



Research Paper

Association of carbonated soft drink and fast food intake with stress-related sleep disturbance among adolescents: A global perspective from 64 countries

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ABSTRACT

Background: Poor quality sleep adversely impacts on adolescent wellbeing. More multinational research is needed to understand modifiable risk factors, such as dietary behaviours. This study aimed to examine the association of carbonated soft drink and fast food intake with stress-related sleep disturbance among adolescents across 64 countries.

Methods: We analysed the Global School-based Student Health Survey data from 175,261 adolescents (mean age 13.8 [0.98]; 48.5% females). Adolescents reported frequency of stress-related sleep disturbance and consumption of carbonated soft drinks and fast foods. Country-level estimates were obtained by using multivariable logistic regression and meta-analysis to obtain pooled estimates.

Findings: Overall, 7.5% of adolescents reported sleep disturbance during the past 12 months (males: 6.6%; females: 8.4%). Meta-analysis showed that adolescents having carbonated soft drinks ≥ 3 times/day had over 50% higher odds of reporting sleep disturbance than $< \text{once/day}$ (OR=1.55, 95% CI 1.42–1.70 for males; 1.51, 1.37–1.68 for females). Adolescent males who had fast foods ≥ 4 days/week had 55% higher odds of reporting sleep disturbance than ≤ 1 day/week (1.55, 1.39–1.73), while the odds was 50% higher in females (1.50, 1.32–1.70). Carbonated soft drinks ≥ 3 times/day and fast foods ≥ 4 days/week were significantly associated with sleep disturbance in all but low-income countries for both genders; while the associations were significant in males and mixed in females across WHO regions.

Interpretation: Our findings suggest strong positive associations between carbonated soft drink and fast food intake with stress-related sleep disturbance. Prospective studies are needed to understand the directionality of the relationship.

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1. Introduction

Sleep quality has been recognised as a contributor to mental health and cognitive development of young people [1,2]. Sleep deprivation and poor sleep quality have been associated with emotional (e.g., depression and anxiety) and behavioural (e.g., aggression and bullying) problems among adolescents [3,4]. Inadequate sleep and sleep disturbance can adversely impact adolescents' motor skills, immune function, attention, daytime functioning, and academic performance and can increase the

risk of suicidal ideation and drug and alcohol abuse [1,2]. Inadequate sleep among adolescents also has metabolic consequences of weight gain and obesity [5], which is an established risk factor for cardio-metabolic disorders including diabetes and cardiovascular disease during adulthood [6]. Evidence on the modifiable factors associated with sleep disturbance in adolescents may, therefore, contribute to promoting mental health and physical wellbeing.

Emerging evidence suggests that unhealthy dietary behaviours, including the consumption of high-calorie carbohydrate-rich foods, are associated with sleep deprivation, sleep difficulties, and poor sleep quality among children and adolescents [7–11]. A 12-country study with children aged 9–11 years reported an association of higher consumption of sugar-sweetened beverages with short sleep

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Research in context

Evidence before this study

There are several single-country studies on associations between fast food and soft drink consumption, and sleep disturbance in adolescents with only two multi-country studies. The most recent multi-country study, conducted in 2011/13, examined the relationships between sugar-sweetened beverage consumption and sleep patterns among students aged 9–11 years in 12 countries.

Added value of this study

This study presents the largest global assessment of the relationships of carbonated soft drink and fast-food intake with stress-related sleep disturbance in adolescents, using nationally representative data from 64 countries. This study showed that frequent consumption of carbonated soft drinks and/or fast food was strongly and positively associated with sleep disturbance in both male and female adolescents in all but low-income countries around the globe.

Implications of all the available evidence

As sleep disturbance was more common among females than males, females may be a priority target group for sleep interventions. Given the variation in associations between carbonated soft drink and fast food consumptions, and sleep disturbance, context specific strategies may be needed to promote healthy eating and drinking, and sleep quality in adolescents across countries and regions.

The survey uses the same standardised sampling technique and study methodology across countries. In each country, participants were selected using a standardised two-stage cluster sampling design. At first, schools were selected based on probability proportional to size sampling. From these schools, classes were randomly selected, and all students in the selected classes were included in the sampling frame and were eligible to participate [15]. GSHS included a set of core questionnaire modules, which address the leading causes and risk factors of poor health and ill-being [15,16]. To ensure socio-cultural adaptability of the questionnaire, countries were allowed to include country-specific examples, options or phrasing [15]. If necessary, the questionnaire was translated, following a rigorous translation and back-translation protocol by WHO and CDC. In each participating country, the questionnaire was pilot-tested with school children aged 13–17 years [15]. Questionnaire items included questions on demographics (e.g., age, sex), dietary behaviours (e.g., consumption of fast foods, carbonated soft drinks), wellbeing (e.g., stress-related sleep disturbance, loneliness, number of close friends), and movement behaviours (e.g. physical activity [PA], leisure-time sedentary behaviours [SB]). The questionnaire was self-administered and participation was anonymous.

From all publicly available GSHS data, we selected all nationally-representative datasets that included the key variables pertaining to the analysis. For countries with more than one GSHS dataset, we used the most recent one available. A total of 64 countries were included in the current analysis (Table A1). The analytical sample consists of adolescent students aged 12–15 years from 64 countries, including 7 low-income, 19 lower-middle-income, 18 upper-middle-income, and 19 high-income countries based on the World Bank classification [17] at the time of the survey. Information on Cook Islands' income classification was not available and as such it remained unclassified.

2.2. Outcome measure

In the GSHS, adolescent students' stress-related sleep disturbance was measured with the question: 'During the past 12 months, how often have you been so worried about something that you could not sleep at night?' with response options: 'never'; 'rarely'; 'sometimes'; 'most of the time'; and 'always'. As used in other research [18], those who answered 'most of the time' or 'always' were considered to have stress-related sleep disturbance.

2.3. Study factors

Fast food consumption was assessed with the question: 'During the past 7 days, on how many days did you eat food from a fast food restaurant, such as [country specific examples of fast food outlets]'. In some countries, the questionnaire included specific examples of fast foods (e.g., burger, French fry, pizza in Afghanistan) and in other countries, names of popular/common fast food outlets were provided as examples (e.g., McDonalds, Burger King, or Barneys in Uruguay). Details of country-specific definitions of fast foods can be found in the WHO's GSHS data repository [12]. For modelling purposes, this variable was categorised into three groups: '≤1 day', '2–3 days', and '≥4 days', with '≥4 days/week' being considered as high.

Consumption of carbonated soft drinks was assessed with the question: 'During the past 30 days, how many times per day did you usually drink carbonated soft drinks, such as [country specific examples of drinks]?' The questionnaire included country-specific examples of carbonated soft drinks (e.g., Yacinthe lemonade in Seychelles; Frubu in Fiji) in addition to popular soda drinks such as Coca Cola, Fanta, Sprite. Details of country-specific examples of carbonated soft drinks can be found in the WHO's GSHS data repository [12]. The adolescents were instructed not to include diet soft drinks. This variable was categorised as 'none to <once', '1–2 times', and '≥3 times' per day with '≥3 times/day' being considered as high, as used elsewhere [19]. More than two

duration (<9 h/day) [10]. US adolescents with insufficient sleep (<10 h/day) reported more frequent consumption of carbonated soft drinks (i.e. soda) than those with sufficient sleep [7]. In that study, however, consumption of juices and other sugar-sweetened beverages such as sports drinks or fruit-flavoured drinks were not associated with insufficient sleep [7]. According to a recent study in South Korea, adolescents with high fast food (e.g., pizza, hamburger, fried chicken) or carbonated soft drink (e.g., soda) consumption had lower odds of being satisfied with sleep [8].

Most of these studies, however, are all single-country [7–9] and there is a limited number of multi-country studies found in the published literature [10,11]. To our knowledge, there has been no global evaluation that offered a comprehensive assessment of the association of carbonated soft drink or fast food consumption with sleep difficulties of adolescents. The aim of this study, therefore, was to examine if the consumption of fast foods or carbonated soft drinks is associated with stress-related sleep disturbance among nationally representative samples of school children from 64 countries around the globe.

2. Methods

2.1. Data sources

This study analysed publicly available data from the Global School-based Student Health Survey (GSHS), collected between 2009 and 2016 [12]. The GSHS is a population-based survey of school-going children and adolescents around the world. As a global health surveillance system for school children, the GSHS collects data on different aspects of adolescent health, including dietary behaviours (e.g., fast food and carbonated soft drink consumption) and wellbeing (e.g., stress-related sleep disturbance). The aim of the surveillance is to inform the development of appropriate adolescent and school health policies and programmes across different countries [13,14].

categories were used for both fast food and soft drink consumption to explore possible dose-response in the relationships.

2.4. Covariates

Adolescents self-reported age, sex, smoking status, alcohol consumption, movement behaviours, loneliness, number of close friends, and food insecurity in the survey. Food insecurity was assessed with one item: "During the past 30 days, how often did you go hungry because there was not enough food in your home?" with response options being never, rarely, sometimes, most of the time, and always. This variable was used as a proxy of socioeconomic status [20] as the GSHS did not include any direct measure of socioeconomic status. Smoking status and alcohol consumption were respectively assessed using the items: "During the past 30 days, on how many days did you smoke cigarettes?" and "During the past 30 days, on how many days did you have at least one drink containing alcohol?". Trained survey staff measured participants' height and weight. Body mass index (BMI) was categorised as underweight (BMI < -2SD), overweight (BMI > +1SD), and obese (BMI > +2SD), relative to median BMI, by age and sex based on the WHO Child Growth Standards [21].

Physical activity (PA) was assessed with one item: 'During the past 7 days, on how many days were you physically active for a total of at least 60 min per day?' The response options were 0–7 days. Consistent with the WHO recommendations, we defined participants as 'sufficiently active' if they did ≥ 60 min/day of PA on seven days of the week [22]. Leisure-time SB was assessed with one item: 'How much time do you spend during a typical or usual day sitting and watching television, playing computer games, talking with friends, or doing other sitting activities?' (excluding time spent in school or doing homework). The response options were: '>1', '1–2', '3–4', '5–6', '7–8', or '>8' h/day. We defined prolonged SB as spending ≥ 3 h/day in leisure-time sitting [23].

Loneliness was measured using one item: 'In the past 12 months, how often have you felt lonely?' and the response options included: never, rarely, sometimes, most of the time, and always. Responses of 'most of the time' or 'always' was considered as an indicator of loneliness. The number of close friends was assessed by asking: 'How many close friends do you have?' and the response options were 0, 1, 2, and '3 or more.'

2.5. Ethical considerations

The GSHS received ethics approval from the Ministry of Education or a relevant Institutional Ethics Review Committee, or both, in each of the participating countries. Parents/guardians of the school children were informed about the purpose and content of the survey, privacy of their children, and volunteer nature of participation [15]. Only those adolescents and their parents or guardians who provided written or verbal consent participated in the GSHS. As the current study used retrospective, de-identified, publicly available data, ethics approval was not required for this secondary analysis. Detailed methods of the GSHS have been described on both the US CDC [13] and the WHO [14] websites.

2.6. Statistical analyses

Country-specific weighted estimates were computed for the prevalence of stress-related sleep disturbance for male adolescents (hereafter males), female adolescents (hereafter females) by taking into account the weighting factor that was applied to each student record to adjust for non-response and the varying probability of selection.

In examining the association of consumption of carbonated soft drinks and fast foods with stress-related sleep disturbance for males and females separately, a set of covariates was initially considered including age, food insecurity, BMI, smoking, alcohol intake, loneliness,

and number of close friends, as informed by the current literature [24]. Before conducting multivariable modelling, the collinearity of the potential covariates was examined. The variables with the strongest association with the outcomes were considered in the modelling. Loneliness was not considered in any subsequent analyses due to its high collinearity with the number of close friends. Similarly, alcohol intake was excluded from the subsequent analyses due to its significant association with smoking. Also, country-level missing data were more common for alcohol consumption than smoking. The GSHS sampling weights were used to adjust the estimates of the association. The weighting allowed one participating student to represent many other students with similar demographic characteristics, and hence made the GSHS results generalizable to the entire population of students, not just those who took part in the survey. To find country-level estimates by sex, the association of (a) fast food consumption with stress-related sleep disturbance; and (b) soft drink consumption with stress-related sleep disturbance were examined using multivariable logistic regression models, adjusted for age, BMI, food insecurity, smoking, PA, SB, and number of close friends. A linear trend test was conducted to examine trend in the consumption of fast foods and carbonated soft drinks with stress-related sleep disturbance.

To generate pooled estimates of the association, random effects meta-analyses with the DerSimonian and Laird inverse-variance method [25] were used. Pooled estimates were derived by country income category, using the World Bank country income classification [17], collected at the time of the survey for the respective countries. Furthermore, pooled estimates were estimated by WHO regions (i.e., Africa, The Americas, Eastern Mediterranean, Southeast Asia, Western Pacific). *metan*, a Stata meta-analysis routine, was used to estimate the pooled odds ratios (OR) with 95% confidence interval (CI) for the estimates. In addition, a test of heterogeneity was used to assess whether the true effect in all studies was the same. The level of heterogeneity was quantified using I^2 , which indicates the percentage of variance in a meta-analysis that is attributable to study heterogeneity. Meta-regression was used to assess whether relationship estimates were associated with common global indices, including Human Development Index (2007–2016 data; range 0–1; a high score represents greater human development) [26], Gender Inequality Index (2005–2016 data; range 0–100; a higher score represents greater gender inequality) [27], Gini coefficient (2010–2015 data; range 0–100; a higher coefficient represents greater income inequality) [28], and expenditure on health (total health expenditure as percentage of GDP, 2005–2015 data) [29]. All statistical analyses were performed using Stata 14.0 SE.

2.7. Role of the funding source

This research did not receive any specific funding. The corresponding author had full access to all the data and had final responsibility for the decision to submit for publication.

3. Results

The final analytic sample comprised 175,261 adolescents, which excluded 0.95% of the participants who had missing data for the outcome variable. The participants were aged 12–15 years (mean [SD] 13.8 [0.98, 48.5% females) (Table A2). Overall, 7.5% of adolescents (males: 6.6%; females: 8.4%) reported having stress-related sleep disturbance during the past 12 months. The prevalence of stress-related sleep disturbance increased linearly with the increased frequency of soft drink and fast food consumption in both sexes (Fig. 1). The prevalence of stress-related sleep disturbance for high consumption (≥ 3 times/day) of carbonated soft drinks was 9.6% for males and 13.6% for females, compared to 5.9% and 7.7% respectively of their counterparts who had carbonated soft drinks <once/day ($p_{\text{trend}} < 0.001$). Similarly, 10.5% of males who had high (≥ 4 days in the past 7 days)

consumption of fast food reported stress-related sleep disturbance, compared to 6.2% of their counterparts who had fast foods ≤ 1 day/week ($p_{\text{trend}} < 0.001$). The prevalence of stress-related sleep disturbance among females was: 10.7% for ≥ 4 days/week and 7.9% for ≤ 1 day/week of fast food consumption ($p_{\text{trend}} < 0.001$). The crude and adjusted association estimates of the exposures/study factors and all covariates with stress-related sleep disturbance are presented in Table A3 for males and Table A4 for females.

Overall, the pooled estimates of association from random effect meta-analyses are presented in Figs. 2 and 3. The heteroscedasticity (I^2) ranged from 0 to 68% across various estimates. As shown in Fig. 2, males who had carbonated soft drinks ≥ 3 times/day had 55% times higher odds of having stress-related sleep disturbance than their counterparts who had carbonated soft drinks $< \text{once/day}$ (OR 1.55, 95% CI: 1.42–1.70). Similar odds were observed among male adolescents who had fast foods ≥ 4 days during the past week compared to ≤ 1 day/week (OR=1.55, 95% CI: 1.39–1.73).

Analyses by country income showed similar significant association in all but low-income countries, with adolescents from high-income countries showing the highest estimate for high carbonated soft drink consumption (OR=1.67, 95% CI: 1.42–1.96), and upper-middle-income countries showing the highest estimate for high fast food consumption (OR=1.62, 95% CI: 1.34–1.96) among males (Fig. 2). Similar findings were observed among females (Fig. 3) with adolescents from high-income countries showing the highest association estimates for both high soft drink (≥ 3 times/day) and fast food (≥ 4 days/week) consumption. For example, females in high-income countries who had carbonated soft drinks ≥ 3 times/day had 68% times higher odds of having stress-related sleep disturbance than their counterparts who had carbonated soft drinks $< \text{once/day}$ (OR 1.68, 95% CI: 1.48–1.90). Female adolescents who had fast foods ≥ 4 days/week, compared to ≤ 1 day/week, had 75% higher odds of having stress-related sleep disturbance (OR=1.75, 95% CI: 1.44–2.12) in high income countries.

Analyses by WHO region revealed that frequent consumption of carbonated soft drinks and fast foods were significantly associated with stress-related sleep disturbance in males across WHO regions (Tables 1 and 2) with South East Asia showing the highest estimate for carbonated soft drinks (OR=1.77, 95% CI: 1.26–2.48) and Western Pacific showing the highest estimate for fast foods (OR=1.72, 95% CI: 1.37–2.15). In females, the associations for carbonated soft drinks were significant in all regions but Africa (OR=1.12, 95% CI: 0.85–1.49), and the associations for fast foods were significant in the Americas (OR=1.48, 95% CI: 1.17–1.86), Eastern Mediterranean (OR=1.56, 95% CI: 1.31–1.87) and Western Pacific regions (OR=1.79, 95% CI: 1.31–2.44).

While the lower frequency category (1–2 times/day) of carbonated soft drinks was not associated with stress-related sleep disturbance in both males and females, the lower frequency (2–3 days/week) of fast food consumption was significantly associated stress-related sleep disturbance (OR=1.18, 95% CI: 1.08–1.30) among females with significant association in lower- and upper-middle-income countries, and South East Asia and Western Pacific regions.

Meta regression analyses for females showed a positive association of ORs with country Human Development Index ($\beta=2.15$, 95% CI: 0.63–3.66, $p = 0.006$) for high carbonated soft drink consumption (≥ 3 times/day). Similarly, the association between high consumption of fast foods (≥ 4 days/week) and stress-related sleep disturbance was higher for countries with high development index in females ($\beta=1.78$, 95% CI: 0.36–3.21, $p = 0.015$). None of the other indices were associated with OR for females. For males, there was no significant association between relationship estimates (OR) and global indices.

4. Discussion

To our knowledge, this is the first global study to examine unhealthy diet and stress-related sleep disturbance on a global scale, with adolescent school students from 64 countries. We found that adolescents who frequently consumed carbonated soft drinks ($\geq \text{twice/day}$) and/or fast foods (≥ 4 days/week) had higher odds of reporting stress-related sleep disturbance than those with infrequent- or no-consumption, after adjusting for a set of confounders including age, BMI, food insecurity, smoking, PA, SB, and number of close friends. These cross-sectional relationships were significant in both male and female adolescents in all but low-income countries, and add to the growing evidence on the cross-sectional links between unhealthy diet and poor wellbeing in adolescents.

Overall, the prevalence of stress-related sleep disturbance increased with more frequent consumption of carbonated soft drinks and fast foods. This is consistent with other within country cross-sectional studies [7–9, 30], including our research with Bangladeshi adolescents [19]. Carbonated soft drinks often contain caffeine, which is a known stimulant and has been associated with sleep issues in children [31] and adolescents [32]. The association between sleep disturbance and fast foods consumption in the current study is also consistent with other studies [9]. Fast foods are traditionally energy-dense and nutrient-poor, and high consumption has been associated with various mental health issues [33], including shorter sleep duration [9] and poor sleep quality in adolescents [34]. Previous research has also indicated that higher quality diets (i.e., diets high in vegetables, fruits, dietary fibres, and low-energy-dense foods) are associated with increased sleep duration [35].

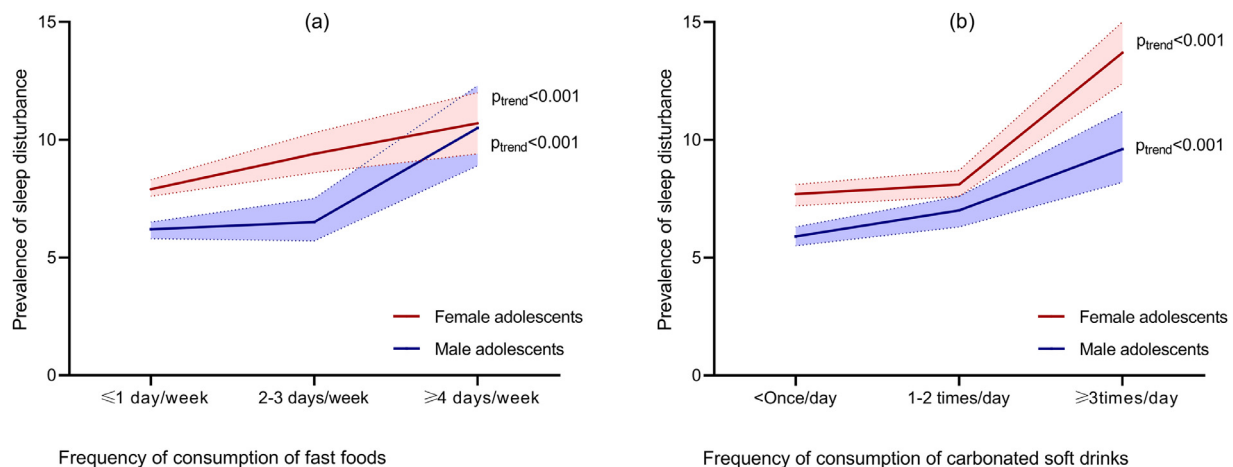


Fig. 1. Prevalence of stress-related sleep disturbance by frequency of consumption of (a) fast foods and (b) carbonated soft drinks, Global School-based Student Health Survey, 2009–2016.

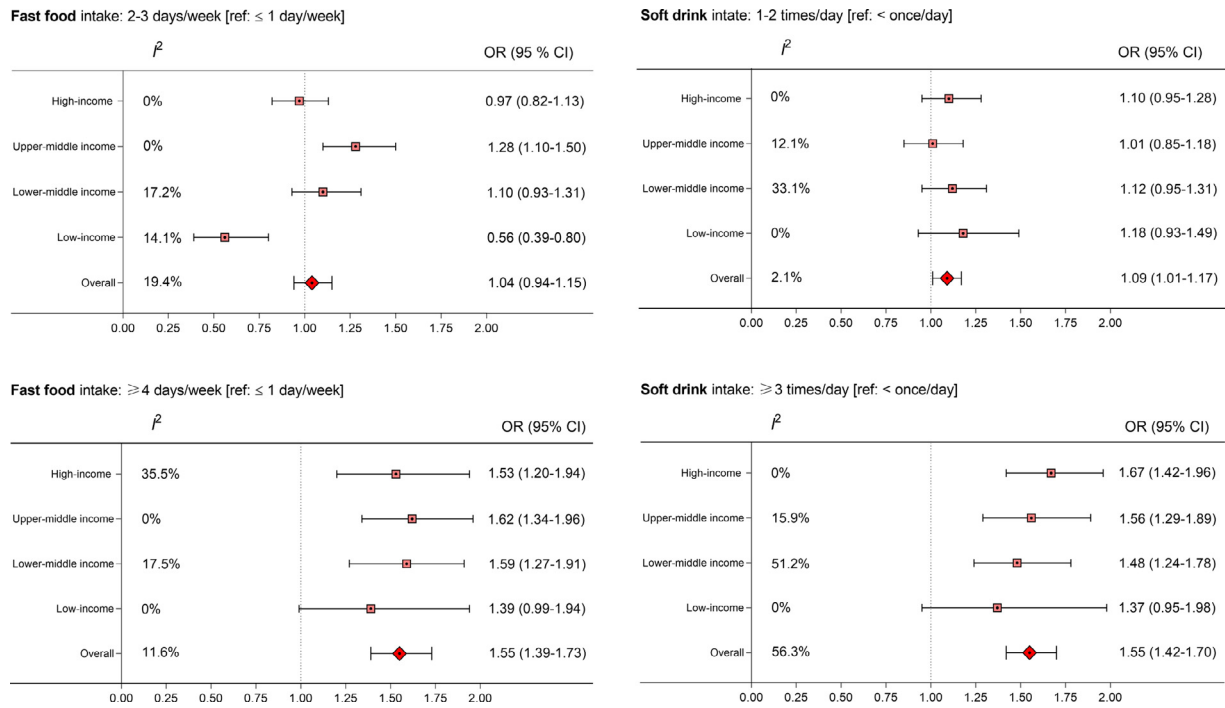


Fig. 2. Association estimates (ORs) of fast food and carbonated soft drink consumption with stress-related sleep disturbance among *male* adolescents, by country-income, Global School-based Student Health Survey, 2009–2016. Abbreviations: OR=odds ratio; CI=confidence interval. I^2 measures the percentage of variance that was attributable to study heterogeneity.

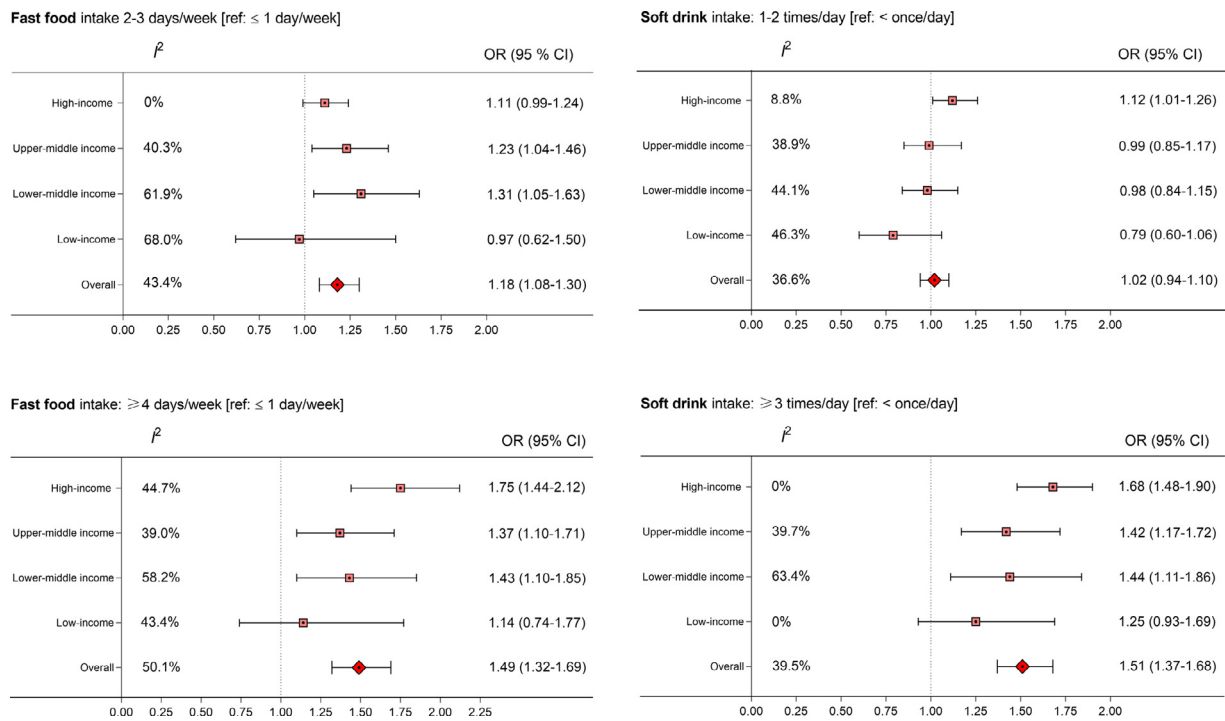


Fig. 3. Association of fast food and carbonated soft drink consumption with stress-related sleep disturbance among *female* adolescents, by country-income, Global School-based Student Health Survey, 2009–2016. Abbreviations: OR=odds ratio; CI=confidence interval. I^2 measures the percentage of variance that was attributable to study heterogeneity.

The odds of adolescents experiencing stress-related sleep disturbance increased by ~55% when frequently consuming carbonated soft drinks and/or fast foods, compared to those with infrequent consumption. Significant associations between more frequent soft drink and fast food consumption with stress-related sleep disturbances were found in males from all WHO regions. In females, significant

associations were found in all WHO regions but Africa (both soft drinks and fast foods) and South East Asia (fast foods). For both sexes, the association estimates were highest in the Southeast Asian region for carbonated soft drinks, and in the Western Pacific region for fast foods, suggesting the most vulnerable populations may be found in these regions. Higher income countries showed significantly higher

Table 1

Association estimates (ORs, 95% CI) of carbonated soft drink consumption with stress-related sleep disturbance among adolescents, by World Health Organization (WHO) regions, Global School-based Student Health Survey, 2009–2016.

WHO regions	Male adolescents				Female adolescents			
	1–2 times/day OR (95% CI)	<i>I</i> ²	≥ 3 times/day OR (95% CI)	<i>I</i> ²	1–2 times/day OR (95% CI)	<i>I</i> ²	≥ 3 times/day OR (95% CI)	<i>I</i> ²
Africa	0.92 (0.72–1.19)	0%	1.61 (1.13–2.31)	27.7%	0.76 (0.62–0.94)	0%	1.12 (0.85–1.49)	18.7%
The Americas	1.05 (0.88–1.24)	3.7%	1.50 (1.24–1.80)	2.6%	1.01 (0.86–1.19)	40.4%	1.57 (1.33–1.85)	28.2%
Eastern Mediterranean	1.06 (0.94–1.19)	0%	1.42 (1.22–1.67)	0%	1.02 (0.91–1.14)	21.5%	1.51 (1.20–1.91)	62.6%
Southeast Asia	1.14 (0.85–1.53)	18.5%	1.77 (1.26–2.48)	0%	1.16 (0.93–1.45)	0%	1.66 (1.15–2.40)	31.4%
Western Pacific	1.17 (0.98–1.40)	17.6%	1.73 (1.42–2.11)	65.2%	1.10 (0.89–1.34)	50.8%	1.61 (1.29–2.00)	33.5%
Overall	1.09 (1.01–1.17)	2.1%	1.55 (1.42–1.70)	56.3%	1.02 (0.94–1.10)	36.6%	1.51 (1.37–1.68)	39.5%
p-value of test of heterogeneity	0.43		<0.001		0.002		0.001	

Reference category: <one time/day.

OR=odds ratio; CI=confidence interval.

*I*² measures the percentage of variance that was attributable to study heterogeneity.

Table 2

Association estimates (ORs, 95% CI) of fast food consumption with stress-related sleep disturbance among adolescents, by World Health Organization (WHO) regions, Global School-based Student Health Survey, 2009–2016.

WHO regions	Male adolescents				Female adolescents			
	2–3 days/week OR (95% CI)	<i>I</i> ²	≥4 days/week OR (95% CI)	<i>I</i> ²	2–3 days/week OR (95% CI)	<i>I</i> ²	≥4 days/week OR (95% CI)	<i>I</i> ²
Africa	1.03 (0.73–1.44)	20.4%	1.63 (1.21–2.19)	0%	1.12 (0.82–1.53)	38.0%	1.11 (0.74–1.68)	49.4%
The Americas	0.91 (0.76–1.10)	0%	1.65 (1.29–2.12)	17.9%	1.06 (0.91–1.22)	21.5%	1.48 (1.17–1.86)	43.4%
Eastern Mediterranean	0.93 (0.75–1.15)	48.3%	1.34 (1.13–1.58)	0%	1.10 (0.91–1.31)	60.4%	1.56 (1.31–1.87)	31.2%
Southeast Asia	1.14 (0.87–1.50)	0%	1.56 (1.04–2.33)	35.6%	1.33 (1.05–1.67)	0%	1.32 (0.80–2.16)	64.0%
Western Pacific	1.33 (1.12–1.58)	1.5%	1.72 (1.37–2.15)	12.6%	1.49 (1.24–1.78)	31.9%	1.79 (1.31–2.44)	61.5%
Overall	1.04 (0.94–1.15)	19.4%	1.55 (1.39–1.73)	11.6%	1.18 (1.08–1.30)	43.4%	1.50 (1.32–1.70)	50.1%
p-value of test of heterogeneity	0.09		0.22		<0.001		<0.001	

Reference category: ≤1 day/week.

OR=odds ratio; CI=confidence interval.

*I*² measures the percentage of variance that was attributable to study heterogeneity.

estimates for both carbonated soft drinks and fast foods, whereas the lowest income countries had non-significant estimates of the associations. Earlier research has reported variations in consumption of carbonated soft drinks and fast foods by country, with low-income countries reporting lower consumption than upper-middle-income countries (48% vs. 57%, respectively) [20]. Considerable heterogeneity has also been observed in anxiety-induced sleep disturbance among adolescents in low-income countries, ranging from 1.8% in Myanmar to 25.8% in Zambia [36]. Adolescents in low-income countries may not have ready access to the same fast food and carbonated soft drink options as their higher income counterparts, potentially influencing the frequency of consumption, which may make it harder to identify any associations. It is also possible that adolescents in low-income countries may be exposed to other nutritional, behavioural or environmental factors that may mediate the associations under study. This highlights the need for developing a better understanding of the link between sleep and other lifestyle behaviours of adolescents in low-income countries.

Our findings suggest that poorer dietary quality with frequent consumption of carbonated soft drinks and/or fast foods are associated with stress-related sleep disturbances, although the direction of this association is unclear. Sleep disturbance might also affect diet quality. Sleep restriction affects decision making relative to food intake via stimulation of the salience, reward, and pleasure systems [37]. This can lead to increased intake of foods high in fat, carbohydrate, and overall energy [37]. There appears to be no difference in energy metabolism when sleep is restricted but more energy is expended in waking hours leading to increased total energy expenditure and subsequent effects on appetite [37]. A lack of sleep may affect levels of appetite-regulating hormones (e.g., ghrelin and leptin), which can lead to an increase in hunger [2], which then precipitates more frequent fast food consumption. Sleepiness has also been associated with individuals reporting more intense taste sensations,

particularly for sour and umami flavours, and a preference for high fat sweet foods, potentially linked to changes in ghrelin levels [38]. While poor sleep quality is associated with elevated emotional eating in women, short sleep can induce stress and elevated food consumption in emotional eaters [39], suggesting potential effects of poor sleep quality and stress on increasing appetite.

Taken together, the findings of our study highlight the concurrence of stress-related sleep disturbance, and frequent consumption of carbonated soft drink and fast food in adolescents around the world. As other research has demonstrated that unhealthy behaviours are likely to cluster together among adolescents [40], simultaneous targeting of multiple unhealthy behaviours may be a productive approach. As stress-related sleep disturbance was more common among female than male adolescents, females may be a priority target group for associated interventions that could target stress management and/or sleep quality. Evidence from a number of countries has shown promising results of sugar tax on sales of soft drinks, which can be considered as a proxy of lower consumption [41]. As the types of foods available at schools are important determinants of adolescents' eating behaviours [42], creating school environments that limit access to carbonated soft drinks and fast foods may also be beneficial. Family can also be instrumental in promoting healthy eating as the adoption and maintenance of children's dietary behaviours are influenced by their familial environments [43]. Importantly, strategies need to be customised and tailored across countries or regions to meet their local needs.

A strength of this study is the use of nationally-representative samples of school-going adolescents from a large number of countries with diverse socio-cultural and -economic background. The GSHS used the same standardised methods such as the type of sample (e.g., school based), data collection procedures, and wording of questions across surveys, which facilitated valid assessments of cross-national or regional differences in stress-related sleep

disturbance. The results presented were obtained by using weighted analyses, where the GSHS weighting accounted for distribution of the population by sex and age. The broad range of data collected in the GSHS enabled the inclusion of a range of potential covariates in the current study.

This study is limited by the cross-sectional design, and as such directionality of the associations cannot be established. Data for this study are self-reported and therefore vulnerable to social desirability and recall bias. The GSHS data include only adolescents in schools, and therefore information from adolescents who were unable to attend school or who had dropped out was not available, which compromises the generalisability of the findings. The assessment of fast food and carbonated soft drinks was based only on frequency, which may not represent the amount. Fast food consumption was assessed as food from a fast food restaurant. However, these restaurants may also offer nutrient balanced foods, which are quickly prepared and eaten during a short time. Other research has demonstrated that high calorie, low-nutrient density foods with high proinflammatory potential are those foods associated with sleep problems, rather than the fast food regardless its nutritional value [44,45]. Assessment of carbonated soft drinks did not specify energy drinks which are also known to be associated with reduced sleep quality [46]. Assessment asked about being so worried as to disrupt sleep at night. This could alternatively be considered as a measure of stress rather than sleep disturbance. The GSHS also did not collect other data on stress, so that could not be included in the modelling. GSHS also did not collect data on sleep duration, efficiency or onset latency for a more comprehensive assessment of sleep quantity and quality. Although SB was included as a confounder, assessment of this did not specify in the examples time spent on mobile/smart phones, or computer use, which are common leisure-time activities in adolescents, and also associated with sleep disturbance in adolescence [47,48]. In the absence of parental education, income and similar variables, we used food insecurity as a proxy measure for socioeconomic status in the analyses. Unmeasured residual confounders such as socioeconomic status and parenting style may potentially contribute to the associations of carbonated soft drinks and fast food consumption with stress-related sleep disturbance. Recall periods for the assessment of the three behaviours did not completely overlap: fast food consumption was based on the past 7 days, carbonated soft drink consumption was based on the past 30 days, and sleep disturbance was based on the past 12 months. It may be that the more recent data was recalled more accurately. Varying levels of heterogeneity in the meta-analyses were observed when pooling estimates across time and locations; however, random effects meta-analyses were likely to minimise the potential effects of the heterogeneity across studies. The study includes data collected over a period of eight years (2009–2016) and as such, period effects on the results is a possibility.

Our study demonstrates that frequent consumption of carbonated soft drinks and/or fast foods is associated with stress-related sleep disturbance in adolescents across the globe, with some variation across WHO regions and country income groups. However, the directionality of the relationship remains unknown. Prospective studies with robust measurement of diet quality and sleep are required to further understand these associations, including their causal pathways. Such evidence can inform strategies to promote healthy lifestyles among adolescents around the globe.

Declaration of Interests

The authors have no conflict of interest to disclose.

Authors' contributions

AK and RU conceptualised and designed the study, and extracted and collated data from the GSHS database. AK analysed the data.

AK, CD, NWB, SRK, and RU interpreted the results. AK, CD, and RU drafted the article. NB and SRK revised the article critically for intellectual content. All authors gave final approval of the version to be published. AK and RU had access to the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. All listed authors meet authorship criteria and no others meeting the criteria have been omitted.

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Data sharing statement

The data for the current study are publicly available at the World Health Organization NCD Microdata Repository (URL: <https://extranet.who.int/ncdsmicrodata/index.php/catalog>).

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.eclinm.2020.100681.

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