Adolescent substance use and its association to sleep disturbances: A systematic review[☆,☆☆]

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ABSTRACT

Purpose: To identify adolescents' substance use and its association to sleep disturbances.
Methods: Databases were searched using terms: "smoking", "tobacco use", "electronic cigarette", "alcohol drinking", "marijuana use" and "substance use" combined with "sleep" and "adolescents". Articles were selected based on: adolescents residing in North America, aged between 10 and 21 years old, examining substance use and sleep disturbances as a dependent variable, and published within 10 years. The Buysse's *sleep health* RuSATED framework was used for analysis.
Results: Thirteen articles were reviewed establishing the relationship between tobacco, alcohol and marijuana use and sleep disturbances. Positive associations were reported between all substances used and sleep disturbances in sleep health domains of Regularity, Timing, Efficiency, and Duration. Alertness problems were also positively associated with tobacco and alcohol use. The most common disturbance reported was the insufficient sleep Duration. The least reported deficiencies were Satisfaction and Alertness.
Conclusions: Evidence for associations between substance use and sleep disturbances in Regularity, Timing, Efficiency, and Duration domains may result in sleep deprivation, which poses a serious health risk among growing adolescents. Future research should prospectively examine disturbances in all sleep health domains including Satisfaction and Alertness with the addition of more objective sleep measures to assess long term effects of sleep deprivation in this population.
Implications and contributions: Understanding the adolescents' substance use in relation to their sleep disturbance with sleep as a dependent variable, provides future direction for sleep health promotion in adolescents with substance use to prevent further health consequences.

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Sleep health is vital for all age groups. Yet, adolescents, in particular, require an adequate amount and quality of sleep as a prerequisite to their mental and physical well-being, and quality of life.[1,2] However, currently 60–70% of adolescents do not obtain enough sleep on school nights in the United States (US),[3] and about 10% of young adults (ages 19–24) experience insomnia.[4] Among adolescents, when substance use and sleep disturbances co-occur, further exploration of the relationship is warranted.[5]

Substance use among adolescents may contribute to sleep pattern changes and subsequent chronic sleep loss. As a result, sleep deprivation occurs, which influences adolescents' physical, mental, emotional and social development, including brain maturation and decision-making skills.[6] Sleep deprivation also produces excessive daytime sleepiness, performance decline, increased impulsivity, and irritability in mood, which impacts adolescent behavioral and emotional development.[2,7] Moreover, inadequate sleep and substance use, separately, modulate

the onset of psychiatric conditions such as anxiety and depressive symptoms.[8,8]

Adolescence is a vulnerable time when a relatively high prevalence of youths engage in substance use of tobacco, alcohol or marijuana either experimentally or recreationally.[10,11] In 2017, approximately 3.6 million US middle and high school students reported using of tobacco products with a steep increase in the use of electronic cigarettes (e-cigarettes).[12] Ogeil and Phillips reported in a study of adolescents that nicotine dependence was associated with poor sleep quality and increased use of sleep medication and sleep disturbances.[13]

In adults, alcohol use initially causes sleep-inducing effects by depressing brain activities; however, during sleep, alcohol induces a stimulating effect, which disturbs normal sleep stages resulting in sleep fragmentation and early morning awakenings (EMA).[14] Similar findings have been described in a nationally representative survey of adolescents and young adults (National Longitudinal Study of Adolescent Health) ($n = 14,089$) where Popovici et al. observed that adolescent alcohol use, specifically binge drinking, was positively and significantly associated with sleep disturbances such as difficulty initiating sleep (DIS), difficulty maintaining sleep (DMS), and snoring/sleep apnea.[15] Furthermore, adolescent marijuana use was associated with sleep disturbances such as sleep loss, poor sleep quality (increased sleep latency and reduced slow wave sleep), and vulnerability to the sleep deprivation effects.[16]

Given the value of sleep health in adolescent development, it is vital to systematically review the literature on the relationship between substance uses and sleep disturbances in adolescents and young adults in the US to understand the scope of the problem. Adolescents around the globe have varied social and environmental aspects related to substance use and sleep health. For example, Eastern Asian countries such as Japan and Korea report shorter sleep duration than the West.[17] Adolescents' substance use and sleep health may vary due to the influence of cultures, gender roles, legal age limit, access to substances, social expectations, and other health risk-taking behaviors, which all play a role in shaping their sleep–wake cycle. Due to these variations, the current review will limit focus to the association of adolescents' substance use and sleep disturbances specific to the continental region: North America (US and Canada).

In adolescents, the variances between the weekday and weekend bed time and the number of hours slept have been extensively studied.[18–20] However, the ease of initiating or maintaining sleep or the perceived satisfaction of their sleep need to be further explored. To address the multiple factors related to healthy sleep and the association between substance use and sleep disturbances, the current review uses the Buysse's framework of *sleep health*[21] to recognize measurable characteristics of sleep among adolescent who use substances. The *sleep health* framework provides fundamental targets for health promotion and prevention activities for all age group using six dimensions of sleep (RuSATED): **R**egularity, **S**atisfaction, **A**lertness (during waking hours), **T**iming, **E**fficiency, and **D**uration.[22] By using the *sleep health* framework, the multidimensional pattern of sleep-wakefulness will be explored to guide our understanding of the association between substance use and sleep disturbances among adolescents when sleep is a dependent variable, with the long term goal of promoting adolescent sleep health.[21]

The key public health concern for adolescents in North America is the presence of both substance use and sleep disturbances.[23] Although previous studies among the adolescent population reported that quality of sleep has significant association with the use of tobacco, alcohol, and other substances,[23,24] there is limited understanding of this relationship. Hence, this review focuses on the association of substance use and sleep disturbances when sleep is a dependent variable. To our knowledge, apart from one clinical review article,[10]

there are no systematic reviews conducted that explore adolescents' substance use in relation to their sleep disturbance and sleep health. Thus, this systematic review aims to a) identify adolescents' substance use and its association to sleep disturbances evaluating with Buysse's *sleep health* framework, and b) describe the methodological limitations and gaps of literature of the relationship between this phenomena of the reviewed studies.

Methods

This review follows the protocol of Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) for systematic reviews.[25] Based on the purpose of the study, inclusion and exclusion criteria are described below and the literature search process is shown in Fig. 1.

Search strategy

Studies were selected from searches in four major electronic databases: PubMed, the Cumulative Index of Nursing and Allied Health Literature (CINAHL), Web of Science, and PsycINFO. Medical subject headings (MeSH terms [mh]) and other search terms included: "smoking"[mh], "tobacco use"[mh], "tobacco"[mh], "electronic cigarette", "electronic nicotine delivery systems"[mh], "alcohol drinking"[mh], "marijuana use"[mh], and "substance use" combined with "sleep"[mh]. Terms "adolescents" [mh] or "students"[mh] were combined to grasp broader target population. The population was limited to adolescents aged between 10 and 21 years old. Initial search was conducted from September to October 2017, and additional search was completed in September 2018.

Eligibility criteria

Studies were included if: (i) they were written in English, and published in a peer-reviewed journal in the past 10 years; (ii) the population studied consisted of adolescents aged 10 to 21 years old residing in North America (US or Canada); (iii) examined substance use including any combination of tobacco products (cigarettes and/or electronic cigarettes), alcohol, and/or marijuana (independent variables), and their associations with sleep disturbances (dependent variable) during adolescence. Studies were excluded if they involved: (i) the age of participants not specified or reported; (ii) treated sleep (independent variable) as moderator for substance use behaviors; (iii) participants were evaluated on the indirect effect of smoking such as second-hand smoking; (iv) explored sleep or substance use behaviors separately; (v) focused on the caffeine or soda consumption; (vi) gray literature including dissertation, conference proceeding paper, abstract, or editorials; and (vii) focused on testing specific smoking cessation or substance use intervention programs.

This study includes ages between 10 and 21 years old to provide a comprehensive understanding of substance use on sleep health in broad range of adolescence. Various definitions of adolescence exist as the adolescent is historically referred from 12 to 18 years of age, and with those aged 18 to 21 as late adolescent or young adult.[26,27] However, American Academy of Pediatrics defines adolescent from 11 to 21 years old,[28] and World Health Organization defines adolescent from 10 to 19 years old.[29] Accordingly, in this review, we used an inclusion criteria for those who were 10 to 21 years old to grasp a broader age range and thus, provide a deeper understanding of the unique characteristics of sleep among these sub-populations in the North America region.
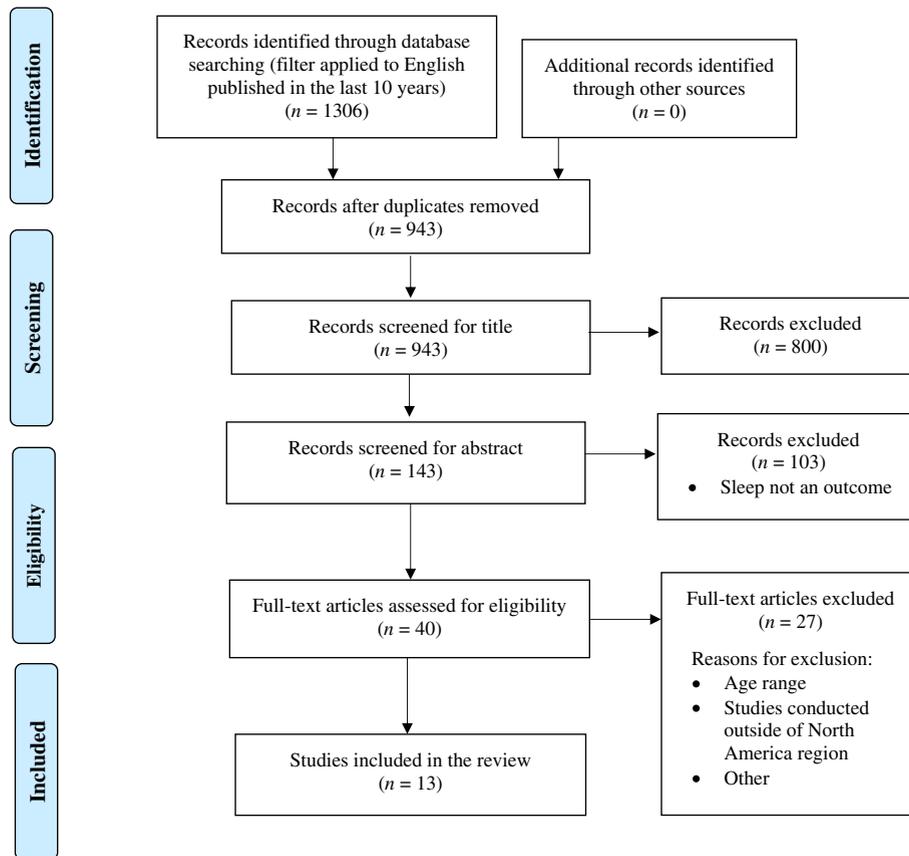
Fig. 1. PRISMA flow diagram for the identification, screening, eligibility, and inclusion of studies.

Data extraction and synthesis

The primary author initially reviewed all study titles and abstracts based on the eligibility criteria and identified potentially relevant articles. After reading articles in full text, data were extracted and organized into literature matrix tables. The coding by the primary coder was double-checked by the secondary and third coder.

Sleep health framework

Six dimensions (**RuSATED**) identified in Buysse's *sleep health* framework were used to provide a comprehensive understanding of the associations between substance use and sleep disturbances in the context of sleep health.[22] Framework dimension are defined as follows: '**R**egularity' is the consistency in the pattern of going to sleep and waking up across both weekdays and weekends; '**S**atisfaction' is the subjective reporting of good verses bad sleep and other problems related to sleep (sleep quality); '**A**lertness during waking hours' is the ability to maintain attentive wakefulness and not to experience decreased daytime functioning; '**T**iming' is the placement of sleep within the 24-hour day; '**E**fficiency' is the ease of initiating and/or maintaining sleep (that includes DIS, DMS, EMA and Pittsburgh Sleep Quality Index [PSQI] measures of sleep onset latency [SOL], wake after sleep onset [WASO] and sleep efficiency [SE = time in bed/total sleep time*100]); and '**D**uration' is the total number of hours of sleep obtained per 24 hours.

Quality assessment

Studies were examined to evaluate the methodological quality for ensuring internal and external validity. The authors followed the Agency for Healthcare Research and Quality (AHRQ) quality evaluation guidelines to evaluate the included observational studies.[30] Adopting the assessment criteria addressed by AHRQ, the following domains were evaluated: study question; study population; outcome measure; statistical analysis; results; and discussion. Domains were evaluated on whether the study authors fully addressed (marked with ●), partially addressed (◐), or failed to address (○) each domain and its subcomponents. Detailed description of each domain is provided in the Table 4. Two authors independently assessed the quality of the included articles and any disagreements encountered were resolved through discussion and consensus. With this process, major gaps and methodological limitations were reported.

Results

A total of 13 studies were identified evaluating substance use (tobacco, and/or alcohol, and/or marijuana) among adolescents in the North America region where sleep disturbance was a dependent variable. All of the studies were conducted in the US with an exception of one in Canada.[31] The sample size in the studies ranged from 42 to 26,205 (total *n* = 42,842); adolescents in the age ranges between 10 and 22 years old, with half of the studies consisting of students from secondary schools.[31–35] Although one of the inclusion criteria was to limit the age to 21 years old, four studies that included 22 years olds adolescents (mean age below 21 years old) were included in this review.[36–39] This following exception to the four studies was made to provide valuable information within the sub-group of late adolescents, consisting of those newly graduated secondary school students in a college setting.

Detailed characteristics of study participants, and the prevalence and measures of substance uses (tobacco, alcohol, and marijuana)

are described in Table 1. While most studies used the definition of the current substance use in the past 30 days as recommendation by the CDC,[40,41] the included studies used various substance use measures (table 1). In the current study, the prevalence of substance use for adolescents (10–18 years) and late adolescents (19–22 years) was observed in the ranges of 11.7 to 35.8% and 32 to 65%, respectively. While the majority of the studies did not provide differential dose–response relationship nor details about how adolescent used substances, Fucito et al. found significantly shorter sleep duration among the late adolescents who tended to report more frequent heavy drinking.[37] Moreover, there was a significant difference between the numbers of smoking occasions on subsequent recent DIS among the high school students.[33] Four studies evaluated sleep for all of three substances used[35,42–44]; three studies for smoking and alcohol use[31,33,36]; four studies for alcohol use only[32,37–39]; and two studies[34,45] for tobacco use only. All reviewed studies used descriptive quantitative study designs with the majority being cross-sectional, and 31% (n = 4) were longitudinal studies that examined the relationship between adolescent substance use and sleep disturbances.[31–33,43]

Table 3 provides a detailed description of the sleep disturbances and related *sleep heath* dimensions included in this review. The majority of the studies reported sleep duration issues (Duration), while 46% (n = 6) also reported other characteristics such as sleep quality (i.e., daytime functioning (Alertness) and the prevalence of sleep problems (i.e., DIS, DMS, EMA) (Efficiency). Two studies used PSQI to evaluate the sleep quality (Satisfaction)[37,45]; two studies assessed sleep disturbances using either Sleep Problem Scale (SPS)[36] or the Sleep Problem Questionnaire (SPQ)[42]; and for others, sleep patterns of onset and offset (Timing) were used. Two studies examined the gender differences[35,39] and two on racial differences[33,44] in average hours of sleep per night.

Tobacco use and sleep health

Table 2 summarizes the nine studies[31,33–36,42–45] that examined the association between tobacco use and sleep disturbances. Among these studies, the number of smoking occasions in the past 30 days was associated with greater sleep problems such as subsequent recent and chronic DIS (Efficiency),[33,42] shorter total hours of sleep in a week (Duration),[35,43] later sleep onset and offset (Timing),[45] and difficulty in daytime functioning (Alertness).[45] While the majority of studies reported that the current tobacco use was significantly associated with sleep disturbances, one of the longitudinal studies found no effect between initiating tobacco use with the sleep duration.[31]

In two studies, e-cigarette and chewing tobacco were evaluated.[34,35] One study compared cigarette users, e-cigarette users, dual users, and non-users, and found that those adolescents who used e-cigarettes tended to have shorter total sleep time on weekends compared to non-users, but there was no association between the frequency of e-cigarette use and weekday sleep time.[34] In the second study of rural adolescents, current smokers tended to sleep fewer hours than never-users; however, this was not found among the users of chewing tobacco.[35]

Table 3 outlines tobacco use and *sleep health* dimensions. Positive associations were found with sleep disturbances in the dimensions of Alertness, Timing, Efficiency, and Duration; in particular, they were tired upon awakening, had daytime dysfunction, later sleep onset and offset, and greater problems with sleep efficiency and shorter sleep duration. Regularity was not examined except for shorter weekend sleep hours for e-cigarette users. There were no associations with Satisfaction (i.e., weekday sleep quality) related to e-cigarette,[34] and Duration related to tobacco use[31] and chewing tobacco.[35]

Alcohol use and sleep health

Eleven studies[31–33,35–39,42–44] provided an explanation of how substance use, specifically the alcohol use among adolescents correlated with their sleep disturbances. The consumption of alcohol and heavy drinking were associated with sleep disturbances in all six dimensions of *sleep health* (i.e., Regularity, Satisfaction, Alertness, Timing, Efficiency, Duration) (Table 3). Evidence of shorter sleep duration (Duration) was found in six studies.[31,32,35,37,39,43] Insufficient sleep (Duration) was associated with those who reported alcohol use compared to those who did not,[35,37,39] and a longitudinal study also found a decreased likelihood of having sufficient sleep among alcohol users particularly those who were binge drinkers.[31]

Alcohol use was associated with a later sleep–wake schedule (Regularity), which in turn was associated with the increase in the daytime sleepiness (Alertness).[39] Adolescents who reported sleep problems were also more likely to report that their sleep difficulties brought about negative consequences on their life, or that they used alcohol in order to initiate sleep.[42] These findings were consistent with those who used alcohol mixed with energy drinks with the reporting having greater sleep problems (i.e., DIS, DMS, WASO, waking up tired) (Efficiency).[36] One study found significant relationship between heavy drinkers with having shorter sleep duration; however, this was not found in within-person sleep duration, number of minutes awake, or ratings of self-perceived sleep quality of alertness upon awakening.[37] In addition, the increased alcohol consumption was associated with the later sleep onset and offset (Timing), but only one study reported that there was no significant association between total sleep hours with their alcohol use.[38] Greater sleep problems with less satisfaction (low Satisfaction) were reported in one study among those that used alcohol mixed with energy drinks.[36]

Marijuana use and sleep health

Four studies[35,42–44] reported relationship between marijuana use and sleep disturbances. Current marijuana use was positively associated with more weekend sleep and total sleep in 1 week (Regularity)[43]; greater oversleep during weekend compared to weekdays and more total sleep in a week (Duration)[43]; DIS and DMS (Efficiency issues); and waking up feeling tired and worn out (Alertness issues).[42,44] No studies reported findings about the dimension on the Satisfaction and Timing. There was no negative or null associations between substance use and sleep disturbances found among included studies.

Summary of methodological issues

Table 4 summarizes the results of the quality appraisal. The most common deficit was related to the measurement because most studies only used subjective measures by using sleep diary, self-reported questionnaires or surveys, and only one added objective sleep measures using Actigraphy.[37] Moreover, most studies did not provide information on the reliability or validity of the instruments used. Study population data descriptions were not detailed, and explicit inclusion and exclusion criteria were not provided for over half of the studies.[31,32,34,35,37,39,45] In addition, there were issues related to sampling where only two studies used stratified sampling,[32,44] and most studies did not report random sampling techniques. Moreover, several did not report the sampling techniques used.[32,37,38] Although many studies consisted of fairly large sample sizes, most studies were exploratory in design which explains the likeliness of utilizing non-probability sampling method. This may be a threat of external validity, which indicates mixed and limited generalizability of findings to the population. Most studies were cross-sectional studies.

Table 1
Summary of study participants, characteristics of sleep and substance use behaviors.

Author(s)/ Year/ Title	N	Characteristics of study participants					
		Age range/ mean	Demographics	Sleep behavioral characteristics	Prevalence of substance use		
					Tobacco	Alcohol	Marijuana
Fucito et al., (2018)[37]	42	18–22 y (mean age 20.52, SD = 1.31)	Female (48%); mostly White/Caucasian (69%), university students reporting concerns about their sleep and at least one occasion of heavy drinking in the past month	•Overall poor sleep quality = average Pittsburgh Sleep Quality Index (PSQI) global score of 11.81 (SD = 2.35)	n/a	•Average no. of drinks consumed in a typical drinking week = 18.7 (SD = 13.56); heaviest drinking week = 27.8 (SD = 22.19)	n/a
Haynie et al. (2018)[32]	2497	10th–12th grade	Female (55%), mostly White/Caucasian (62%), from a nationally representative cohort of secondary school students	•Mean no. of hours slept during scheduled school day across all waves = 7.58 •Mean no. of hours slept during non-school day across all waves = 9.26 •Average chronotype = 04:30 am •Mean range of discrepancy hours between weekday and weekend sleep = 2 h 24 min - 2 h 48 min	n/a	•35.8% = consumed alcohol/past mo 25.6% = ever heavy episodic drinking (≥5 for boys or ≥4 for girls drinks in a row on an occasion /past mo (mean across all 3 waves)	n/a
Patte & Leatherdale. (2018)[31]	26,205	9th–12th grade	Female (55%), mostly White/Caucasian (71%), secondary school students	•46% = reported having insufficient sleep (<8 h) per day	•1.9% = current cigarette smokers	•13% = consumed ≥5 drinks on one occasion / past y	n/a
Bellatorre et al. (2017)[33]	1394	10th–12th grade	Non-Hispanic Black (28.6%): female (61.9%), mean BMI (25.1 ± 6.15), snoring or sleep apnea (31.1%) Non-Hispanic White (71.4%): female (54.2%), mean BMI (24.3 ± 5.45), snoring or sleep apnea (29.1%) from a nationally representative cohort of students	•Mean no. of times trouble falling asleep in the past mo by Non-Hispanic Blacks (mean of three waves) = 2.14; Non-Hispanic Whites = 2.43 •Mean no. of times trouble staying asleep in the past mo by Non-Hispanic Blacks (mean of three waves) = 2.21; Non-Hispanic Whites = 2.25 •Mean no. of sleep duration hours on weekdays for Non-Hispanic Blacks =7.27; Non-Hispanic Whites = 7.61 (mean across 3 waves) •Mean no. of sleep duration hours on weekends for non-Hispanic Blacks = 9.16; Non-Hispanic Whites = 9.25 (mean across 3 waves) •Snoring or sleep apnea by non-Hispanic Blacks = 31.1%; non-Hispanic Whites = 29.1% (at wave 1)	•Mean no. of occasions smoked/ past mo by Non-Hispanic Blacks = 1.12 (mean across 3 waves) •Mean no. of occasions smoked/ past mo by Non-Hispanic Whites = 1.75 (mean across 3 waves)	•25.3% = consumed alcohol/past mo among non-Hispanic Black •34.4% = consumed alcohol/past mo among non-Hispanic White	n/a
Bonar et al. (2017)[36]	560	Mean 19.57 y (SD = 1.75)	Female (67%), mostly White/Caucasian (82.3%), university students	•Reported relatively low levels of sleep problems	•13.4% = current cigarette smokers	•32% = ever consumed alcohol mixed with energy drinks	n/a
Dunbar et al. (2017)[34]	2488	Mean 17 y (SD = 0.67)	Female (54%), mostly Hispanic (47%), secondary school students	•None reported	•21% = used electronic cigarettes/past y •12% = used cigarettes/past y	n/a	n/a

Study	N	Age	Sample	Sleep	Cigarette/tobacco	Alcohol	Marijuana/drugs
Bilsky et al. (2016)[45]	94	12–17 y	Female (44%); mostly White/Caucasian (88.2%) in a community setting reporting ever tried cigarette smoking	•None reported	•100% = current smokers (27.6% = triers; 24.5% = experimenters; 15.9% = regular smokers; 31.9% = daily smokers)	n/a	n/a
Reichenberger et al. (2016)[35]	322	14–19 y	Female (44.4%), secondary school students living in a rural area	•Average hours of sleep/d = 8.02 h •Male tended to go to bed later than girls •Being in a higher grade associated with later bedtimes	•20% = current cigarette smoker •18% = chewing tobacco use/past mo	•29% = drank alcohol /past mo •61% of those who drank reported >5 drinks in 1 h/past mo	•6% = marijuana use/past mo •1.3% = use of other illicit drugs/past mo
Van Reen et al. (2016)[38]	878	18–22 y (mean age 18.6)	Female (66%) first-year college students in a university setting	•Average no. of hours/d = 7 h and 15 min	n/a	•63.0% = alcohol use/past 6 mo •37.0% = non-alcohol drinkers	n/a
Zhabenko et al. (2016)[42]	1852	14–20 y	Female (58.7%), mostly White (73.6%), receiving public assistance (27.4%), dropped out of school (3.8%) presented at the emergency room in a community setting	•37.6% = reported sleep difficulties affected their daytime functioning/past mo	•27.3% = current cigarette smoker	•27.2% = unhealthy alcohol use (>3 drinks for ages 14–17, >4 drinks for ages 18–20)/past y •4.0% = use alcohol to get to sleep	•31.2% = Marijuana use.
Pasch et al. (2012)[43]	704	10–17 y (mean age 14.7)	Female (51%), mostly non- White/Caucasian (86%) receive free/reduced cost lunch (12%); in a community setting	•Average weekday hours of sleep/d = 8.26 •Average weekend hours of sleep/d = 9.62 •Average hours of total week sleep = 60.50 •Weekend sleep delay = 1.52 •Weekday sleep delay = 2.89	•5.1% = current cigarette smoker	•11.7% = ≥1 times alcohol use/past mo	•3.1% = ≥1 time marijuana use/past mo
Perez et al. (2010)[44]	5570 (US: 4901; Mexico: 669)	14–16 yrs	9th grade students; Hispanic (100%) residing on the border of US-Mexico community	•36% = reported prevalence of disturbed sleep (difficulty initiating and maintaining sleep, early morning awakening) among Mexican sample; 28% = in US sample	•Yes (descriptive not provided)	•Yes (descriptive not provided)	•Yes (descriptive not provided)
Singleton & Wolfson. (2009)[39]	236	18–22 y	Female (52.5%), mostly White/Caucasian (89%) undergraduate students living on-campus (82%) in a university setting	•24% = reported getting the recommended 8.4 hours of sleep on weekday nights •79% = reported average weekday bedtimes after midnight (mean 1:06 AM) •90% = reporting going to bed after 1 AM on the weekends (mean 2:45 AM) •Female's average sleep midpoint was 18 min Earlier than of male's •Females reported higher levels of daytime sleepiness than male	n/a	•15% = reported abstained from drinking •> 65% = reported drinking at least 1–2 times/wk Average no. of drinks consumed on a typical weekend night = 5.57 (SD = 3.96)	n/a

Note. BMI = body mass index; no. = number; PSQI = Pittsburgh Sleep Quality Index; US=United States.

Table 2
Overview of study characteristics.

Author (year)	Study aims	Research design and sampling	Data collection	Measurement/ instrument (substance use)	Measurement/ instruments (sleep)	Analysis method	Results	Threat to validity
Fucito et al. (2018)[37]	To examine the bi-directional relationship between alcohol consumption and daily variations in sleep assessments among college students	Quantitative; cross-sectional, purposive sampling	Self-administered questionnaire, sleep diary, Actigraphy	Binge drinking (Alcohol Use Disorders Identification Test-Consumption [AUDIT-C]; frequency of alcohol use (Daily Drinking Questionnaire ([DDQ], no. of alcohol drinking occasions/ past mo)	Pittsburgh Sleep Quality Index (PSQI, 19-item: subjective sleep quality, sleep duration, SOL, sleep disturbances, habitual sleep efficiency, sleep medication, and daytime dysfunction); sleep pattern (sleep onset, sleep offset, TST, WASO)	Descriptive statistic; hierarchical multiple linear regression analyses	Both greater drinks in a typical week and greater drinks in a heaviest drinking week was positively correlated with greater sleep disturbances on the PSQI. On days of greater number of drinks consumption than normal as well as heavy drinking (yes/no) significantly predicted later bed time on the night, and later wake time the following day. However, there were no significance in the within-person sleep duration, number of minutes awake, or ratings of perceived sleep quality or perceived alertness upon waking. Those who often drank more heavily on an average had significantly shorter sleep durations.	Small sample size, limited generalizability
Haynie et al. (2018)[32]	To examine bi-directional longitudinal associations between sleep and alcohol use in a nationally representative contemporary sample of high school-aged youth (NEXT Generation Health Study Wave 1–3)	Quantitative; longitudinal, stratified cluster sampling	Survey	Frequency of alcohol use (no. of alcohol drinking occasions/past mo); frequency of heavy episodic drinking (no. of times/past mo participants had 5 (for male) or 4 (for female) drinks in a row on an occasion)	Sleep duration (sleep onset and offset during scheduled school days and non-school days); chronotype (mid-sleep time on non-school days); social jet lag (absolute difference between non-school day sleep mid-point and scheduled school day sleep mid-point)	Descriptive statistic; structural equation modeling	Significant positive cross-lagged associations between alcohol use and sleep duration were shown across the waves. Ever alcohol use and heavy episodic drinking predicted shorter non-school day (weekends, vacation days) sleep duration; later chronotype; and more social jet lag among older adolescents.	Self-report bias
Patte & Leatherdale. (2018)[31]	To examine commonly proposed risk and prospective factors for sleep deprivation over time among a large cohort of Ontario and Alberta secondary school students (COMPASS study Wave 1–4)	Quantitative; longitudinal, convenience sampling	Survey	Frequency of cigarette smoking (no. of days smoked/past mo); ever smoked 100 or more whole cigarettes/lifetime; frequency of heavy episodic drinking (no. of times/past mo participants had 5 drinks in a row on an occasion); frequency of marijuana or cannabis use (no. of times/past year)	Sleep duration (≥8 hours as sufficient sleep and< 8 hours as insufficient sleep)	Descriptive statistic; logistic regression analyses	Those that initiated binge drinking (≥ 5 drinks on one occasion) had decreased likelihood of meeting the recommendations for sleep duration (≥8 hours/day). No longitudinal effect was found between initiating cannabis or tobacco use with sleep durations.	Self-report bias; limited generalizability
Bellatorre et al. (2017)[33]	To evaluate the longitudinal reciprocal associations between sleep problems, sleep duration, and smoking among non-Hispanic White and non-Hispanic Black youth using data from a longitudinal study	Quantitative; prospective cohort, longitudinal; convenience sampling	Survey	Frequency of cigarette (no. of days smoked/past mo)	Sleep duration (weekday and weekends, phase delay); sleep problem (chronic DIS, recent DIS, DMS)	Descriptive statistic, t-test, chi-square test, structural equation modeling	Significant reciprocal, prospective effect of number of smoking occasions on subsequent recent DIS found across all models. Effect of number of smoking occasions on subsequent recent DIS was stronger in non-Hispanic White than non-Hispanic Black participants.	Self-report bias; limited generalizability
Bonar et al. (2017)[36]	To examine links between depressive symptoms and sleep problems with alcohol mixed with	Quantitative; cross-sectional,	Survey	Binge drinking (AUDIT-C); drug abuse (Drug Abuse Screening Test [DAST])	Sleep Problem Scale (SPS, 4-item: troubling falling asleep, trouble staying asleep, wake up several	Descriptive statistic; multivariable	Many of those who consumed alcohol mixed with energy drinks were current smokers. Users of	Self-report bias; limited generalizability

Author (Year)	Purpose	Design	Method	Substance use measure	Sleep measure	Analysis	Findings	Limitations
	energy drinks use among college students	convenience sampling			times/night, wake up tired measuring past-month sleep difficulties)	logistic regression analyses	alcohol mixed with energy drinks had significantly higher scores on measures of sleep problems.	
Dunbar et al. (2017)[34]	To examine the health profiles of youth that report EC use compare to those who either use cigarettes only, dual uses, or neither (CHOICE program, Wave 7)	Quantitative; cross-sectional, convenience sampling	Survey	Frequency of EC use (no. of times/past y; frequency of cigarette and smokeless tobacco use (no. of times/past year	Sleep duration (average sleep hours on weekdays, average sleep hours on weekends; and sleep quality (average sleep quality ranging from very bad (1) to very good (4))	Descriptive statistic; analysis of variance (ANOVA), bivariate logistic regression analyses	When compared to youth those who use electronic cigarettes only, cigarettes only, dual users, and non-users, who used electronic cigarette only tended to have shorter total sleep time on weekends compared to non-users. However, there was no significant association between frequency of electronic cigarette use and weekday sleep time or sleep quality.	Self-report bias; limited generalizability
Bilsky et al. (2016)[45]	To examine the mechanism in which anxiety sensitivity and cigarette smoking level interact in their relationship to sleep onset latency among adolescent cigarette smokers	Quantitative; cross-sectional, purposive sampling	Survey	Frequency of cigarette smoking (Smoking History Questionnaire [SHQ], no. of cigarettes smoked/day)	Pittsburgh Sleep Quality Index (PSQI, 19-item: subjective sleep quality, sleep duration, sleep onset latency, sleep disturbances, habitual sleep efficiency, sleep medication, and daytime dysfunction)	Descriptive statistic; correlation, hierarchical multiple regression analyses	Daytime dysfunction in PSQI was positively correlated with smoking level. Fear of the negative consequences of anxiety-related sensations interacted with smoking level to relate to SOL despite controlling of age and gender. When compared to non-daily smokers, daily smokers went to bed later and woke up later.	Self-report bias; limited generalizability
Reichenberger et al. (2016)[35]	To assess association between health-risk behaviors (alcohol, nicotine, drug use, and risky sexual behaviors) and sleep, and to explore whether the mode of substance use (e.g., smoking vs. chewing tobacco) differed in their associations with sleep in a rural setting	Quantitative; cross-sectional; convenience sampling	Survey	Frequency of cigarette smoking; chewing tobacco or snuff use (no. of days/past mo); frequency of alcohol use (no. of alcohol drinking occasions/past mo); frequency of heavy episodic drinking (no. of times/past mo participants had 5 drinks in a row on an occasion); frequency of marijuana and other drug use	Sleep pattern (sleep onset, sleep offset); sleep duration (number of hours between reported sleep onset and offset)	Descriptive statistic, chi-square test, analysis of covariance (ANCOVA)	Rural adolescent who reported tobacco use tended to sleep fewer hours ($\mu = 7.77$) than did those who reported not ($\mu = 8.12$). Sleep was not associated with chewing tobacco use. Significantly fewer hours of sleep was observed across those who consumed alcohol in the last 30 days and for binge-drinkers.	Self-report bias; limited generalizability; heterogeneous sample
Van Reen et al., 2016[38]	To examine differences in self-reported sleep patterns and self-reported alcohol use among first-semester college students who do or do not report drinking during the last 6 months of high school	Quantitative; prospective, convenience sampling	Survey; sleep diary	Frequency of alcohol use (no. of times/past 6 mo of high school; no. of drinks/day in first y college); alcohol related problems (Brief-Young Adult Alcohol Consequences Questionnaire [B-YAACQ], no. of consequences experienced/past mo)	Sleep pattern (sleep onset, sleep offset; TST, SOL, WASO)	Descriptive statistic; ANOVA	Later sleep patterns were found in those reporting alcohol use. Increased alcohol consumption was associated with the timing of sleep (i.e., later sleep onset and offset). Reported TST was not significantly associated with their alcohol use.	Self-report bias; limited generalizability
Zhabenko et al. (2016)[42]	To determine correlates of sleep problems among adolescents to assess the associations between sleep problems reasons for emergency department (ED) visit, depression, unhealthy alcohol use, and other drug use	Quantitative; cross-sectional; convenience sampling	Self-administered questionnaire	Binge drinking (AUDIT-C); substance use screening (Alcohol, Smoking, and Substance Involvement Screening Test [ASSIST], use /past year)	Sleep Problems Questionnaire (SPQ, 4-item: trouble falling asleep, wake up several times/night, trouble staying asleep, wake up after usual amount of sleep feeling tired and worn out); Insomnia Symptom Questionnaire (ISQ, 13-item)	Descriptive statistics, bivariate correlation, multivariate negative binominal regression	Greater sleep problems were significantly associated with having greater unhealthy alcohol use, and having marijuana or tobacco use. Being female and tobacco use were associated with severity of sleep problems among adolescents, while alcohol and marijuana use were not statistically significant in multivariate analysis.	Self-report bias; limited generalizability
Pasch et al. (2012)[43]	To examine the bi-directional longitudinal relationships between sleep duration, sleep	Quantitative; longitudinal, random and	Self-administered questionnaire	Frequency of tobacco use (use /past mo); frequency of alcohol use (use/past mo); frequency of	Sleep duration (weekdays and weekends, total week sleep); sleep patterns (weekend sleep delay,	Descriptive statistic, structural	At baseline, cigarette use predicted less weekend and total sleep on entire week (weekday and	Self-report bias; limited generalizability

Table 2 (continued)

Author (year)	Study aims	Research design and sampling	Data collection	Measurement/ instrument (substance use)	Measurement/ instruments (sleep)	Analysis method	Results	Threat to validity
	patterns, and substance use in adolescence across a 2-year period	convenience sampling		marijuana use (use/past mo)	the difference between weekday and weekend wake-up time)	equation modeling	weekend combined) at follow-up, while alcohol use was predicted of less weekend sleep and having less difference between weekday and weekend wake-up time. With marijuana use at baseline, more weekend sleep, greater difference between weekday and weekend wake-up time, and more total sleep on entire week were predicted at follow-up.	
Perez et al. (2010)[44]	To explore relationship between disturbed sleep and demographic and health characteristics, among adolescents living on both sides of the Texas-Mexico border, 2000–2003	Quantitative; multistage stratified cluster, multistage stratified sampling	Survey	Frequency of cigarette smoking (use/past mo); frequency of alcohol use (no. of days/past mo); frequency of marijuana use (no. of times/past mo)	Sleep patterns (TST on weekdays and weekends, felt rested upon waking up, overall sleep quality in the past mo); sleep disturbances (DIS, DMS, EMA in the past mo)	Descriptive statistic, Pearson correlations, multiple logistic regression	Among both locations in US and Mexico on the Mexico border, drinking alcohol and using marijuana were positively associated with sleep disturbances.	Self-report bias; limited generalizability
Singleton & Wolfson. (2009)[39]	To examine the links among alcohol use, sleep, and academic performance in college students	Quantitative; cross-sectional; random sampling	Survey	Frequency of alcohol use (non-, light, moderate, heavy drinkers); amount consumed (no. of drinks/ typical weekend night); frequency of heavy episodic drinking (no. of times/past 2 wk Participants had 5 (for male) or 4 (for female) drinks in a row on an occasion)	Sleep duration (average hours of daily sleep); sleep patterns (timing of sleep, the difference between weekday and weekend nighttime sleep hours, the difference between weekday and weekend bedtimes); Sleepiness Index (daytime alertness)	Descriptive statistic; ordinary least squares regressions; mediation analysis	Students who drank more had less nighttime sleep, had later sleep schedules, got more sleep on weekends compared with weekdays, and had greater delays between weekday and weekend bedtimes. Sleep patterns mediated the relationship between alcohol use and daytime sleepiness; two predictor variables: being male and in the lateness of one's sleep schedule were significant for sleepiness.	Self-report bias; limited generalizability (single site)

Note. ANOVA = analyses of variance; ASSIST = Alcohol, Smoking, and Substance Involvement Screening Test; AUDIT-C = Alcohol Use Disorders Identification Test-Consumption; B-YAACQ = Brief-Young Adult Alcohol Consequences Questionnaire; DAST = Drug Abuse Screening Test; DDQ = Daily Drinking Questionnaire; DIS = difficulty initiating sleep; DMS = difficulty maintaining sleep; EC = electronic cigarette; EMA = early morning awakening; ISQ = insomnia symptom questionnaire; no. = number; PSQI=Pittsburgh sleep quality index; SHQ = smoking history questionnaire; SPQ = sleep problems questionnaire; SPS=Sleep Problem Scale; SOL = sleep onset latency; TST = total sleep time; WASO = wake after sleep onset.

Table 3
Association between substance use and sleep disturbances using Buysse's *sleep health framework*

Dimensions and its definition in *sleep health* framework	Substance use associations with sleep disturbances + positive, − negative, 0 null		
	Tobacco	Alcohol	Marijuana
Regularity	Shorter weekend sleep hours for e-cigarette users +[34]	Later sleep schedules and more sleep on weekends compared with weekdays +[39]	Greater weekend oversleep -[43]
Consistency in the pattern of going to sleep and waking up across both weekdays and on weekends		Less weekend oversleep +[43]	
		Delayed sleep schedule and discrepancy in hours of sleep between weekday and weekend sleep +[32]	
Satisfaction	None	Greater sleep problems (with alcohol mixed with energy drinks) +[36]	None
The subjective reporting of good vs. bad sleep and other problems related to sleep	Weekday sleep quality and the frequency of e-cigarette use 0 [34]	Perceived sleep quality 0 [37]	None
(sleep quality)			
Alertness during waking hours	Wake up after usual amount of sleep feeling tired and worn out +[42]	Wake up after usual amount of sleep feeling tired and worn out +[42]	Wake up after usual amount of sleep feeling tired and worn out +[42]
Maintain attentive wakefulness and no decreased daytime functioning	Daytime dysfunction +[45]	Increased daytime sleepiness +[39]	
Timing	Later sleep onset and later sleep offset +[45]	Later sleep onset and sleep offset +[37–39]	None
The placement of sleep within the 24-hour day		Delayed sleep schedule +[32,39]	
Efficiency	Greater sleep problems (DIS, DMS, WASO) +[42]	Greater sleep problems (DIS, DMS, WASO) +[42]	Greater sleep problems (DIS, DMS, WASO) +[42]
The ease of initiating and/or maintaining sleep (PSQI = increase SOL and, WASO SE = TST/TIME in Bed*100)	Recent and chronic DIS +[33]	DIS, DMS, EMA +[44]	DIS, DMS, EMA +[44]
(DIS, DMS, EMA)	None	Within-in person number of minutes awake 0 [37]	None
Duration	Shorter weekend sleep and total hours of sleep in 1 week +[35,43]	Shorter sleep duration +[39]	More weekend sleep, and more TST in 1 week -[43]
Total number of hours of sleep obtained per 24 hours		Shorter sleep duration among heavy drinkers +[35,37]	
		Shorter non-school day sleep duration +[32,43]	
		Decreased likelihood of having sufficient sleep +[31]	
		Non-school day sleep duration -[32]	
	Tobacco use 0 [31]	TST 0 [38]	None
	Chewing tobacco 0 [35]	Within-in person sleep duration 0 [37]	

Note. DIS = Difficulty initiating sleep; DMS = difficulty maintaining sleep; e-cigarette = electronic cigarette; EMA = early morning awakening; PSQI=Pittsburgh sleep quality index; SOL = sleep onset latency; TST = total sleep time; WASO = wake after sleep onset.

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Table 4
Quality of studies

Study author (year)	Domains					
	Study question[a]	Study population[b]	Outcome measure[c]	Statistical analysis[d]	Results[e]	Discussion[f]
Fucito et al. (2018)[37]	●	◐	●	●	●	●
Haynie et al. (2018)[32]	●	◐	◐	●	●	●
Patte & Leatherdale. (2018)[31]	●	◐	◐	●	●	●
Bellatorre et al. (2017)[33]	●	◐	◐	●	●	●
Bonar et al. (2017)[36]	●	●	◐	●	●	●
Dunbar et al. (2017)[34]	●	◐	◐	●	●	●
Bilsky et al. (2016)[45]	●	◐	◐	●	●	●
Reichenberger et al. (2016)[35]	●	◐	◐	●	●	●
Van Reen et al., 2016[38]	●	◐	◐	●	●	●
Zhabenko et al. (2016)[42]	●	●	◐	●	●	●
Pasch et al. (2012)[43]	●	●	◐	●	●	●
Perez et al. (2010)[44]	●	●	◐	●	●	●
Singleton & Wolfson. (2009)[39]	●	◐	◐	●	●	●

Note. ● = domain completely addressed; ◐ = domain partially addressed; ○ = domain not addressed.
  [a] Study question: Was the purpose of the study clear and appropriate?
  [b] Study population: Was the study population adequately described? Were the detailed description of sampling procedures reported?
  [c] Outcome measure: Were primary and secondary outcomes clearly defined? Were outcomes assessed on both subjective and objective findings? Was the method of assessment standard valid and reliable?
  [d] Statistical analysis: Were statistical tests appropriate? Was there an assessment of confounding? Were multiple comparisons taken into consideration?
  [e] Results: Were the outcome effect and measures of precision provided?
  [f] Discussion: Were conclusions supported by results with the consideration of potential biases of the studies?

Four studies used longitudinal aspects in an observational design.[31–33,43] In this way, a temporal relationship was confirmed with only limited studies. Apart from these limitations, all studies addressed the study question, with clear descriptions of statistical analysis, results, and discussion domains.

Discussion

This study provides a systematic review of studies that examine the association between substance use (tobacco, alcohol and/or marijuana) with sleep as a dependent variable in adolescents residing in North America. Collectively, the preponderance of the evidence suggested that tobacco, alcohol and marijuana use were positively associated with sleep disturbances in adolescents as outlined in Table 3, demonstrating issues in most of the dimensions of *sleep health* framework for all substances used. The adolescent substance users had inconsistent patterns between weekdays and weekends (Regularity), woke up tired and worn out despite having usual amounts of sleep (Alertness), had later sleep–wake schedules (Timing) with longer sleep latency (Efficiency), and shorter sleep hours (Duration). On the other hand, Satisfaction during waking hours was less often examined.

Substance use and sleep have been studied extensively in adults,[46,47] and findings of the association between adolescent substance use and sleep were consistent with those of adults. Current adult tobacco users had significantly more sleep problems such as shorter overall sleep duration, longer SOL, DMS, EMA, and feeling unrested compared with non-users.[48] Similarly, higher cigarette consumption among adults was associated with poor sleep quality.[49,50] Among the adult drinkers, those with greater alcohol dependence/ abuse problems predicted worsening of sleep quality.[51] Daily marijuana use were associated with having lower sleep quality and higher insomnia severity while daytime sleepiness did not differ between non-users or non-daily user groups.[52] These findings were consistent with the adolescents, though when assessing weekend sleep, marijuana use was associated with greater weekend oversleep.[43]

The findings of this review were consistent with observations seen across adolescents in different countries. For example, a study conducted in Turkey reported that excessive daytime sleepiness was experienced more frequently by adolescent smokers[53] which was also consistent with the findings among Peruvian students.[54]

Likewise, in China, current smokers were more likely to report sleep problems including the symptoms of DIS, DMS, and EMA in the past 30 days than never smokers.[55] For alcohol, drinking on a weekly basis was associated with snoring, difficulty breathing during sleep, DIS, DMS, and EMA.[56] However, it was found that marijuana use decreased the likelihood of inadequate sleep among adolescents in Ghana, which contradicts the relationship found in our study.[57]

Among the three substances, adolescent tobacco use has declined over the last decades. However, more recently the popularity of electronic vapor products with adolescents has become an alternative source of nicotine use. In this review, only one study evaluated the use of e-cigarettes and sleep and found that e-cigarette users have shorter weekend sleep hours.[34] Given the prevalence of e-cigarette use among adolescents as the newest form of substance use, its association with sleep deprivation is a concern that requires further qualitative and quantitative studies. Moreover, with relatively few studies examining marijuana use and sleep, more studies relating to all domains of sleep health is warranted in this population.

In spite of the strong association between adolescent substance use and sleep disturbances, limited studies explored contributing factors related to these associations. For adolescents who actively engage in substance use behaviors with their peers, getting sufficient recommended hours of sleep on school days may not be of their priority. Hence, not meeting the recommended hours of sleep during this critical developmental stage followed by the risk of poor decision-making may increase substance use.[43] Future research is needed to better understand various factors contributing to the association between substance use and sleep, including peer influences and mental health issues among adolescents.[58] In addition, there is a need to include objective sleep measures in future studies. Although self-reported sleep measure is practical and cost-effective, sleep questionnaires used in epidemiologic studies have shown inconsistent results in comparison with objective measures such as Actigraphy.[59] Hence, future research is warranted to use both objective and subjective data in reporting findings using measures with good reliability and validity.

Although this is the first study to provide a systematic review on adolescents' substance use and sleep using various dimensions of the *sleep health* framework, there may be some potential limitations. Although multiple search engines were included, there could be chances of missing studies that were not part of the search engines

used. Our search process was conducted with the studies included within the timeframe from 2007 to 2018, which may have potentially missed studies published in the past or in recent months.

In this review, we noted that some studies indicated that the nature of the relationship between substance use and sleep was at times reciprocal.[31–33,43] This reciprocal relationship is challenging when delineating directional relationship between substance use and sleep. However, we attempted to identify studies that examined the relationships between substance use as an independent variable and sleep as a dependent variable. In that way, we tried to obtain in-depth insights and understandings regarding the relationship when substance use was an independent variable and how those relationships were reported in the currently existing studies. For example, regression-based studies allowed determination of how substance use may or may not predict sleep disturbances among adolescents, and longitudinal studies provided knowledge of the temporal relationship of sleep when adolescents used substances.

The current study focuses on the studies that examined the association between substance use (independent variable) and sleep (dependent variable) among the adolescent population. Although most studies included in this review examined uni-directional relationship, there are limitations. A few articles in this review employed structural equation or cross-lagged models, which could have allowed for reporting bi-directional (reciprocal) relationship between substance use and sleep disturbance.[32,33,43] In addition, a few longitudinal studies reported that the relationship between substance use and sleep disturbances was reciprocal, portraying as a vicious cycle of increased risk for worsening of health outcomes.[32,43] For instance, Pasch et al. found that adolescents who have later weekend bedtimes were more likely to use alcohol at follow-up,[43] and Haynie et al. reported that the timing of sleep predicted subsequent alcohol use.[32] In addition, most studies were cross-sectional, which does not allow for a temporal understanding between the substance use and sleep. Thus, it should be noted that temporal relationships or bi-directional relationships between substance use and sleep are inconclusive in the current review.

None of the studies distinguished the age sub-groups to report their findings; however, we examined four studies that included 22 year olds (mean age is below 21 years old) to provide important insights into the study questions using a broader perspective. We found that the studies focusing on late adolescents or young adults had higher prevalence of alcohol use (35–65%) versus secondary students (11–31%). There is a need to evaluate sub-groups by considering the unique characteristics of different age groups in future studies. We were not able to further analyze findings based on the sub-groups because of the heterogeneous nature of the included studies. In addition, although minimal, this exception in the inclusion criteria could have skewed our findings. Furthermore, in spite of reporting how each study has defined substance use, we found that it was challenging to conduct the analysis due to varied measurement tools for each substance. The various ways substance use operationalized in the studies reviewed may have impacted the findings and comparability across studies. This needs to be considered in the future studies.

Conclusion

Adolescence is a critical time in forming sleep habits in relation to their rapid physiological, biological, and hormonal changes.[60,61] The reviewed studies identify sleep disturbances that are associated with adolescents' substance use. Future use of longitudinal designs could extend the findings of this review and provide a deeper understanding of adolescent substance use and sleep disturbances. With the current evidence consisting of mostly small number of descriptive, self-reported sleep related studies and the considerable limited

generalizability, it may be difficult to draw a definite conclusion. However, the findings of this review warrant the attention of health care professionals to assess the effects of chronic sleep problems especially among adolescent substance users. Sleep quality, daytime cognitive and physical functioning, mood, and sleepiness are all integral part of the developmental stage in adolescence. Hence, future research on adolescents should incorporate the six dimensions of *sleep health* framework to gain insight into their sleep health, hygiene, and future health promotion efforts. Additionally, the current assessment of available evidence highlights the need for further research to determine the consequences of sleep disturbance in adolescent substance users over time.

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