hits, we excluded duplicates, conference proceedings, studies that fell outside the scope of the review, those conducted in children or in clinical samples, review/position papers, and clinical trials, thus retaining 14 studies for this review (**Figure 1**). Using a standardized extraction form, we obtained the following information from each of the studies: reference (author, year); study population (N, mean age, age range; country); dietary data collection tool; sleep assessment method and sleep variable studied; statistical analysis method and adjustment for covariates; main results.

The methodological quality of each of the 14 studies was evaluated by two independent reviewers (VAA and JPJ) using the National Institutes of Health (NIH) Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies, which resulted in a 3-level quality score ("good"=3.0, "fair"=2.0, or "poor"=1.0) [23]. The quality score is computed on the basis of 14 items that take into consideration the following aspects of the work: research question, study population, eligibility criteria, sample size justification, exposure assessed prior to outcome measurement, sufficient timeframe, different levels of exposure of interest, exposure measures, repeated exposure assessment, outcome measures, blinding of outcome assessors, follow-up rate, and statistical analyses [23].

The present research was based on previously published and publicly available data; as such it was exempt from an ethics committee review.

Results

Characteristics of the selected studies

All 14 studies included in this systematic review were cross-sectional and published in English between 2016 and 2023 (**Table 1**). Most of the research was from Brazil (8 studies), with other studies conducted in Spain (2 studies), Italy (1 study), Paraguay (n=1), Iran (n=1), and China (1 study). Twelve of the studies (86%) examined UPF consumption as the exposure, while 2 (14%) investigated UPF consumption as the outcome. Three of the 14 studies used mixed adolescent-adult samples: de Oliveira *et*

al. reported that participants aged 17-19 y constituted 40.7% of the sample [24]; Werneck *et al*. reported that 30.4% of the participants were older than 14 y [25]; Ruggiero *et al*. presented findings from separate analyses in children/adolescents (ages 5-19 y) and adults (ages 20-97 y) [26]. Three studies reported baseline UPF-sleep association in the context of longitudinal analyses of unrelated outcomes; 2 studies were conducted during the COVID-19 pandemic.

Next, substantial heterogeneity was noted among the subjective sleep indices used (i.e., sleep quality, average sleep duration, anxiety-induced insomnia, daytime napping, excessive daytime sleepiness), with more than half of the studies (57%) relying on a single question to evaluate sleep. In turn, two studies relied on accelerometry to assess sleep duration [27] and multidimensional sleep parameters including sleep onset and offset, total sleep time and variability, and sleep efficiency [28]. Four studies assessed sleep quality using the Pittsburgh Sleep Quality Index (PSQI), however, the definition of poor sleep quality differed: a PSQI score >4 [29], a PSQI score >5 [30], a continuous variable without a cutoff [31], or a dichotomous variables for which the cutoff was not indicated [32]. In turn, diet was examined using food frequency questionnaires (FFQ) (9 studies), a NOVA-specific questionnaire (2 studies) and 24-h recalls (3 studies).

Given the substantial methodological heterogeneity, a meta-analysis was deemed unfeasible.

Summary of the association between UPF consumption (exposure) and sleep indices (outcomes)

Among the 12 studies that investigated UPF as the exposure and sleep as an outcome, 6 studies reported significant associations [25, 28-30, 32, 33] while the rest reported non-significant associations [24, 27, 34-37]. There was marked heterogeneity in the statistical analyses used. Of the 6 studies reporting statistically significant findings, 5 employed multivariable analyses with notable variability in the covariates included in the models. The research by Menezes-Junior *et al*. [30] observed that during the COVID-19 pandemic, the highest frequency of UPF consumption and the lowest frequency of fresh or minimally processed food consumption were associated with increased risk of poor sleep quality (PSQI >5) in logistic regression models adjusted for age, sex, marital status, income, and anxiety symptoms (OR=2.44; 95% CI: 1.32-4.50). That study used probability sampling in two Brazilian cities, including

1,762 adults aged ≥18 y [30]. Similarly, using a sample of 2,499 Brazilian young adults aged 18-19 y, Sousa *et al*. [29] observed that the highest quartile of UPF consumption was associated with increased risk of poor sleep quality (PSQI >4). The authors used Poisson regression models adjusted for age, socio-economic class, education, screen time, and marital status of the parents (PR=1.14; 95% CI: 1.03-1.27) [29]. Interestingly, a subsample of participants from the same cohort were also studied by da Silva *et al*. [27] who reported non-significant findings regarding the link between UPF intake and accelerometry-assessed sleep duration. Next, in a mixed adolescent-adult sample of 99,791 participants from the nationally representative Adolescent School-Based Health Survey in Brazil, Werneck *et al*. [25] observed that daily UPF consumption was associated with higher odds of anxiety-induced sleep disturbances (males: OR=1.48, 95% CI 1.30-1.70; females: OR 1.46, 95% CI 1.34-1.60) in logistic regression models adjusted for age, ethnicity, physical activity, food insecurity, type of city, and region of residence. In that study, the outcome was a self-report of "insomnia due to worries or concerns" [25].

The study by Kramer Fiala Machado *et al*. [28] relied on both objective and subjective sleep measures and reported sex-specific associations according to sleep clusters from analyses adjusted for wealth index, skin color, education, current occupation, shift work, and having children < 2 y of age. Specifically, the highest percentage of individuals in the highest tertile of UPF intake was found among men who were shorter and poorer sleepers (adjusted prevalence =35.9%; 95% CI: 31.3-40.5); among women, late and poor-quality sleepers presented a higher percentage of individuals in the highest tertile of UPF intake (adjusted prevalence =43.0%; 95% CI: 37.7-48.2) compared to healthy sleepers [28]. In turn, the study by Hajmir *et al*. [32] reported that overweight and obese women with "higher NOVA classification system" had poorer sleep quality in models adjusted for age, BMI, occupation, economic status, education, marital status, energy intake, and physical activity (OR=2.51; 95% CI: 1.23-5.14). However, these authors modelled the entire 4-level NOVA system on a continuous scale without distinguishing UPF [32]. Finally, Rodriguez *et al*. [33], who conducted their research during the COVID-19 pandemic, performed chi-squared tests and reported that among participants with insufficient sleep

(defined as <8 h), 46.5% and 30.5% had moderate and excessive intake of processed food and UPF, respectively. In that study, NOVA Groups 3 and 4 were analyzed together [33].

Among the 6 studies reporting null associations between UPF consumption and sleep, 3 used bivariate analyses (Mann-Whitney test, Chi-squared tests, simple linear regression) [24, 34, 36], 1 study used ANOVA adjusted for sex and age [35], 1 study used multivariable linear regression models adjusted for gender, age, skin color, education, economic class, occupation, alcohol use, smoking, screen time, physical activity, illicit drug use, anxiety, depressive symptoms, lean and fat mass [27], and 1 study used Poisson regression adjusted for age, marital status, income, and timing of menopause [37]. The null bivariate and age- and sex-adjusted associations came from baseline descriptive analyses of the China Nutrition and Health Survey [34] and the Spanish SUN cohort [35, 36] where the sleep variable was a self-report of taking a nap (h/d). These studies pertained to longitudinal investigations of incident events and sleep was not a primary outcome. Likewise, non-significant results with UPF were observed by de Oliveira *et al*. studying 432 adolescents and young adults from one Brazilian city, using bivariate models (a significant association emerged between low intake of unprocessed/minimally processed food (NOVA Group 1) and inadequate sleep duration) [24] and by Noll *et al*. in a convenience outpatient sample of 225 women aged ≥40 y, using adjusted Poisson regression and various menopausal symptoms, including sleep problems, as outcomes (PR=0.92; 95% CI 0.75-1.13) [37].

Summary of the association between sleep (exposure) and UPF consumption (outcome)

Both studies investigating sleep as an exposure and UPF as an outcome reported significant associations. In a sample of 2,826 adults aged 20-59 y participating in the Brazilian Cohort of Universities of Minas Gerais, Mattar *et al*. [38] observed that the average sleep duration over the past 12 mo was inversely and directly associated with UPF consumption (standardized coefficient= -0.05; $p<$ 0.01). Their findings were based on a path analysis including sex, age, income, employment, time spent on a computer, number of meals/d, and fried food intake [38]. In turn, Ruggiero *et al*. [26] reported that lower sleep quality defined as self-reported restless sleep, was associated with increased UPF intake (beta=2.34; 95% CI: 1.45-3.23) in a sample of 8,569 adults aged 20–97 y participating in the Italian

Nutrition and Health Survey. Their linear regression model was adjusted for age, sex, BMI, education, geographical area, place of residence, sports activity, occupation, marital status, energy intake, smoking, prevalent CVD, hypertension, T2D, hyperlipidemia, and cancer [26].

Study quality evaluation

Using the NIH Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies [23,] the methodological quality of each of the 14 studies was evaluated by two independent reviewers and the consensual quality ratings are presented in **Table 1**. The rating took into consideration only the UPF and sleep aspects of each study, regardless of any other primary or secondary exposures or outcomes investigated. Thus, the quality evaluation performed as part of this systematic review does not fully reflect the overall methodological quality of each study. The average rating across the 14 studies was 2.14 points ("fair"), with the rating ranging between "poor"=1.0 point and "good"=3.0 points. The ratings did not vary by the presence or absence of statistically significant findings. All studies had clearly specified study samples and all but one study had a clearly stated research question. In turn, only three studies provided a sample size justification or a statistical power description. Given the cross-sectional design of all studies included in the review, several methodological aspects, such as assessment of the exposure preceding the outcome, availability of repeated measures, and loss to follow-up were not applicable. Finally, none of the studies reported whether the outcome assessors were blinded to the exposure status of the participants.

Discussion

This systematic review of observational research in adults revealed that the association between UPF consumption and sleep has been the subject of several cross-sectional studies but has not been investigated prospectively. More than half of the reviewed studies (57%) were carried out in Brazil where the NOVA classification originated and where it has been the subject of a substantial body of research. In fact, Brazil is among more than a dozen countries that have addressed food processing in their national dietary guidelines [39].

Among the 12 studies that examined UPF consumption as the exposure and sleep as an outcome, half reported null findings and half observed significant associations. The latter reported that increased UPF consumption among adults was inversely associated with sleep problems, with the risk estimates ranging from 1.14 to 2.51 [25, 29, 30, 32]. The associations were consistent across sex [25, 28] and are congruent with findings among adolescents [40]. Of note, significant inverse associations were reported by the two studies conducted during the COVID-19 pandemic [30, 33] which has been independently associated with reduced sleep quality [41] and increased UPF consumption, especially during the lockdown periods [42].

Mechanistically, the impact of diet on sleep has been attributed to neuroendocrine regulation (e.g., serotonin, orexin, noradrenaline, histamine) and neuro-inflammatory processes that alter brain functionality via the gut-brain axis [43]. Indeed, the correct functioning of the sleep-wake cycle is promoted by melatonin, which is exclusively synthesized from dietary tryptophan, via serotonin [21]. Various dietary sources of tryptophan, serotonin, and melatonin, such as dairy, fish, fruit, and vegetables have been shown to have sleep-promoting effects [21, 44]. These foods are generally categorized as Groups 1 or 3 in the NOVA classification system, falling outside of the UPF category, Group 4. Moreover, reviews of the epidemiological and mechanistic evidence have highlighted the central role of the intestinal microbiota in connecting UPF and health status via alterations in the composition and function of the microbiota which are involved in food digestion, metabolism, and maturation of host immunity [10, 13].

The significant association of UPF consumption with risk of sleep problems is consistent with the large body of scientific evidence regarding the deleterious impact of UPF on a wide range of physical and mental health outcomes [10, 13-18]. To our knowledge, only one literature review with a meta-analysis has addressed the link between UPF and sleep [22]. These authors reviewed 15 cross-sectional studies carried out among children/adolescents (n=8) and adults (n=7), and modeling intake of any type of processed food as the exposure. Only two of the studies included in that review relied on NOVA for the assessment of UPF, with the other 13 studies using a variety of food groups (e.g., fast food, junk food,

salty snacks, confectionary, soft drinks, etc.). The authors reported stronger effect sizes among the studies that used NOVA compared to those that used other processed food classifications. In addition, among adults, there were null findings for short sleep duration and statistically significant results for poor sleep quality [22].

Among the 6 studies that reported null findings in the present review, 1 was focused on menopausal symptoms, including sleep problems among 225 women aged ≥40 y [37]. A recent literature review evoked specific etiologic aspects of postmenopausal sleep difficulties, which might result from decreased estrogen and melatonin levels, vasomotor and psychological disturbances, and weight gain [45]. The postmenopausal period may thus underscore a physiological context where adherence to dietary patterns ensuring sufficient melatonin synthesis might be especially relevant. Next, 3 studies with non-significant findings pertained to baseline descriptions of cohorts used for the prospective investigation of chronic diseases [34-36]. For example, two of the studies, one regarding the incidence of obesity (N= 8,451) and the other regarding the incidence of hypertension (N= 14,790), were conducted within the Spanish SUN cohort by the same research team. In both studies, the sleep variable was a self-report of taking a nap (h/d), which did not vary significantly by the level of UPF consumption. It is possible that UPF intake differentially impacts daytime versus nighttime sleep parameters. Moreover, studies of napping included a single question related to this behavior and did not capture the intentionality of the nap. Future research ought to assess total sleep duration more thoroughly, including daytime and nighttime sleep, before conclusions could be drawn.

While De Oliveira *et al*. [24] did not find a significant association between UPF intake and sleep duration, assessed with a single question, they reported a significant correlation between low consumption of unprocessed or minimally processed food and inadequate sleep duration using a mixed adolescent-adult sample of 432 participants. Specifically, the median intake of such food among participants with adequate (defined as 8-10 h sleep/d) and inadequate sleep duration was 996.2 and 729.9 kcal/d, respectively. As noted above, a certain quantity of sleep-promoting compounds, such as tryptophan,

serotonin, and melatonin, can be obtained by a diet containing substantial amount of unprocessed plant-based food [21, 44].

It is interesting to note that 5 of the 6 studies showing significant associations between UPF consumption and sleep assessed sleep quality whereas 5 of the 6 studies that reported null findings examined sleep duration (with 2 studies measuring solely napping duration from a single question). Thus, it is possible that diet quality is a more important modulator of sleep quality rather than sleep quantity. Future studies should extend beyond single questions of sleep duration and quality to truly capture overall sleep health, which includes concepts related to regularity, satisfaction, alertness, timing, efficiency, and duration [46]. In the present review, only one study [28] employed a comprehensive assessment of sleep with objective and subjective measures such as accelerometry-assessed sleep onset and offset, total sleep time and variability, sleep efficiency, along with PSQI and Epworth's excessive daytime sleepiness [47]. In turn, Noll *et al*. [37] employed a composite sleep index based on both the Women's Health Questionnaire, where 2 of the 37 items pertain to sleep (insomnia underscored by difficulty falling asleep, early waking and restlessness) [48], and the Kupperman-Blatt Menopausal Index where insomnia is one of 11 types of menopausal symptoms that are all grouped together [49].

Two of the 14 studies included in this review investigated sleep as the exposure and UPF consumption as the outcome of interest. Both studies reported significant inverse associations between sleep duration [38] or quality [26] and UPF consumption in adjusted analyses. This is in line with the large body of observational and experimental evidence regarding the impact of sleep on dietary choices and diet quality and quantity [21]. For example, poor sleep quality has been associated with higher intakes of energy, sugar and fat, and lower intakes of fruit, vegetables, and whole grains [50-52]. Such dietary behaviors have been explained by a combination of factors, including an increased opportunity to eat due to added wake time, altered time of intake (i.e., late evening), changes in hormonal regulation, in reward valuation, and in taste sensitivity, a potential homeostatic compensation effect for nocturnal energy deficit, and increased susceptibility to food stimuli [21, 43, 53]. The current review adds to the available knowledge by expanding the range of dietary outcomes influenced by sleep disturbances.

Mechanistically, an increased hedonic drive for foods might explain shifts toward poor diet quality following periods of inadequate sleep [21]. Indeed, UPF exposure has been positively associated with appetitive drive and hedonic valence [54].

This review revealed substantial heterogeneity in the reporting of UPF intake, which included number of servings per day or per week, grams per day, kcal per day, and percentage contribution of UPF to mean daily energy intake. Thus, differences among the reviewed studies might be partly due to different UPF amounts consumed within each NOVA category. This methodological heterogeneity might also help explain the differences between the studies showing significant associations and those reporting null findings. Dietary data for the studies came from various sources, including standard or semi-quantitative FFQ (9 studies), a NOVA-specific questionnaire (2 studies), and 24-h recalls (3 studies). It has been suggested that the use of multiple 24-h dietary records is preferrable over FFQ for UPF estimation [13]. In the present review, however, only two studies relied on more than one 24-h recall [34, 37], finding no association between UPF consumption and menopause-related insomnia symptoms and sleep duration. Methodological heterogeneity was also observed in the self-reported sleep measures, which included average sleep duration, sleep quality, afternoon napping, and anxiety-induced insomnia/sleep disturbance, with more than half of these studies relying on a single question for the assessment of sleep. Finally, in the case of anxiety-induced sleep problems, the measure pertained to "insomnia due to worries or concerns" rather than an actual anxiety assessment or diagnosis [25].

Findings regarding the bidirectional association between diet and sleep have been evaluated and summarized in several systematic reviews. For example, Sutanto *et al*. [55] reviewed observational and intervention studies regarding the role of the dietary macronutrient composition in sleep duration and reported inconclusive findings without a dose-dependent association. These authors concluded that the macronutrient profile alone may not play a strong role in sleep [55]. Next, evidence for the role of specific food groups, micro- and macro-nutrients, and dietary patterns in sleep quality among children, adolescents, and adults was recently reviewed by Godos *et al*. [43]. Whereas the methodological quality of the included studies was not high according to the NIH quality assessment measure, the authors were

able to conclude that for some aspects of the diet (e.g., protein, carbohydrate content), the type and quality might be more important than the quantity of intake [43].

An increased dietary share of UPF has been associated in a direct, dose-response manner with the dietary content of free/added sugars, saturated fat, trans fat, sodium, and energy density, whereas an inverse dose-response association has been found with protein, fiber, potassium, vitamins A, C, D, and E, calcium, zinc, magnesium, phosphorus [56] and water intake [57]. Higher UPF intakes have been inversely associated with intake of fruit, vegetables, legumes, and seafood [58] which are all sources of sleep-promoting compounds. Indeed, prospective research has shown that individuals adhering to nutrient-dense and fiber-rich diets, such as the Mediterranean diet, have better sleep health [59] and lower risk of insomnia [60]. In contrast, higher dietary glycemic index and glycemic load, underscored by an increased intake of added sugars, starch, and refined grains, have been suggested as independent risk factors for insomnia incidence [61]. Likewise, pooled fully adjusted analyses of three large US cohorts demonstrated that a higher dietary inflammatory potential was associated with a significantly greater risk of obstructive sleep apnea [62].

The present systematic review is subject to some limitations. It cannot provide any evidence of causal effects as it included only cross-sectional research. It was based on published observational studies, none of which employed non-linear modelling. Another important limitation pertains to the inconsistent adjustment for potential confounders of the UPF-sleep association. The review identified notable methodological weaknesses related to the assessment of diet and sleep. It is recommended that future research in this domain employ validated tools and established criteria for the assessment of sleep, such as the DSM-5 criteria for chronic insomnia [63], the Berlin questionnaire for obstructive sleep apnea [64], and Epworth Sleepiness Scale [47] (used in only one of the reviewed studies). Objective measures of sleep (also used in only one of the reviewed studies) including duration, wake after sleep onset, and sleep efficiency are likewise needed. In addition, future epidemiological research conducted outside of Brazil could augment the generalizability of the overall evidence.

A strength of the review was the use of a single definition of UPF which can facilitate the comparison of findings across studies and across countries. The NOVA classification system has been recognized by the Food and Agriculture Organization of the United Nations and by the Pan American Health Organization as a valid tool for nutrition and public health research and policy development [12, 56]. The findings from this review are well positioned to inform sleep-focused primary and secondary prevention programs and serve as impetus for future epidemiological and experimental research evaluating whether improvements in sleep could have a favorable effect on diet and vice versa.

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Table 1. Cross-sectional evidence of the bidirectional association between consumption of ultra-processed food (UPF, as defined by NOVA) and sleep parameters among adults

Reference	Study sample	Dietary data & UPF quantity	Sleep data & sleep parameter	Statistical model	Main results	Comment	Quality rating [23]
UPF intake as exposure							
Da Silva et al. [27]	N=964; 18-19 y; Brazil	FFQ; Brazilian Food Composition Table; Nutritional Composition Table of Foods Consumed in Brazil; average daily % calories from UPF= 57.6% (±13.3); 38.6% of sample consumed UPF	Accelerometry-assessed average sleep duration over 4-7 nights	Linear regression adjusted for age, gender, skin color, education, economic class, work, alcohol use, smoking, screen time, physical activity, illicit drug use, anxiety, depressive symptoms, lean and fat mass	NS association between UPF intake and sleep duration (β= 0.00003; 95% CI: −0.004, 0.005; p=0.99)	Multiple sampling strategies (subsample of [29])	QR=2.5
De Oliveira et al., 2022 [24]	N=432; 14-19 y; Brazil	FFQ; median UPF intake: 726.8 and 582.9 Kcal/d in those with adequate and inadequate sleep, respectively	1 question about average sleep duration; adequate if 8-10 h sleep/d	Mann-Whitney test	NS association between UPF intake and sleep duration; low un-processed or minimally processed food intake associated with inadequate sleep duration (p<0.05)	Randomly selection of adolescent residents of one city	QR=1.5
Hajmir et al., 2022 [32]	N=278 overweight/obese women;	FFQ; median UPF intake: 415.60	PSQI: no cutoff cited for good/poor sleep quality	ANCOVA, logistic regression adjusted for age,	Women with "higher NOVA classification	Multistage random sampling of health center	QR=2.0

	18-56 y (mean age= 36.5 y); Iran			BMI, education, occupation, economic and marital status, energy intake, physical activity	system" had poorer sleep quality in fully adjusted analysis (OR=2.51; 95% CI 1.23, 5.14; p=0.012)	outpatients; unclear if UPF measured in g/d or Kcal/d; UPF does not refers only to Group 4 NOVA	
Kramer Fiala Machado et al., 2023 [28]	N=2,738; 22 y; Brazil	FFQ; UPF (as daily % of energy contribution) consumed by 31.0% of men and 35.5% of women	Accelerometry-assessed sleep onset & offset, total sleep time & variability, sleep efficiency over 3-7 nights; PSQI – continuous scale; Epworth's excessive daytime sleepiness– continuous scale	Poisson regression adjusted for wealth index, skin color, years of schooling, current occupation, shift work, having children < 2 y	Among men, shorter & poorer sleepers had highest % of individuals in highest tertile of UPF intake (35.9%; 95% CI: 31.3, 40.5); among women, late & poor-quality sleepers presented higher % of individuals in highest tertile of UPF intake (43.0%; 95% CI: 37.7, 48.2)	Recruitment from 1993 Pelotas Birth Cohort; multi-dimensional sleep clusters	QR=3.0
Li et al., 2021 [34]	N=12,451; >20 y; China	3 consecutive 24-h dietary recalls; mean UPF intake 41.5 g/d; in short sleepers (<6 h/d): 7.8% and 8.6% had no UPF intake and UPF intake ≥50 g/d, respectively	1 question about sleep duration recorded as <6, 6-9 and >9 h/d	Chi-squared tests	NS association between UPF intake and sleep duration (*p*=0.81)	Baseline component of longitudinal analyses of obesity; China Nutrition and Health Survey	QR=1.5

Mendonça et al. 2016 [35]	N=8,451; mean age= 37.6±11.0 y; Spain	Semi-quantitative FFQ; mean UPF intake in servings/d ranged from 1.5 (Q_1) to 6.1 (Q_4)	1 question about 'siesta sleep' (h/d)	ANOVA adjusted for sex and age	NS association between UPF intake and taking a nap (p=0.12)	Baseline component of longitudinal analysis of obesity; SUN cohort	QR=2.5
Mendonça et al. 2017 [36]	N=14,790; mean age= 36.3 y; Spain	Semi-quantitative FFQ; mean UPF intake in servings/d ranged from 2.1 (T_1) to 5.0 (T_3)	1 question about 'siesta sleep' (h/d)	Simple linear regression	NS association between UPF intake and taking a nap (p=0.05)	Baseline component of longitudinal analysis of hyper-tension; SUN cohort	QR=2.5
Menezes-Júnior et al., 2022 [30]	N=1,762; ≥18 y; Brazil	FFQ; UPF quantity not reported	PSQI: good sleep quality score ≤5; poor sleep quality score >5	Logistic regression adjusted for age, sex, marital status, income, anxiety symptoms	Highest frequency of UPF intake & lowest frequency of fresh or minimally processed foods intake associated with increased risk of poor sleep quality (OR=2.44; 95% CI: 1.32-4.50)	COVID-19 context; probability sampling in 2 cities	QR=3.0
Noll et al. 2022 [37]	N=225; post-menopausal women ≥40 y; Brazil	3 non-consecutive 24-h dietary recalls; mean UPF intake: 459.5 & 524.2 Kcal/d in those with better & worse quality of life (including sleep), respectively	Women's Health Questionnaire (2 items about sleep); insomnia from Kupperman-Blatt Menopausal Index	Poisson regression adjusted for age, marital status, income, early/late menopause	NS association between UPF intake & sleep disorders (PR=0.92; 95% CI 0.75-1.13)	Non-probability convenience outpatient sample; sleep problems assessed as 1 component of menopausal symptoms	QR=3.0
Rodriguez et al., 2022 [33]	N=273; 18-60 y (mean age 36.5±13.2); Paraguay	NOVA-based FFQ; among participants with insufficient sleep,	1 question about hours of sleep (≥9 h optimal; <8 h insufficient)	Chi-squared tests	Statistically significant association between moderate	COVID-19 context; non-probability sample;	QR=1.0

		46.5% & 30.5% had moderate & excessive processed & UPF intake, respectively			& excessive processed & UPF intake & sleep duration (p=0.033)	processed & UPF modelled together	
Sousa et al. 2020 [29]	N= 2,499; 18-19 y; Brazil	FFQ; mean UPF energy contribution: 34.9% & 36.4% in those with good & poor sleep quality, respectively	PSQI: good sleep quality score ≤4; poor sleep quality score >4	Poisson regression adjusted for age, socio-economic class, education, screen time, parental marital status	Highest quartile of UPF intake associated with increased risk of poor sleep quality (PR=1.14; 95% CI: 1.03-1.27)	Multiple sampling strategies (includes sample of [27])	QR=2.5
Werneck et al., 2021 [25]	N=99,791; 11-19 y; Brazil	NOVA-based questionnaire, past 7 days; UPF intake 7 times/week: 36.3% & 43.5% of boys and girls, respectively	1 question about anxiety-induced insomnia/sleep disturbance over past 12 months, 5 response options from 'never' to 'very frequently'	Logistic regression adjusted for age, ethnicity, physical activity, food insecurity, city type, region of residence	Daily UPF consumption associated with higher odds of anxiety-induced sleep disturbance (males: OR=1.48, 95% CI 1.30-1.70; females: OR 1.46, 95% CI 1.34-1.60)	Nationally representative Adolescent School-Based Health Survey; associations mediated by loneliness & eating while watching TV	QR=2.0
UPF intake as outcome							
Mattar et al., 2022 [38]	N=2,826; 20-59 y; Brazil	Semi-quantitative FFQ; mean UPF energy contribution (%) range: 12.4 (Q_1) - 39.5 (Q_4); in short sleepers (≤6 h/d): 31.8% & 36.4% in Q_1 and Q_4, respectively	1 question about average sleep duration (h/d) over past 12 months	Path analysis including sex, age, income, employment, time on computer, meals/d, fried food intake	Sleep duration inversely & directly associated with UPF intake (std coeff= -0.05; p< 0.01)	Cohort of Universities of Minas Gerais	QR=1.5

Ruggiero et al., 2021 [26]	N=8,569; 20–97 y (mean age= 56.9 ±14.6); Italy	1 day 24-h dietary recall; European Food Propensity Questionnaire; mean UPF energy contribution: 17.3%; mean UPF intake: 154.8 g/d	1 question about general sleep quality, response options: restful vs restless	Multiple linear regression adjusted for age, sex, BMI, education, geographical area, place of residence, sports activity, occupation, marital status, energy intake, smoking, prevalent cancer, cardiovascular disease, hyper-tension, diabetes, hyperlipidemia	Lower sleep quality associated with increased UPF intake (beta=2.34; 95% CI: 1.45-3.23)	Italian Nutrition and Health Survey; nationwide sample of N=9,078 aged 5-97 y	QR=1.5

BMI, body mass index; CI, confidence interval; FFQ, food frequency questionnaire; NS, non-significant; OR, odds ratio; PR, prevalence ratio; PSQI, Pittsburgh Sleep Quality Index; Q, quartile; QR, study quality rating ranging from "poor"=1.0 to "good"=3.0; T, tertile; UPF, ultra-processed food and beverages

Figure captions

Figure 1. Study selection flowchart