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Original Article

Tobacco smoke exposure and inadequate sleep among U.S. school-aged children

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ABSTRACT

Objective/background: Inadequate sleep and tobacco smoke exposure (TSE) have been separately linked to adverse childhood health consequences. Our objective was to assess the association between home TSE status and inadequate sleep among U.S. school-aged children.
Methods: We analyzed 2018–2019 National Survey of Children's Health data, and included 17,851 children ages 6–11 years. Children were classified into three parent-report TSE groups: (1) did not live with a smoker (no TSE at home); (2) lived with a smoker who did not smoke inside the home (thirdhand smoke (THS) exposure only); and (3) lived with a smoker who smoked inside the home (secondhand smoke (SHS) and THS exposure). Parent-report of inadequate sleep on most weeknights was defined as <9 h, following age-specific national guidelines. We fitted a weighted multivariable logistic model to assess the association between TSE groups and inadequate sleep, adjusting for child covariates (sociodemographics, overweight status, health status, physical activity, and screen time).
Results: About 13% and 1% of school-aged children were exposed to home THS only and home SHS and THS, respectively; approximately 36% overall had inadequate sleep. Compared to children with no TSE at home, children who were exposed to home THS only had higher odds of inadequate sleep (AOR = 1.44, 95%CI = 1.20–1.73); those exposed to home SHS and THS had higher odds of inadequate sleep (AOR = 1.83, 95%CI = 1.20–2.78).
Conclusions: TSE is associated with school-aged children having inadequate sleep, even when smokers did not smoke inside the home. Promoting parental smoking cessation is essential to fully protect children from related risks.

1. Introduction

Despite decreases in adult tobacco smoking rates in the U.S., [1], nearly 40% of children remain exposed to tobacco smoke [2]. Child tobacco smoke exposure (TSE) consists of exposure to freshly emitted tobacco smoke (ie, secondhand smoke (SHS)) and exposure to smoke residue that is detectable in and beyond the physical environment where tobacco has been smoked (ie, thirdhand smoke (THS)). THS may be trapped in smokers' clothing and objects (eg, toys), and pollutants may subsequently spread to other people (eg, children) [3]. Thus, children who live with smokers who actively smoke tobacco around them are at risk of inhaling SHS; even when smokers are not actively smoking tobacco around them, smokers' children are at risk of involuntarily inhaling, ingesting, and dermally absorbing THS pollution [3]. While smoke-free home rules have increased over time, less than 40% of homes with at least one smoker and one child have not implemented voluntary smoking bans [4]. Given that homes are the main setting for TSE among children [5], it is important to consider overall TSE patterns, including both SHS and THS exposure, among children who live with smokers who smoke tobacco inside their homes, and potentially exclusive THS exposure among children who live with smokers who do not smoke tobacco inside their homes.

Inadequate sleep is another public health problem that has negative effects on school-aged children's healthy development and overall well-being [6]. Inadequate amount of sleep during the childhood years has been linked to poor physical health outcomes

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such as obesity, adverse mental and emotional health issues such as altered emotional regulation and behavior problems, and low academic performance [7–10]. Further, nicotine exposure may affect sleep patterns among nonsmokers who are involuntarily exposed to tobacco smoke given the pathophysiology of nicotine, the addictive substance present in tobacco smoke pollutants, that leads to increases in the stimulation of dopamine, acetylcholine, and glutamate systems [5]. Polysomnographic studies indicate that acute nicotine exposure delivered via a transdermal nicotine patch has been associated with disruptive sleep physiology including decreased total sleep time among nonsmoking, healthy adults [11–13]. Specifically, a study published in 1994 including 20 nonsmoking male and female adults with a mean age of about 47 years found that transdermal nicotine significantly reduces total sleep time, rapid eye movement (REM) sleep time, and sleep efficiency, and prolongs initial sleep latency [11]. Another study published in 1994 including 12 nonsmoking adults with a mean age of 30 years reports that transdermal nicotine decreases REM sleep time and is associated with early morning awakening [12]. A more recent study published in 2017 including 16 nonsmoking male young adults with a mean age of 24 years reports similar findings that transdermal nicotine is associated with decreased total sleep time, decreased REM sleep time, decreased sleep efficiency, increased wakefulness after sleep onset, and increased sleep latency [13].

Evidence suggests that child tobacco smoke exposure (TSE) is associated with sleep-related diseases including sleep-disordered breathing (eg, habitual snoring, obstructive sleep apnea) [14,15], and sleep bruxism (ie, grinding or clenching teeth during sleep) [16]. Prior research among school-aged children with asthma suggests that TSE is also associated with several sleep-related problems including daytime sleepiness and sleep-onset delay, but not with the sleep parameter of sleep duration [17]. Prior work among other populations reports an association between TSE and inadequate sleep among three-year-olds [18], adolescents [19], and nonsmoking adults [20], including pregnant women [21,22] and men [23]. However, the potential association between home TSE status and inadequate sleep among school-aged children remains understudied. Thus, it is important to clarify the relationship between home TSE status, including both SHS and THS exposure, and sleep duration to potentially inform future TSE reduction policies and interventions among school-aged children.

This study assessed the association between home TSE status and inadequate sleep among U.S. school aged-children ages 6–11 years. Child home TSE status included three parent-report groups: (1) no TSE at home defined as the child did not live with a smoker; (2) home THS exposure only defined as the child lived with a smoker who did not smoke inside the home; and (3) home SHS and THS exposure, defined as the child lived with a smoker who smoked inside the home. We hypothesized that school-aged children with home SHS and THS exposure or THS exposure only would be more likely to have report of inadequate sleep compared to children with no TSE at home.

2. Materials and methods

2.1. Participants and procedures

We performed a secondary analysis of the combined 2018–2019 National Survey of Children's Health (NSCH) data [24]. The NSCH is conducted by the U.S. Census Bureau in collaboration with the U.S. Health Resources and Services Administration's Maternal and Child Health Bureau who provides funding and direction to collect child health and well-being data via a U.S.-wide, cross-sectional survey [25,26]. A university-based institutional review board (IRB) determined that this study was not human subjects research and exempted it from review due to no identifying information being available in the NSCH public use data sets.

The 2018–2019 NSCH methodology are available at length elsewhere [25,26]. Briefly, in both data collection years, NSCH randomly selected and recruited households by mailing potential participants a short screener to complete via the Internet or by paper that identified children ages 0–17 years in their household. Adults who lived with at least one child were asked to complete an age-appropriate questionnaire, and the current study was limited to adult household members who completed the age-specific topical questionnaire for children ages 6–11 years. The overall weighted response rates were 43.1% (N = 30,530) and 42.4% (N = 29,433) for the 2018 and 2019 NSCH surveys, respectively [25,26].

A total of 17,851 school-aged children ages 6–11 years were included in the current study, after excluding those of other ages due to varying sleep hour duration recommendations and NSCH topical questionnaires for these age groups (ie, 0–5 years, 12–17 years).

2.2. Measures

2.2.1. Child home TSE status

Parents reported whether the child lived with any household members that smoked combustible tobacco products (ie, cigarettes, cigars, and pipe tobacco). If parents responded that the child lived with a smoker (ie, yes), then a follow-up question was asked about whether anyone smokes inside their home. We combined both questions to create the independent variable of interest, home TSE status, and classified children into the three levels: (1) did not live with a smoker (no TSE at home); (2) lived with a smoker who did not smoke inside the home (proxy for home THS exposure only); and (3) lived with a smoker who smoked inside the home (proxy for home SHS and THS exposure).

2.2.2. Inadequate sleep

Parents reported how many hours of sleep their child got on most weeknights with six options ranging from <6 h to ≥11 h. NSCH calculated an adequate sleep variable that followed the age-specific sleep guidelines by the American Academy of Sleep Medicine [6] for school-aged children and dichotomized this for public-use into: adequate sleep (≥9 h per 24 h) and inadequate sleep (<9 h per 24 h) [27].

2.2.3. Child and family covariates

We included the following sociodemographics: child age, sex, race/ethnicity (non-Hispanic White, Black, Other/Multiracial, and Hispanic), parent education level (≤high school graduate or equivalent, some college, college degree), family structure of the child's household (two parents currently married, two parents not currently married, single parent, and other structure), and federal poverty level. The NSCH used family income and family size variables to calculate U.S. Census Bureau's poverty thresholds, and did not publicly provide family income nor family poverty threshold data to protect participants' confidentiality [27]. Therefore, the NSCH provided a calculated federal poverty level variable for public use based on State Children's Health Insurance Program groups that consider family income relative to family size and number of children ages 0–17 years. Four federal poverty level percent categories were provided for analysis: 0–199%, 200–299%, 300–399%, and ≥400%. State Children's Health Insurance Program eligibility levels vary by U.S. state with a median eligibility level of 255% for children

(eg, $52,989 income per year as of 2018 and $54,392 income per year as of 2019 for a family size of three), and eligibility levels ranged from 175% to 405% across U.S. states in 2018 and 2019 [28,29].

We selected covariates on child physical activity, overweight status [30,31], electronic screen time [32,33], and mental, emotional, developmental, and behavioral health [34], since these have been linked to inadequate sleep among children. Specifically, parents were asked whether a doctor or other healthcare provider told them that their child was overweight (no/yes). Parents were also asked to report about how often their child was physically active for at least 60 min per day in the past week (0, 1–3, 4–6, 7 days per week), and how often their child spent on screen time during most week days, such as using televisions, computers, cellphones, and other electronic devices (<1, 1, 2, 3, ≥4 h per weekday). Parents were asked several questions on their child's mental, emotional, developmental, and behavioral health, and the NSCH provided a variable for public use on whether the child had a mental, emotional, developmental, or behavioral problem (no/yes) [27]. Specifically, this variable was derived from whether the child had been diagnosed by a healthcare provider with one or more reported problem (eg, behavioral and conduct problem, depression, anxiety problem, attention deficit disorder or attention-deficit/hyperactivity disorder) and/or had an ongoing emotional, developmental, or behavioral problem.

2.3. Statistical analysis

We applied the sampling weights provided with the NCSH data set to reflect the demographic composition of U.S. children ages 6–11 years and provide generalizable estimates. We first calculated descriptive statistics for all variables, and present raw sample sizes with weighted percentages. We examined associations between the child covariates and home TSE status via chi-square tests for all categorical variables and an analysis of variance (ANOVA) for child age. Central to our study aim, we fitted a weighted unadjusted logistic regression model to assess the association between home TSE status and inadequate sleep, and present unadjusted odds ratios (ORs) and 95% confidence intervals (95%CIs). Then, we added the child covariates (ie, sociodemographics, overweight status, physical activity, screen time, and mental, emotional, developmental, or behavioral problem) and fitted a weighted multivariable logistic regression model to understand how these additional variables attenuated crude associations, and present adjusted ORs (AORs) and 95%CIs. The *p*-value was set to 0.05 for statistical significance. Analyses were conducted using SPSS Complex Samples (version 27.0).

3. Results

The average age of the 17,851 school-aged children was 8.55 (SE = 0.03) years, and 50.7% were male, 50.4% were non-Hispanic White, 13.4% were non-Hispanic Black, 11.1% were non-Hispanic Other race including Multiracial, and 25.0% were of Hispanic origin (Table 1). Nine percent of children had an overweight status and 23.0% had a mental, emotional, developmental, or behavioral problem. About half (49.6%) of parents had obtained at least a college degree, and most (63.4%) children lived in a household with two parents who were currently married. Federal poverty level varied with 40.7% in the lowest 0–199% category followed by 31.3% in the highest ≥400% category. Over 1-in-4 (28.2%) children participated in physical activity for at least 60 min/day on all seven days, and over 1-in-10 (11.4%) spent <1 h/day on electronic screen time on most week days.

3.1. Child and family covariates with parent-reported home TSE status

A total of 12.8% ($n = 2355$) of school-aged children were exposed to home THS only and 1.4% ($n = 311$) were exposed to home SHS and THS. Most child and family covariates differed based on parent-reported home TSE status, with the exception of child age and sex (see Table 1). Higher rates of children with home THS exposure only were non-Hispanic White (58.0%), had an overweight status (12.2%), had a mental, emotional, developmental, or behavioral problem (31.8%), did not engage in physical activity (6.7%, ie, 0 days/week) and had high screen time ≥4 h/day (24.3%). Higher rates of children with home SHS and THS exposure were non-Hispanic White (63.9%) and non-Hispanic Black (22.7%), had an overweight status (13.1%), had a mental, emotional, developmental, or behavioral problem (43.4%), did not engage in physical activity (9.8%, ie, 0 days/week) and had high screen time ≥4 h/day (43.2%). Children with THS exposure only and children with SHS and THS exposure had respective high rates of living in homes with lower parent education level of ≤high school graduate or equivalent (38.6% and 57.4%) and lower federal poverty level of 0–199% (53.7% and 82.5%), and respective low rates of living with two parents who were currently married (53.1% and 24.5%) (see Table 1).

3.2. Parent-reported child home TSE status and inadequate sleep

Of the total school-aged child sample, 35.7% ($n = 5642$) had report of inadequate sleep <9 h per 24 h on average. Specifically, 0.3% ($n = 61$) had <6 h of sleep, 0.9% ($n = 166$) had 6 h of sleep, 4.9% ($n = 881$) had 7 h of sleep, 25.4% ($n = 4534$) had 8 h of sleep, 35.2% ($n = 6284$) had 9 h of sleep, 28.4% ($n = 166$) had 10 h of sleep, and 4.8% ($n = 859$) had ≥11 h of sleep. A total of 46.4% and 61.0% of children with THS exposure only and SHS and THS exposure, respectively, had report of inadequate sleep (Table 2).

Unadjusted model results indicated that when compared to children with no TSE at home, those exposed to home THS only had 1.71 increased odds (95%CI = 1.43–2.06) of inadequate sleep. Those exposed to home SHS and THS had even higher odds (OR = 3.11; 95%CI = 2.07–4.67) of inadequate sleep. Similarly, adjusted model results indicated that compared to children with no TSE at home, children exposed to home THS only had higher odds of inadequate sleep (AOR = 1.44, 95%CI = 1.20–1.73); those exposed to home SHS and THS were at even higher odds (AOR = 1.83, 95%CI = 1.20–2.78) of inadequate sleep, while adjusting for child age, child sex, child race/ethnicity, child overweight status, child mental, emotional, developmental, or behavioral problem, parent education level, family structure, federal poverty level, child physical activity, and child screen time.

4. Discussion

This study found that TSE is associated with U.S. school-aged children having parent-reported inadequate sleep <9 h as defined by the American Academy of Sleep Medicine [6], even when smokers did not smoke inside their home. The current study found that children who lived in homes in which indoor smoking was allowed and were exposed to combined SHS and THS were more likely to have parent-reports of inadequate sleep compared to children with no TSE at home. Thus, we build upon prior work that also found associations between TSE and inadequate sleep among young children, adolescents, and adults [18–20], and clarified the association between home TSE including SHS and THS exposure among school-aged children. Specifically, a Swedish population-based cohort study found that three-year-olds who lived with parental smokers were at increased odds of having poor sleep, even

Table 1
Characteristics of U.S. school-aged children according to home TSE status, 2018–2019 NSCH.

Characteristic	Overall (N = 17,851)	Home TSE Status			
		No TSE (n = 15,185)	THS Exposure Only (n = 2355)	SHS and THS Exposure (n = 311)	p-value
	n (%)[a]	n (%)[a]	n (%)[a]	n (%)[a]	
Child Age, *M* (SE)	8.55 (0.03)	8.54 (0.03)	8.56 (0.07)	8.66 (0.18)	0.802
Child Sex					0.712
Male	9278 (50.7)	7905 (50.8)	1198 (49.3)	175 (52.8)	
Female	8573 (49.3)	7280 (49.2)	1157 (50.7)	136 (47.2)	
Child Race/Ethnicity					<0.001
Non-Hispanic White	12,198 (50.4)	10,282 (49.0)	1696 (58.0)	220 (63.9)	
Non-Hispanic Black	1184 (13.4)	1022 (13.8)	114 (10.0)	48 (22.7)	
Non-Hispanic Other/Multiracial	2289 (11.1)	1970 (11.4)	289 (10.0)	30 (7.7)	
Hispanic	2180 (25.0)	1911 (25.9)	256 (22.0)	13 (5.8)	
Child Overweight Status					0.026
No	16,630 (91.0)	14,225 (91.5)	2132 (87.8)	273 (86.9)	
Yes	1221 (9.0)	960 (8.5)	223 (12.2)	38 (13.1)	
Child Mental, Emotional, Developmental, or Behavioral Problem					<0.001
No	13,315 (77.0)	11,553 (78.8)	1590 (68.2)	172 (56.6)	
Yes	4536 (23.0)	3632 (21.2)	765 (31.8)	139 (43.4)	
Parent Education Level					<0.001
≤High school graduate/GED	2740 (27.6)	1990 (25.3)	607 (38.6)	143 (57.4)	
Some college	4378 (22.8)	3330 (21.0)	918 (33.1)	130 (33.8)	
>College degree	10,733 (49.6)	9865 (53.7)	830 (28.3)	38 (8.8)	
Family Structure					<0.001
2-parents, currently married	12,154 (63.4)	10,814 (65.8)	1241 (53.1)	99 (24.5)	
2-parents, not currently married	1257 (8.3)	902 (7.8)	302 (11.3)	53 (13.3)	
Single parent	3410 (21.0)	2698 (19.7)	603 (27.5)	109 (34.6)	
Other family type	1030 (7.3)	771 (6.7)	209 (8.2)	50 (27.6)	
Federal Poverty Level					<0.001
0–199%	5184 (40.7)	3956 (37.9)	1011 (53.7)	217 (82.5)	
200%–299%	2973 (15.9)	2445 (15.6)	474 (18.0)	54 (11.2)	
300%–399%	2581 (12.1)	2278 (12.7)	285 (9.6)	18 (3.2)	
≥400%	7113 (31.3)	6506 (33.8)	585 (18.7)	22 (3.0)	
Child Physical Activity ≥60 Minutes/Day					0.032
0 days/week	757 (5.8)	611 (5.6)	119 (6.7)	27 (9.8)	
1–3 days/week	6298 (37.7)	5330 (37.7)	857 (38.0)	111 (36.6)	
4–6 days/week	5590 (28.3)	4882 (29.1)	644 (24.1)	64 (19.1)	
7 days/week	5206 (28.2)	4362 (27.6)	735 (31.2)	109 (34.5)	
Child Screen Time Spent on Most Week Days					<0.001
<1 h/day	2125 (11.4)	1962 (12.3)	153 (6.8)	10 (2.1)	
1 h/day	4189 (22.3)	3716 (23.5)	444 (16.6)	29 (8.5)	
2 h/day	6129 (33.3)	5237 (33.9)	802 (29.9)	90 (27.1)	
3 h/day	3079 (18.1)	2525 (17.4)	480 (22.5)	74 (19.2)	
≥4 h/day	2329 (14.9)	1745 (12.9)	476 (24.3)	108 (43.2)	

Abbreviations: TSE, tobacco smoke exposure; SHS, secondhand smoke exposure; THS, thirdhand smoke exposure; NSCH, National Survey of Children's Health.
[a] n refers to raw sample size and % refers to weighted column percent unless otherwise noted.

Table 2
Associations of home TSE status with inadequate sleep <9 hours among U.S. school-aged children, 2018–2019 NSCH.

	Inadequate Sleep (<9 Hours)	Unadjusted Logistic Regression			Adjusted Logistic Regression[b]		
	n (%)[a]	OR	95% CI	p-value	AOR	95% CI	p-value
Child Home TSE Status							
No TSE at Home	4500 (33.5)	Ref	Ref	Ref	Ref	Ref	Ref
THS Exposure Only	967 (46.4)	1.71	1.43–2.06	<0.001	1.44	1.20–1.73	<0.001
SHS and THS Exposure	175 (61.0)	3.11	2.07–4.67	<0.001	1.83	1.20–2.78	0.005

Abbreviations: TSE, tobacco smoke exposure; SHS, secondhand smoke exposure; THS, thirdhand smoke exposure; NSCH, National Survey of Children's Health; Ref, reference group; OR, odds ratio; AOR, adjusted odds ratio; CI, confidence interval.
[a] n refers to raw sample size and % refers to weighted row percent.
[b] Logistic regression adjusting for child age, sex, race/ethnicity, overweight status, mental, emotional, developmental, or behavioral problem, parent education level, family structure, federal poverty level, child physical activity, and child screen time.

after adjusting for mother's education and family structure [18]. A British Columbia cohort study among 13-18-year-olds with SHS exposure suggests a dose–response relationship between SHS exposure and sleep duration frequencies. Specifically, as the frequency of SHS exposure in the past month increased by one category (ie, low SHS exposure defined as at least once in the past month, medium SHS exposure defined as at least once a week, high SHS exposure defined as every day or almost every day), nighttime sleep duration hours on weekdays and weekends decreased, even after adjusting for adolescent sociodemographics (ie, age, sex, ethnicity, family income level) and current cigarette smoking status [19]. Further, a large U.S. national study of adults found never or former smokers with reports of SHS exposure were more likely to have insufficient rest and sleep compared to never smokers with no

SHS exposure, even after adjusting for covariates of sociodemographics (ie, age, sex, race/ethnicity, education level, employment status), body mass index, exercise behavior, heavy alcohol drinking, and mental illness [20].

This is the first study, to our knowledge, to assess the associations between THS exposure only and inadequate sleep among a U.S. population-based sample of school-aged children. While more pronounced unadjusted odds were indicated in children exposed to SHS and THS exposure relative to children with no TSE at home, children who lived in homes in which indoor smoking was not allowed and were exposed to THS only were also at increased odds of having parent-reports of inadequate sleep <9 h. However, after adjustment for important covariates, effect sizes of children with THS exposure only and SHS and THS exposure were similar for inadequate sleep. Thus, exposure to SHS and/or THS constituents, including nicotine that has stimulating effects [5], may potentially influence school-aged children's sleep inadequacy. Our findings suggest that promoting parental smoking cessation is essential to fully protect children from SHS and THS exposure and related health risks such as inadequate sleep, especially since even minimal exposure can be hazardous to children's health [5]. Further, there are many negative physical and mental health consequences associated with inadequate sleep during the school-aged years, including but not limited to, daytime sleepiness [35], poor emotional regulation [32], poor academic achievement [36], obesity, and lower overall child well-being [7]. A systematic review on parental knowledge of children's healthy sleep behaviors found that parents with higher knowledge typically had children with healthier sleep practices [37]. Thus, it is also strongly encouraged to incorporate a parent education component into programming to educate parents on the potential for TSE to result in their children having inadequate sleep even if there are smoke-free rules, but THS exposure, in homes of smokers.

The study strengths include addressing a gap in the literature on home TSE, defined as exposure to SHS and/or THS, and inadequate sleep among U.S. school-aged children who participated in the most recent NSCH surveys. Meanwhile, several limitations should be noted. While we used combined 2018–2019 data, NSCH is a cross-sectional survey and longitudinal or causal associations to evaluate biologic plausibility between TSE status and inadequate sleep could not be ascertained. Parents are the respondents for the NSCH, and thus, parent-reports of the included variables may be underestimated or overestimated, especially on child TSE status and sleep hours due to social desirability bias. The NSCH includes two questions about household tobacco product use, and does not collect data on whether household members use noncombustible tobacco products (eg, electronic cigarettes) to determine children's exposure to secondhand and thirdhand aerosol. Future research should consider the additional assessment of noncombustible tobacco products given the current tobacco landscape where 4.5% of U.S. adults currently use electronic cigarettes [1]. Similarly, we were unable to assess cumulative child TSE from potential sources (eg, babysitter) and locations (eg, family cars) nor were able to assess whether children lived in close proximity to smokers who do not live with them, such as if they lived in multi-unit housing where THS can migrate between units [38]. Therefore, future research should consider comprehensive measures of reported child TSE as well as objective measures of TSE. Objectively measuring TSE could include using nicotine measurement via levels of cotinine, a nicotine metabolite commonly used to measure SHS and THS exposure, and hand nicotine [3], which is a promising marker to assess THS exposure in children's environments [39]. Future studies should also consider objectively assessing TSE pollutants that are present in their homes (eg, air monitoring) to examine which pollutants are associated with inadequate sleep patterns. However, it is important to note that the current findings on covariates associated with TSE aligns with other national research that used serum cotinine to measure TSE [40], suggesting that parent-reported measures used in this study are largely valid.

Due to the use of secondary, parent-reported data, we were unable to objectively measure sleep duration or other important sleep parameters (eg, sleep quality [41,42]) via polysomnography and actigraphy. The NSCH provided one categorical question on children's sleep hours on most weeknights; NSCH did not ask about sleep hours during school nights or weekend nights nor provided a quantitative variable for sleep hours. We were unable to assess child TSE status with excess sleep ≥12 h, another dimension of sleep duration with associated health risks during childhood [6,43]. Thus, the one NSCH measure on sleep hours may not have aligned with objectively measured or daily diary reports of sleep hours among children. Additionally, the time of year the survey was collected was not publicly available to allow for potential assessment of inadequate sleep patterns during the school academic months and summer months. Future research should consider obtaining these data during different times of year since children's inadequate sleep patterns may vary from the school academic months versus summer months versus other school breaks. Further, the NSCH does not collect data on diet, caffeine intake, and start times of schools, which are other covariates to consider for inadequate sleep among school-aged children [44–46]. The NSCH does not provide variables for child height, weight, or body mass index for children <10 years old, but we were able to account for parent-report of child overweight status in our analysis. Finally, we were unable to assess other potential confounders that should be included in future studies, including household or parent rules, such as limiting the amount of time children spend outside on school nights, which may account for TSE and inadequate sleep.

5. Conclusions

We examined the association between exposure to THS only and exposure to SHS and THS and inadequate sleep among a nationally representative sample of U.S. school-aged children. Compared to children who did not have TSE at home, we found that children exposed to THS only were at increased likelihood of inadequate sleep. We also found that children with SHS and THS exposure had even more pronounced increased odds of inadequate sleep than children with no TSE at home, but had similar odds to children with THS exposure only after accounting for important child covariates. Encouraging smoking cessation among parents and other household members is essential to shield children from TSE associated health consequences. Comprehensive school- and community-based interventions are highly encouraged to work towards the U.S. Healthy People 2030's child-related objectives of decreasing the proportion of children exposed to SHS, and increasing the proportion of children who get adequate sleep [47]. Parents and other adult household members should be involved in these initiatives, especially since they have an integral role of promoting healthy sleep behaviors in the child's home environment. For example, parents could be taught how to improve or maintain their child's sleep hygiene such as by avoiding daytime naps, decreasing screen time in the evening, and establishing a developmentally appropriate, routine sleep schedule to promote adequate sleep and decrease common sleep problems among children [48]. School-aged children could be taught about healthy sleep hygiene including limiting electronic screen time, especially before bed; the importance of having a standard bedtime routine and schedule; and the dangers of TSE and future tobacco use. While a prior systematic review on sleep education programs found that programs increased sleep knowledge, changes in sleep behaviors varied and

the majority of included studies focused on high schools versus elementary schools [49]. Thus, a multi-level approach is needed to educate families of elementary school children and early adolescents on the importance and benefits of not using tobacco products and to equip parents on how to eliminate all TSE from children's homes to improve children's overall health and sleep patterns. Prospective studies that use objectively measured TSE and sleep could provide further important information about how home TSE influences sleep duration and other sleep-related parameters among school-aged children over time.

Credit author statements

Ashley L. Merianos: Conceptualization, Methodology, Formal analysis, Writing – original draft, Funding acquisition; E. Melinda Mahabee-Gittens: Conceptualization, Writing – original draft, Funding acquisition; Kelvin Choi: Conceptualization, Methodology, Writing – review & editing.

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Conflict of interest

None.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: https://doi.org/10.1016/j.sleep.2021.08.012.

References

[1] Cornelius ME, Wang TW, Jamal A, et al. Tobacco product use among adults - United States, 2019. MMWR Morb Mortal Wkly Rep 2020;69(46):1736–42. https://doi.org/10.15585/mmwr.mm6946a4.
[2] Brody DJ, Lu Z, Tsai J. Secondhand smoke exposure among nonsmoking youth: United States, 2013-2016. NCHS Data Brief 2019;(348):1–8.
[3] Matt GE, Quintana PJ, Destaillats H, et al. Thirdhand tobacco smoke: emerging evidence and arguments for a multidisciplinary research agenda. Environ Health Perspect 2011;119(9):1218–26. https://doi.org/10.1289/ehp.1103500.
[4] King BA, Patel R, Babb SD, et al. National and state prevalence of smoke-free rules in homes with and without children and smokers: two decades of progress. Prev Med 2016;82:51–8. https://doi.org/10.1016/j.ypmed.2015.11.010.
[5] U.S Department of Health and Human Services. The health consequences of smoking–50 years of progress. A report of the Surgeon General. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health; 2014.
[6] Paruthi S, Brooks LJ, D'Ambrosio C, et al. Consensus statement of the American Academy of Sleep Medicine on the recommended amount of sleep for healthy children: methodology and discussion. J Clin Sleep Med 2016;12(11):1549–61. https://doi.org/10.5664/jcsm.6288.
[7] Chaput J, Gray CE, Poitras VJ, et al. Systematic review of the relationships between sleep duration and health indicators in school-aged children and youth. Appl Physiol Nutr Metabol 2016;41(6 Suppl 3):S266–82. https://doi.org/10.1139/apnm-2015-0627.
[8] Cassoff J, Bhatti JA, Gruber R. The effect of sleep restriction on neurobehavioural functioning in normally developing children and adolescents: insights from the attention behaviour and sleep laboratory. Pathol Biol 2014;62(5):319–31. https://doi.org/10.1016/j.patbio.2014.05.017.
[9] Astill RG, Van der Heijden KB, Van Ijzendoorn MH, et al. Sleep, cognition, and behavioral problems in school-age children: a century of research meta-analyzed. Psychol Bull 2012;138(6):1109–38. https://doi.org/10.1037/a0028204.
[10] Dewald JF, Meijer AM, Oort FJ, et al. The influence of sleep quality, sleep duration and sleepiness on school performance in children and adolescents: a meta-analytic review. Sleep Med Rev 2010;14(3):179–89. https://doi.org/10.1016/j.smrv.2009.10.004.
[11] Davila DG, Hurt RD, Offord KP, et al. Acute effects of transdermal nicotine on sleep architecture, snoring, and sleep-disordered breathing in nonsmokers. Am J Respir Crit Care Med 1994;150(2):469–74. https://doi.org/10.1164/ajrccm.150.2.8049831.
[12] Gillin JC, Lardon M, Ruiz C, et al. Dose-dependent effects of transdermal nicotine on early morning awakening and rapid eye movement sleep time in nonsmoking normal volunteers. J Clin Psychopharmacol 1994;14(4):264–7.
[13] Choi J, Lee YG, Jeong D. Transdermal nicotine patch effects on EEG power spectra and heart rate variability during sleep of healthy male adults. Psychiatr Investig 2017;14(4):499–505. https://doi.org/10.4306/pi.2017.14.4.499.
[14] Jara SM, Benke JR, Lin SY, et al. The association between secondhand smoke and sleep-disordered breathing in children: a systematic review. Laryngoscope 2015;125(1):241–7. https://doi.org/10.1002/lary.24833.
[15] Montgomery-Downs HE, Gozal D. Snore-associated sleep fragmentation in infancy: mental development effects and contribution of secondhand cigarette smoke exposure. Pediatrics 2006;117(3):e496–502. https://doi.org/10.1542/peds.2005-1785.
[16] Montaldo L, Montaldo P, Caredda E, et al. Association between exposure to secondhand smoke and sleep bruxism in children: a randomised control study. Tobac Contr 2012;21(4):392–5. https://doi.org/10.1136/tobaccocontrol-2011-050217.
[17] Yolton K, Xu Y, Khoury J, et al. Associations between secondhand smoke exposure and sleep patterns in children. Pediatrics 2010;125(2):e261–8. https://doi.org/10.1542/peds.2009-0690.
[18] Johansson A, Ludvigsson J, Hermansson G. Adverse health effects related to tobacco smoke exposure in a cohort of three-year olds. Acta Pædiatrica 2008;97(3):354–7. https://doi.org/10.1111/j.1651-2227.2007.00619.x.
[19] Schwartz J, Bottorff JL, Richardson CG. Secondhand smoke exposure, restless sleep, and sleep duration in adolescents. Sleep Disorder 2014;2014:374732. https://doi.org/10.1155/2014/374732.
[20] Sabanayagam C, Shankar A. The association between active smoking, smokeless tobacco, second-hand smoke exposure and insufficient sleep. Sleep Med 2011;12(1):7–11. https://doi.org/10.1016/j.sleep.2010.09.002.
[21] Xu X, Liu D, Zhang Z, et al. Sleep duration and quality in pregnant women: a cross-sectional survey in China. Int J Environ Res Publ Health 2017;14(7):817. https://doi.org/10.3390/ijerph14070817.
[22] Ohida T, Kaneita Y, Osaki Y, et al. Is passive smoking associated with sleep disturbance among pregnant women? Sleep 2007;30(9):1155–61. https://doi.org/10.1093/sleep/30.9.1155.
[23] Nakata A, Takahashi M, Haratani T, et al. Association of active and passive smoking with sleep disturbances and short sleep duration among Japanese working population. Int J Behav Med 2008;15(2):81–91. https://doi.org/10.1080/10705500801929577.
[24] Child and Adolescent Health Measurement Initiative, 2018-2019 National Survey of Children's Health (2 years combined data set). Data resource center for child and adolescent health supported by cooperative agreement from the U.S. Department of health and human services, health resources and services administration, maternal and child health bureau. 2021.
[25] U.S. Census Bureau. National survey of children's health methodology report. Available at: https://www.childhealthdata.org/learn-about-the-nsch/methods; 2018. Updated 2019.
[26] U.S. Census Bureau. National survey of children's health methodology report. Available at: https://www2.census.gov/programs-surveys/nsch/technical-documentation/methodology/2019-NSCH-Methodology-Report.pdf; 2019. Updated 2020.
[27] Child and Adolescent Health Measurement Initiative. 2018-2019 National Survey of Children's Health (2 years combined data set): child and family health measures, National performance and outcome measures and subgroups et al. Data resource center for child and adolescent health supported by cooperative agreement U59MC27866 from the U.S. Department of health and human services, health resources and services administration, maternal and child health bureau. 2021. version 1.0.
[28] Brooks T, Wagnerman K, Artiga S, et al. Medicaid and CHIP eligibility, enrollment, and cost sharing policies as of January 2018: findings from a 50-state survey. The Henry J. Kaiser Family Foundation; 2018. Available at: https://files.kff.org/attachment/Report-Medicaid-and-CHIP-Eligibility-Enrollment-Renewal-and-Cost-Sharing-Policies-as-of-January-2018. Updated 2018.

[29] Brooks T, Roygardner L, Artiga S. Medicaid and CHIP eligibility, enrollment, and cost sharing policies as of January 2019: findings from a 50-state survey. The Henry J. Kaiser Family Foundation; 2019. Available at: https://files.kff.org/attachment/Report-Medicaid-and-CHIP-Eligibility-Enrollment-Renewal-and-Cost-Sharing-Policies-as-of-January-2019. Updated 2019.
[30] Miller MA, Kruisbrink M, Wallace J, et al. Sleep duration and incidence of obesity in infants, children, and adolescents: a systematic review and meta-analysis of prospective studies. Sleep 2018;41(4). https://doi.org/10.1093/sleep/zsy018. 10.1093/sleep/zsy018.
[31] Li L, Zhang S, Huang Y, et al. Sleep duration and obesity in children: a systematic review and meta-analysis of prospective cohort studies. J Paediatr Child Health 2017;53(4):378–85. https://doi.org/10.1111/jpc.13434.
[32] Belmon LS, van Stralen MM, Busch V, et al. What are the determinants of children's sleep behavior? A systematic review of longitudinal studies. Sleep Med Rev 2018;43:60–70. https://doi.org/10.1016/j.smrv.2018.09.007.
[33] LeBourgeois MK, Hale L, Chang A, et al. Digital media and sleep in childhood and adolescence. Pediatrics 2017;140(Suppl 2):S92–6. https://doi.org/10.1542/peds.2016-1758J.
[34] Gregory AM, Sadeh A. Sleep, emotional and behavioral difficulties in children and adolescents. Sleep Med Rev 2012;16(2):129–36. https://doi.org/10.1016/j.smrv.2011.03.007.
[35] Moreira GA, Pradella-Hallinan M. Sleepiness in children: an update. Sleep Med Clin 2017;12(3):407–13. https://doi.org/10.1016/j.jsmc.2017.03.013.
[36] Berger RH, Diaz A, Valiente C, et al. Sleep duration moderates the association between children's temperament and academic achievement. Early Educ Dev 2018;29(5):624–40. https://doi.org/10.1080/10409289.2017.1404884.
[37] McDowall PS, Galland BC, Campbell AJ, et al. Parent knowledge of children's sleep: a systematic review. Sleep Med Rev 2017;31:39–47. https://doi.org/10.1016/j.smrv.2016.01.002.
[38] Matt GE, Quintana PJE, Hoh E, et al. Persistent tobacco smoke residue in multiunit housing: legacy of permissive indoor smoking policies and challenges in the implementation of smoking bans. Prev Med Rep 2020;18:101088. https://doi.org/10.1016/j.pmedr.2020.101088. Published 2020 Apr 2.
[39] Mahabee-Gittens EM, Merianos AL, Jandarov RA, et al. Differential associations of hand nicotine and urinary cotinine with children's exposure to tobacco smoke and clinical outcomes. Environ Res 2021;202:111722. https://doi.org/10.1016/j.envres.2021.111722.
[40] Merianos AL, Jandarov RA, Choi K, et al. Tobacco smoke exposure disparities persist in U.S. children: NHANES 1999–2014. Prev Med 2019;123:138–42. https://doi.org/10.1016/j.ypmed.2019.03.028.
[41] Ohayon M, Wickwire EM, Hirshkowitz M, et al. National Sleep Foundation's sleep quality recommendations: first report. Sleep Health 2017;3(1):6–19. https://doi.org/10.1016/j.sleh.2016.11.006.
[42] So CJ, Palmer CA, Gonzalez RD, et al. Which objective sleep elements predict children's perceptions of good sleep quality? A preliminary investigation based on polysomnography and actigraphy. Sleep Health 2021;7(1):65–71. https://doi.org/10.1016/j.sleh.2020.07.001.
[43] Hirshkowitz M, Whiton K, Albert SM, et al. National Sleep Foundation's updated sleep duration recommendations: final report. Sleep Health 2015;1(4):233–43. https://doi.org/10.1016/j.sleh.2015.10.004.
[44] Vander Wyst KB, Whisner CM, Reifsnider E, et al. The combined impact of sleep and diet on adiposity in infants, toddlers, and young children: a systematic review. J Dev Behav Pediatr 2019;40(3):224–36. https://doi.org/10.1097/DBP.0000000000000636.
[45] Owens JA, Mindell J, Baylor A. Effect of energy drink and caffeinated beverage consumption on sleep, mood, and performance in children and adolescents. Nutr Rev 2014;72(Suppl 1):65–71. https://doi.org/10.1111/nure.12150.
[46] Zhang J, Li AM, Fok TF, et al. Roles of parental sleep/wake patterns, socioeconomic status, and daytime activities in the sleep/wake patterns of children. J Pediatr 2010;156(4):606–12. https://doi.org/10.1016/j.jpeds.2009.10.036. e5.
[47] U. S. Department of Health and Human Services. Healthy People 2030: children objectives. Available at: https://health.gov/healthypeople/objectives-and-data/browse-objectives/children. Updated 2021.
[48] Bhargava S. Diagnosis and management of common sleep problems in children. Pediatr Rev 2011;32(3):91–9. https://doi.org/10.1542/pir.32-3-91.
[49] Rigney G, Watson A, Gazmararian J, et al. Update on school-based sleep education programs: how far have we come and what has Australia contributed to the field? Sleep Med 2021;80:134–57. https://doi.org/10.1016/j.sleep.2021.01.061.