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CLINICAL REVIEW

Functional consequences of inadequate sleep in adolescents: A systematic review

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SUMMARY

During adolescence, changes in sleep patterns due to biological and environmental factors are well documented. Later bedtimes and inadequate sleep, i.e., short and disrupted sleep patterns, insomnia and daytime sleepiness, have become increasingly common. Accumulating evidence suggests that sleep plays a crucial role in healthy adolescent development. This review systematically explores descriptive evidence, based on prospective and cross sectional investigations, indicating that inadequate sleep is associated with negative outcomes in several areas of health and functioning, including somatic and psychosocial health, school performance and risk taking behavior. Findings highlight the need for longitudinal investigations aimed at establishing the underpinnings of these associations and for developing and implementing interventions designed to achieve healthier and more balanced sleep patterns in the adolescent population.

Introduction

In the past decade, there has been an increasing interest in the investigation of sleep in adolescence.[1–4] Growing evidence suggests that sleep plays a crucial role in healthy adolescent development, particularly in the regulation of important daily functions such as behavior, emotion and attention.[1,5–10] The main lines of evidence are obtained from sleep restriction protocols as well as descriptive studies and survey data, in which associations between sleep loss and various functional and behavioral outcomes are explored.

Investigations examining the effects of experimentally induced sleep restriction in adolescents have demonstrated declines in some neurocognitive functions.[1,6,7,11,12] In a review of the evidence, sleepiness was consistently demonstrated in most case-control sleep restriction protocols. However, evidence for cognitive deficits as a function of sleep restriction, was found in tasks of complex cognitive functions such as verbal fluency and creativity, computational speed and abstract problem solving, but not in low complexity tasks such as verbal memory, auditory attention, visual sustained attention, psychomotor speed and computational accuracy.[7] Furthermore, it has been hypothesized that whereas single tasks may be resistant to the effects of sleep deprivation, the performance of two different tasks simultaneously, such as cognitive and emotional tasks, may be particularly sensitive to the effects of sleep loss.[1] Dahl and Lewin have suggested that such dual or multi-tasking may well represent the challenges typically encountered in adolescents' daily lives.[1]

This hypothesis may explain why more consistent relationships have been reported between sleep loss and more global measures of functioning and behavior. Experimental studies have demonstrated increased academic difficulties and attention problems following sleep restriction, based on teacher ratings blind to experimental condition,[13] as well as greater problems with behavioral regulation such as impulse control, emotional regulation and behavioral flexibility.[5]

Despite the potentially serious implications of inadequate sleep on the development and well being of young individuals, to date, the consequences of sleep patterns and disturbances on daytime functioning and health issues in the adolescent population remains a relatively understudied and unappreciated area of investigation.[4] Few descriptive reviews, based primarily on experimental findings (i.e., sleep restriction protocols), have previously been published.[7,10,14] However, a systematic review of descriptive studies based in naturalistic settings on sleep, health and functioning in the healthy

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adolescent population is lacking. The aim of this study was to systematically review the associations between inadequate sleep (i.e., sleep loss, disturbed sleep patterns and insomnia), and impairments in various measures of health (i.e., somatic and psychosocial) and daytime functioning (i.e., school performance and risk behaviors), in the normative healthy adolescent population in a naturalistic setting.

Methods

Study selection

A literature search was conducted using PubMed and PsycNET (which is inclusive of PsycARTICLES and PsycINFO) electronic databases, covering all publications up to December 2012. These databases were chosen as they are considered comprehensive for the areas of health/medicine and psychology, respectively. Search terms for sleep measures were '*sleep*' (covering all aspects of interest regarding sleep, e.g.,: *short sleep duration, sleep loss, sleep disturbances*) and '*insomnia*'. Search terms for outcomes were '*health*', '*performance*', *and* '*risk*'. Finally, the search term '*adolescents*' was included. In order to limit the search to articles focusing on these specific terms, search fields were limited to title and/or abstract. In addition to the database search, reference lists of the chosen articles were scrutinized to assure that no relevant articles were missed.

A flowchart describing the screening process is presented in Fig. 1. Articles chosen met the following inclusion criteria: 1) articles from peer reviewed literature; 2) written in English; 3) reported cross sectional and prospective observational data from original articles; 4) the sample of interest was derived from the normative adolescent population ranging between ages 10–19 y, or the equivalent school grades (grades 5–12). Exceptions to this age range include three prospective studies in which baseline ages were lower.[15–17]

Articles were excluded based on the following criteria: 1) reviews, meta analyses, clinical trials and randomized control trials; 2) polysomnographic studies focused on sleep disordered breathing or parasomnias; 3) sleep was the only outcome measure, sleep and associated outcomes were not the main focus of the investigation, or pilot studies with small sample sizes; finally, 4) delayed sleep phase/chronotype studies were beyond the scope of the present review, with the exception of two studies[18,19] in which evening preference was investigated as a moderator of negative health outcomes related to short sleep duration.

The review was divided to four broad areas of investigation pertaining to aspects of health and daily functioning that are common in the adolescent population and are of considerable investigational interest as potential outcomes of inadequate sleep. Thus, adolescent sleep was explored of in the context of 1) somatic and 2) psychosocial health, as well as 3) academic/school performance and 4) risk behaviors. The specific measures of sleep reviewed are noted throughout the article. In general, these are: sleep duration/loss/deprivation, sleep disturbance and insomnia. For each section, prospective studies were presented first, followed by cross sectional investigations.

Results

Somatic health (Table 1)

General health outcomes

Few prospective studies have followed adolescent sleep disturbances and consequent general health outcomes based on self-report.[20,21] In a 12 mo study on the functional impact of insomnia in over 4000 11–17 y old adolescents based on DSM-IV (Diagnostic and statistical manual mental disorders, fourth edition). symptom criteria,[20] insomnia at baseline significantly increased risks for all subsequent somatic dysfunctions at follow up, which were operationally defined as self reports of perceived health, limitations due to somatic health problems, and impact of illness on family life. Increased risks were dose dependent, with the most severe insomnia increasing risks for all somatic outcomes by approximately twofold, and remaining significant after controlling for age, gender and parental occupation, but not when controlling for concurrent (follow up) insomnia.[20] Short sleep failed to predict any somatic outcomes following adjustment to background variables.[21]

In a cross sectional survey on the association between adequate sleep time and health status and behaviors in Taiwanese adolescents,[22] adequate sleep (defined as 6–8 h regularly) was positively related to health promoting behaviors such as healthy diet, physical activity, proper stress management, life appreciation and responsibility regarding health. Adequate sleepers were also less likely to be overweight.

Cross sectional data have also found a relationship between insomnia, based on DSM-IV criteria, and pubertal development in girls.[23] Girls exhibited an increased risk for insomnia (odds ratio [OR] 2.75) following menses, whereas prior to menses there was no gender difference in risk for insomnia.

Overweight and obesity

The impact of short sleep duration on overweight and obesity in children and adults has been reviewed, demonstrating that short sleep increases the risk of obesity, based on prospective and cross sectional studies.[24] While most prospective pediatric studies reviewed were performed on young children, two followed children into the adolescent years,[16,17] and two focused specifically on adolescents.[25,26] One study prospectively followed nearly 800 children from preadolescence (3rd grade, age 9 y) to early adolescence (6th grade, age 12 y), and demonstrated that shorter sleep in preadolescence increased the risk of being overweight in the 6th grade, when controlling for confounders such as race, maternal education, weight status and normative maturational changes in sleep duration.[16] For each additional hour of sleep in the 3rd grade, the child was about 40% less likely to be overweight three years later. Furthermore, shorter sleep in early adolescence was independently associated with a concurrent risk for being overweight.[16] In a five year prospective study following over 2200 children from ages 3–12 y at baseline,[17] short sleep, later bedtime and earlier wake time were all associated with increased body mass index (BMI) and excess weight five years later. Each additional hour of sleep at baseline subsequently decreased BMI by 0.75 kg/m^2. These relationships were attenuated with age, so that sleep timing and duration were more influential on weight status in the younger rather than the older subjects, suggesting the puberty may play a moderating role.[17] Further support for the moderating effect of puberty may be found in a two wave epidemiologic study on over 13,000 adolescents ages 12–18 y, which found that short sleep duration (<6 h) at wave one failed to predict obesity 1–2 years later, after controlling for obesity at wave one, age, gender, race and parental income.[25] Significant predictors of obesity were depression and television viewing (≥2 h/d), both well documented correlates of inadequate sleep in the adolescent population.[27,28] Similarly, in a two year longitudinal study of a cohort of over 700 adolescents, reduced sleep duration was not associated with BMI or percent body fat when controlling for demographic and lifestyle factors; although a borderline positive relationship ($p = 0.068$) was reached between sleep duration and percent body fat in females.[26] Following adjustment for calories, activity, sedentary activities and depression, this relationship was attenuated. Collectively these findings suggest that

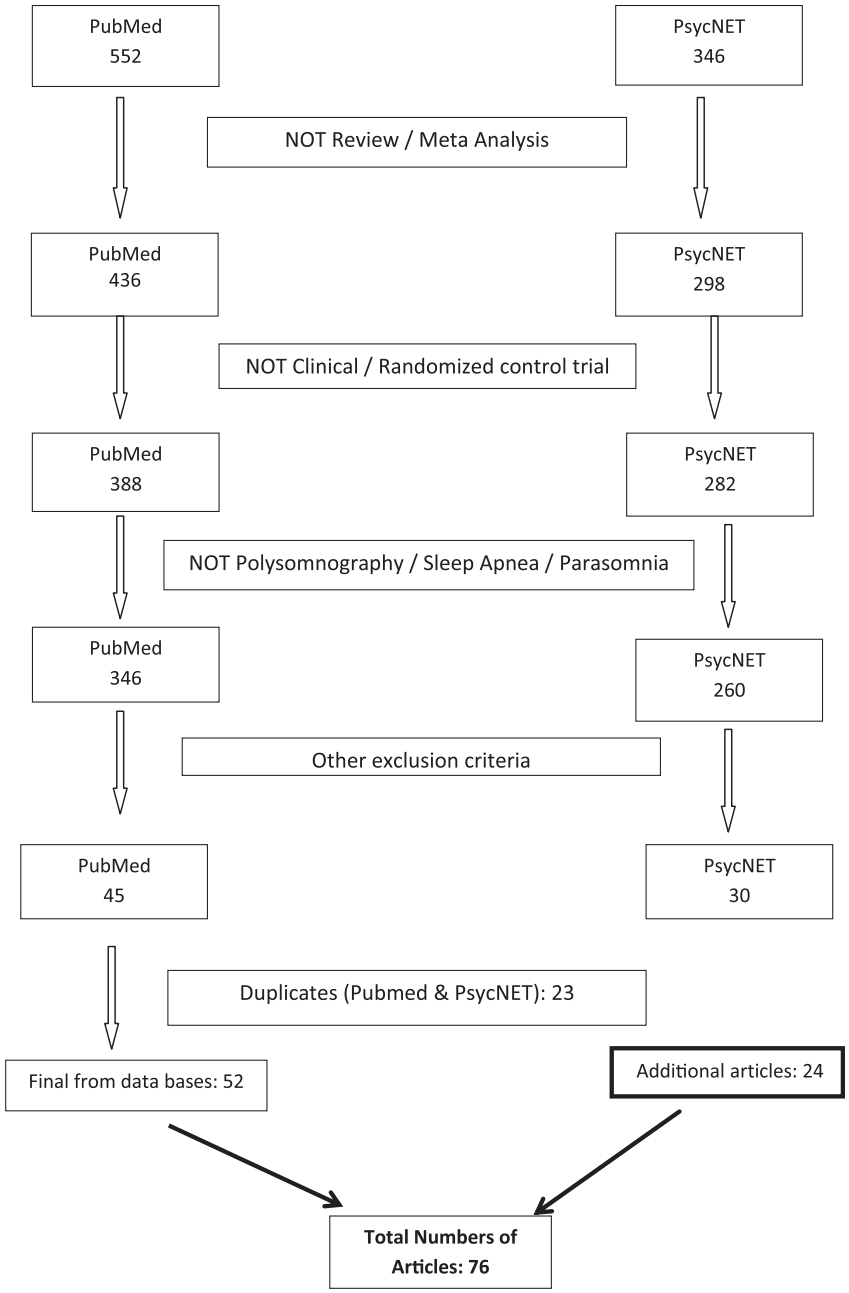

Fig. 1. The flowchart shows the screening process using PubMed and PsycNET electronic search engines in parallel. The top two boxes show the total number of articles found for each search engine using identical search criteria (see text). Moving downward, box-pairs list the number of articles remaining at each screening level. Following the elimination process, duplicates of the remaining articles were removed, and all final articles ($n = 76$) were combined.

factors other than sleep duration are more strongly associated with obesity during adolescence.

In a study comparing sleep patterns vs. sleep durations in relation to weight, physical activity and screen time in over 2000 adolescents (9–16 y old), those with late sleep patterns (i.e., late bedtime and late wake time) had increased risks for obesity (OR 1.5), low physical activity (OR 1.8) and increased screen time (OR 2.9) compared to those with early sleep patterns (early bed and wake times), despite similar sleep durations.[18] Interestingly, these differences were greater than differences between long (early bedtime and late wake time) and short (late bedtime and early wake time) sleepers, with a difference in sleep duration of >2 h/night, suggesting that sleep timing (chronotype) may moderate the effects of sleep duration on overweight and related outcomes in adolescents.

Nevertheless, cross sectional studies in middle and high school students have provided support for an association between short sleep and overweight and/or obesity.[29–41] For example, analysis of a web-based survey of nearly 74,000 students in South Korea found an inverse relationship between sleep duration and both BMI and being overweight or obese.[32] Each 1 h decrease in sleep time increased the likelihood for overweight or obesity by 6.5%. Additional factors associated with an increased odds ratio for obesity were male gender, lower paternal education, sedentary lifestyle, mental stress and lower frequency of exercise.

Other studies have also reported additional psychosocial and lifestyle factors such as sedentary behaviors, inactivity and poor diet.[30,31,38] Interestingly, gender differences have been inconsistently implicated in the relationship between short sleep duration

Table 1
Descriptive prospective and cross sectional studies assessing relationships between sleep and somatic health outcome measures.

Somatic health							
Authors & year	Design	N	Location	Tools	Age/grade	Sleep measure	Outcome measures
General health outcomes							
Chen et al., 2006[22]	Cross sectional	656	Taiwan	Self-report	13–18 y	6–8 h regularly	Health promoting behaviors
Johnson et al., 2006[23]	Cross sectional	1014	USA	Self-report	13–16 y	Insomnia (DSM-IV)	Psychiatric disorders (anxiety, depression), menses (girls)
Roberts et al., 2009[21]	Prospective	4175 (BL) 3134 (12 mo follow-up	USA	Self-report	11–17 y	Sleep duration (<6 h)	Somatic, interpersonal, psychological functioning
Roberts et al., 2002[20]	Prospective	4175 (BL) 3136 (12 mo follow-up	USA	Self-report	11–17 y	Insomnia (DSM-IV)	Somatic, interpersonal, psychological functioning
Overweight and obesity							
Al-Hazzaa et al., 2012[37]	Cross-sectional	2868	Saudi Arabia	Self-report	15–19 y	Sleep duration	BMI
Calamaro et al., 2010[25]	Prospective	13,568	USA	Self-report	12–18 y	Sleep duration	BMI
Gupta et al., 2002[39]	Cross-sectional	383	USA	Self-report, actigraphy	11–16 y	Sleep duration, sleep disturbance	Obesity
Garaulet et al.,2011[38]	Cross sectional	3311	Western Europe	Self-report	12.5–17.5 y	Sleep duration	BMI
Knutson 2005[41]	Cross sectional	4486	USA	Self-report	7–12 grades	Sleep duration	BMI
Liou et al., 2010[31]	Cross sectional	8640	Taiwan	Self-report	13–16 y	Sleep duration	Obesity
Lumeng et al., 2007[16]	Prospective	785	USA	Maternal report	3rd grade at baseline	Sleep duration, sleep problems	Overweight
Lytle et al., 2010[34]	Cross sectional	723	USA	Self-report	10–16 y	Sleep duration	BMI
Lytle et al., 2012[26]	Cross sectional	723	USA	Self-report	10–16 y	Sleep duration	BMI, body fat
Moore et al., 2011[33]	Cross sectional	247	USA	Actigraphy	13–16 y	Sleep time, variability of sleep time	Health related variables (ADHD, birth weight, BMI, asthma)
Noland et al., 2009[36]	Cross sectional	384	USA	Self-report	9–12 grades	Sleep duration	Overweight, stress, harmful behaviors
Olds et al., 2011[18]	Cross sectional	2200	Australia	Self-report	9–16 y	Bed and wake times, sleep duration,	Physical activity, BMI, sedentary behaviors
Park, 2011[32]	Cross sectional	73836	Korea	Self-report	12–18 y	Sleep duration	BMI, obesity
Seicean et al., 2007[30]	Cross sectional	529	USA	Self-report	14–18 y	Sleep duration	Overweight
Snell et al., 2007[17]	Prospective	2281	USA	Sleep diary	3–12 y at baseline	Sleep duration, bed and wake times	BMI, overweight
Wells et al., 2008[35]	Cross sectional	4452	Brazil	Self-report	10–12 y	Sleep duration	BMI, skinfold thickness, blood pressure
Weiss et al., 2010[40]	Cross sectional	240	USA	Self-report Actigraphy	16–10 y	Sleep duration and quality	Obesity
Health conditions							
Auvinen et al., 2010[42]	Cross sectional	1773	Finland	Self-report	15–19 y	Quantity and quality of sleep	Neck, shoulder and lower back pain
Countryman et al., 2012[44]	Cross-sectional	367	USA	Self-report objective measures	15–17 y	Sleep duration	Cardiovascular health
Javaheri et al., 2011[48]	Cross-sectional	907	USA	Actigraph	9–11 y	Sleep duration	Homeostasis model of insulin, BMI
Luntamo et al., 2012[46]	Cross-sectional	2215	Finland	Self-report	13–18 y	Sleep problems	Headache, abdominal pain
Martinez-Gomez et al., 2011[47]	Cross-sectional	183	Spain	Self-report objective measures	13–17 y	Sleep duration	Cardiometabolic risk markers
Matthews et al., 2012[45]	Cross-sectional	245	USA	Actigraphy, Insulin Measures	High school	Sleep duration	Insulin resistance
Narang et al., 2012[43]	Cross-sectional	4104	Canada	Self-report	14–15 y	Sleep habits	Cardiometabolic factors, BMI, lipid profile, blood pressure
Shaikh et al., 2010[49]	Cross-sectional	489	India	Self-report & objective measures	16–19 y	Sleep duration	Blood pressure, cardiovascular reactivity
Wells et al., 2008[35]	Cross-sectional	4452	Brazil	Self-report	10–12 y	Sleep duration	BMI, skinfold thickness, blood pressure

Abbreviations: ADHD, attention deficit hyperactivity disorder; BL, baseline; DSM-IV, Diagnostic and statistical manual of mental disorders, fourth edition; BMI, body mass index.

and obesity. Whereas a U.S. survey of over 4000 adolescents found a strong association only for males,[41] a European survey of over 3000 adolescents has reported the association to be more pronounced in females.[38] Further studies may reveal possible cultural differences that may explain these inconsistent findings.

Finally, to explore the underpinnings of short sleep and weight imbalance, one study followed nutrient intake in 240 adolescents ages 16–19 y using 24-h food recall questionnaires.[40] Sleep was objectively monitored using actigraphy, and 8 h was the cut-point to distinguish short and long weekday sleep. Findings revealed that short sleep was associated with higher caloric intake derived from fat and less caloric intake derived from carbohydrates, even when controlling for gender, race and parental education. These associations were stronger in girls than in boys.[40]

Health conditions

In a 2-year longitudinal Finnish study of nearly 2000 adolescents ages 15–19 y, a composite score of insufficient sleep

quality and quantity predicted neck (OR 3.2) and lower back pain (OR 2.4) in females but not males, in multivariate analyses.[42] Cross-sectional studies have also reported associations between sleep and health conditions in adolescents.[35,43–49] In a Canadian study of over 4000 adolescents, a higher sleep disturbance score (based on the self-report Pittsburgh sleep quality index) was associated with increased markers of cardiovascular risk.[43] Studies have found associations between short sleep duration and cardiometabolic markers[44,47] and impaired insulin resistance.[45,48] Another Finnish study of over 2000 adolescents ages 13–18 y reported that sleep problems (defined as the reported frequency of "problems with falling asleep or sleeping") were common (27%) and often co-occurred with headache and abdominal pain.[46]

In summary, based on self-report, insomnia is linked to poor general health, whereas conversely, adequate sleep is associated with positive health status. Conflicting evidence regarding the nature of the associations between short sleep and overweight/obesity likely suggests that age, gender and lifestyle factors are confounders in this relationship. Finally, evidence is beginning to emerge regarding associations between sleep disturbance and measures indicating poor health conditions, such as pain, cardiovascular and cardiometabolic impairments.

Psychosocial health (Table 2)

Prospective studies have demonstrated that sleep problems and/or sleep deprivation increase the risk for subsequent mental/emotional dysfunction in adolescents.[15,20,21,23,50–52] For example, in a study prospectively following over 2000 young adolescents for three years starting in the 6th grade (ages 11–14 y), shorter sleep increased the risk for depressive symptoms and low self esteem both concurrently and over time.[50]

Roberts and associates reported findings of over 5000 adolescents ages 10–17 y in one baseline and two prospective investigations, examining associations between sleep disturbance and psychosocial outcomes.[20,21,53] Based on the initial survey, the strongest correlates of insomnia and hypersomnia were disturbed mood, fatigue and suicide ideation.[53] In the two prospective investigations, Roberts et al.,[20,21] examined psychological and social functioning outcome measures to include self esteem, depression, perceived mental health, life satisfaction, relations with parents and social support. As with their somatic outcomes (see previous section), baseline insomnia increased the risk for all subsequent psychosocial outcomes in a dose response manner; however, after adjusting for age, gender, parental education and concurrent insomnia at follow up, these associations were maintained for self

Table 2
Descriptive prospective and cross sectional studies assessing relationships between sleep and psychosocial health measures.

Psychosocial health							
Authors & year	Design	N	Location	Tools	Age/grade	Sleep measure	Outcome measures
Coulombe et al., 2011[57]	Cross sectional	980	Canada	Self & parental report	12–16 y	Sleep problems, tiredness	Aggression, attention, anxiety/depression, withdrawal
Fredriksen et al., 2004[50]	Prospective	2259	USA	Self-report	11–14 y	Sleep duration	Depression, self esteem, academic scores
Gregory & O'Connor, 2002[15]	Prospective	490	England	Parental report	4–15 y	Sleep problems	Behavioral/emotional problems.
Johnson et al., 2006[23]	Cross sectional	1014	USA	Self-report	13–16 y	Insomnia (DSM-IV)	Anxiety, depression
Johnson et al., 2006[55]	Prospective	1014	USA	Self-report	13–16 y	Insomnia (DSM-IV)	Psychiatric disorders (anxiety, depression), menses (girls)
Kaneita et al., 2007[59]	Cross sectional	99668	Japan	Self-report	12–18 y	Sleep duration, bedtimes, insomnia, sleep problems	Mental health status
Kanieta et al., 2009[51]	Prospective	698	Japan	Self-report	13 y	Sleep problems	Mental health status
Liu & Zhou, 2002[60]	Cross sectional	1359	China	Self-report		Sleep duration, insomnia	behavioral problems
Mercer et al., 1998[58]	Cross sectional	612	USA	Self-report	9th grade	Reported sleep need	Daytime function, mood
Moore et al., 2009[29]	Cross sectional	247	USA	Self-report, actigraphy	13–16 y	Sleep duration, sleepiness	Psychological functioning
Morrison, 1992[56]	Cross sectional	943	New Zealand	Self-report	13–15 y	Sleep problems	Anxiety, depression, inattention, conduct disorders
Pasch et al., 2010[62]	Cross sectional	242	USA	Self-report	10–16 y	Sleep patterns, sleep duration	Depression, truancy, alcohol and substance use
Patten et al., 2000[52]	Prospective	7960	USA	Self-report, Telephone interview	12–18 y	Sleep problems	Cigarette smoking, Depressive mood
Roberts & Duong, 2012[54]	Prospective	3134	USA	Self-report	11–17 y	Insomnia	Major depression
Roberts et al., 2001[53]	Cross sectional	5423	USA	Self-report	10–17 y	Sleep disturbances	Mood, fatigue, suicide ideation
Roberts et al., 2009[21]	Prospective	4175 (BL) 3134 (12 mo follow-up	USA	Self-report	11–17 y	Sleep duration (<6 h)	Somatic, interpersonal, psychological functioning
Roberts et al., 2002[20]	Prospective	4175 (BL) 3136 (12 mo follow-up	USA	Self-report	11–17 y	Insomnia (DSM-IV)	Somatic, interpersonal, psychological functioning
Umlauf et al., 2011[63]	Cross sectional	20716	USA	Self-report	9.75–18 y	Sleep problems	Risk behaviors, aggressive behavior, worry, socioemotion
Wolfson & Carskadon, 1998[8]	Cross sectional	3120	USA	Self-report	13–19 y	Sleep–wake habits	Mood, school performance and behaviors
Xu et al., 2012[61]	Cross sectional	5226	China	Self-report	Junior & senior schools	Sleep quality	Depression, anxiety and loneliness

Abbreviation: BL, baseline.

esteem, depression and social support, with severe insomnia increasing all risks by nearly twofold.[20] When looking at the psychosocial outcomes of short sleepers, poor perceived mental health and low life satisfaction were consistently found in multivariate analyses.[21]

In a recent prospective two wave investigation of over 3000 community based adolescents, reciprocal associations between insomnia and major depression, both based on DSM-IV criteria, were examined.[54] In multivariate analyses, baseline insomnia increased the risk for subsequent depression and vice versa, both by twofold. Reciprocal associations between sleep disturbances and mental health problems have also been demonstrated in a 2-year follow up study of over 500 young Japanese adolescents (age 13 y at baseline), where the 2-year incidences of poor mental health and sleep disturbance were 35% and 33% respectively.[51] New onset of poor mental health was associated with concurrent and ongoing sleep disturbance; conversely, new onset sleep disturbance was associated with concurrent and ongoing poor mental health. In a study using retrospective interviews of over 1000 adolescents ages 13–16 y to explore the temporal associations between insomnia, depression and anxiety (based on DSM-IV criteria), over 50% of adolescents with insomnia had a comorbid psychiatric disorder.[55] Among those with comorbid conditions, anxiety increased the risk for insomnia, whereas insomnia increased the risk for depression, controlling for other factors.

Cross sectional data have generally reported associations between short or disturbed sleep and negative psychological outcomes, particularly depression and anxiety.[8,23,56–63] In a large survey of nearly 100,000 junior and senior high school students in Japan, short (<7 h) and long (>9 h) sleep were both associated with poor mental health status, whereas self-assessment of sleep quality was linearly related to mental status, i.e., poorer sleep assessment was related to poorer mental health status.[59] In another survey of nearly 1000 healthy 12–16 y olds, troubled sleeping was associated with attention problems and withdrawal as well as anxiety and depression, tiredness was associated with aggression and withdrawal, while long sleep was associated with aggression alone.[57]

However, one study[29] reported associations between measures of depression and anxiety with sleepiness, but not with actigraphy measurements of sleep duration and variability in sleep duration. These findings possibly highlight differences between subjective and objective measurement, as well as different operational definitions of sleepiness, and warrant further investigation.

In summary, ample evidence is provided supporting a strong bidirectional association between sleep disturbance and depression. Additional mental health outcomes associated with sleep disturbance include anxiety, low self esteem, poor psychosocial functioning and poor perceived mental health status.

School performance (Table 3)

High school students spend on average 30–35 h per week in class and an additional 4–5 h per week doing homework.[64] Sleep is a vital necessity for optimal levels of cognitive function, including attention, memory, learning, and higher order executive functions and inevitably has significant influence on academic functioning during adolescence.[65,66]

Despite the vast amount of time and effort dedicated to education and learning during adolescence, there is a significant gap in longitudinal data examining the link between insufficient or inadequate sleep and academic functioning and performance. Only three prospective investigations have examined the associations between sleep disturbance and academic performance with mixed results.[19,21,50] After adjusting for baseline functioning levels and a wide range of sociodemographic factors, one study of over 3000 representative U.S. youth, ages 11–17 y, found that shorter weekday sleep duration was related to poorer grades and problems at school one year later.[21] In contrast, in a three-year study of a representative sample of 2259 middle school students (ages 11–14 y) living in the U.S., this link was not found.[50] Interestingly, causal modeling of similar data among 310 Australian high school students (ages 15–18 y) suggests that during the academic year, circadian evening preference may moderate the relationship between deficient sleep patterns (both sleep quantity and quality) and poor academic performance.[19] In other words, it seems that morning preference may protect teens from sleep loss and possible academic problems.

Despite the scarcity in prospective data, the link between shorter sleep duration and lower grades among middle and high school students has been consistently documented in multiple cross-sectional studies.[8,67–72] One of the first large studies to examine this issue in the U.S. found that among adolescents (ages 13–19 y), those with lower average grades (Cs and lower or ≤74%) went to bed significantly later and received on average 3 h less sleep per week than those reporting higher grades (Bs and higher, ≥75%).[8] Similar results linking poor academic performance to sleep insufficiency, later bedtimes, and weekend oversleep were later replicated across several countries in South America,[71] Europe[67,68] and Asia,[69,70,73] suggesting that this phenomenon is omnipresent and may have significant outcomes for youth.

Cross-sectional research has also found that certain adolescent populations may be at higher risk for sleep-related academic difficulties. For example, one study found that academic performance may be more sensitive to sleep loss in boys than in girls, despite equivalent sleep durations.[67]

Daytime sleepiness, one of the main derivatives of sleep loss has also become a ubiquitous presence among today's adolescents. Survey data from 1600 US high school students showed that about 25% regularly fall asleep in class and an additional 22% fall asleep while doing homework.[74] Several large cross-sectional surveys confirmed the high prevalence of daytime sleepiness in this young population and revealed that it may be related to poor school-related daytime functioning, such as being tardy and reduced academic achievement (based on self-reported lower grades and data from school records).[71,75–79] One study also found similar results, after controlling for socioeconomic factors, such as household income, known to be highly correlated with school achievement.[80]

In sum, although insufficient prospective data make causal inferences difficult to ascertain, clear and consistent associations have been found between sleep loss, sleepiness and lower academic achievement among younger and older adolescents worldwide.

Risk behaviors (Table 4)

Research into the functional consequences of inadequate sleep in adolescents has encompassed some important aspects of daytime function. The most recent addition to this line of research is in the area of risk taking behavior. Recent data from the Youth Risk Behavior Surveillance System (YRBSS),[81] suggests that although health risk behaviors among high school students has shown a decline in the last two decades, many adolescents continue to engage in a wide range of problematic behaviors, placing them at greater risk for morbidity and mortality.[81] Based on the YRBSS data, the frequency of risk behaviors seems to increase with high school grade, while the vast majority of risk behaviors seem to be more common among males (e.g., being in a physical fight, stealing, driving while intoxicated, smoking, using alcohol and drugs) than females (e.g., considering, planning, or attempting suicide).[81]

Five investigations have prospectively followed adolescent sleep loss and/or sleep disturbances and consequent tendency towards

Table 3
Descriptive prospective and cross sectional studies assessing relationships between sleep and school performance measures.

School performance							
Authors & year	Design	N	Location	Tools	Age/grade	Sleep measure	Outcome measures
Chung & Cheung, 2008[69]	Cross sectional	1629	China	Self-report	12–19 y	sleep patterns, sleep disorders	Academic performance, stress, daytime sleepiness and behavior
Drake et al., 2003[77]	Cross sectional	450	USA	Self-report	11–15 y	Daytime sleepiness	Sleep patterns, school achievement, mood, extracurricular activities
Fredriksen et al., 2004[50]	Prospective	2259	USA	Self-report	11–14 y	Sleep duration	Depression, self esteem, academic scores
Gibson et al., 2006[75]	Cross sectional	3235	Canada	Self-report	14–18 y	Sleepiness, Sleep patterns, Sleep Duration	Academic performance, extracurricular activities
Joo et al., 2005[76]	Cross sectional	3871	Korea	Self-report	15–18 y	Sleep habits, sleep duration, sleep problems	School performance sleepiness, depression, risk behaviors
Lazaratou et al., 2005[67]	Cross sectional	713	Greece	Self-report	15–18 y	Sleep duration, sleep complaints	School performance, extracurricular activities
Mak et al., 2012[73]	Cross sectional	22678	Hong Kong	Self-report	12–19 y	Sleep pattern & problems	Academic performance, smoking, alcohol use
Meijer & van den Wittenboer, 2004[68]	Cross sectional	153	Netherland	Self-report	10–13 y	Sleep duration, sleep quality	School performance
O'Brien & Mindell, 2005[78]	Cross sectional	388	USA	Self-report	14–19 y	Sleep patterns	Risk behaviors, daytime functioning and academic performance
Pagel et al., 2007[80]	Cross sectional	238	USA	Self and parental report	7–12 grades	Sleep complaints, sleepiness	School performance, concentration
Perez-Chada, 2007[71]	Cross sectional	2884	Argentia	Self-report	9–17 y	Sleep duration, snoring or witnessed apnea	School performance, sleepiness
Postel et al., 2009[72]	Cross sectional	1551	USA	Self-report	Middle school	Sleep problems, sleep duration	Work related injuries, school performance
Rhie et al., 2011[79]	Cross sectional	3370	Korea	Self-report	5–12 grades	Sleep pattern, sleep duration	School performance, emotional stability, sleepiness
Roberts et al., 2009[21]	Prospective	4175 (BL) 3134 (12 mo follow-up	USA	Self-report	11–17 y	Sleep duration (<6 h)	Somatic, interpersonal, psychological functioning
Warner et al., 2008[19]	Prospective	380	Australia	Self-report	15–18 y	Sleep quality and patterns	Daytime functioning, mood, school grades
Wolfson & Carskadon 1998[8]	Cross sectional	3120	USA	Self-report	13–19 y	Sleep–wake habits	Mood, school performance and behaviors
Yang et al., 2005[70]	Cross sectional	1457	Korea	Self-report	5–12 grades	Sleep–wake habits	Sleepiness, academic performance

Abbreviation: BL, baseline.

risk taking behavior.[52,63,82–84] A 2-year follow up study of 704 U.S. adolescents (ages 10–17 y, comprised of three overlapping cohorts between 2007 and 2010) showed that reduced weekday sleep duration predicted greater cigarette smoking, while reduced weekday and weekend sleep durations predicted increased likelihood for marijuana use two years later.[84] Furthermore, a 4-year longitudinal study of close to 8000 younger and older adolescents (ages 12–18 y at baseline) found a dose–response relationship between cigarette smoking and future self-reported sleep problems.[52] Notably, girls who smoked were about 60–70% more likely to develop sleep problems than boys who smoked.

Insomnia has also been causally linked to increased risk behaviors in four prospective studies.[21,63,82,83] In a large 12-mo follow up study of a representative U.S. sample of over 4000 7–12th grade students, self-reported insomnia, defined as troubled sleep and morning tiredness in the past year, predicted cigarette smoking and drunk driving, above and beyond the effects of school grade, gender, and depressive symptoms.[83] Similarly, a large one year prospective U.S. study of over 4000 representative community based adolescents (Teen Health 2000) of similar ages (11–17 y at baseline) found that adolescents suffering from sleep loss (<6 h/night in the past month) or from at least one insomnia symptom (e.g., trouble initiating or maintaining sleep, non-restorative sleep) coupled with daytime sleepiness were at an increased risk for future alcohol and/or drug problems (OR 0.9–2.6).[21,82] It is however important to note that when baseline psychosocial factors and other functioning problems were adjusted for, the link between sleep difficulties (but not sleep loss) and substance abuse were no longer significant,[82] once again suggesting that the relationship between sleep disturbances and risk behaviors may be more complex and should be further examined in the context of developmental changes, psychiatric and psychosocial problems, and other related areas. For example, sequential two year follow up data among approximately 20,000 inner-city African-American youth (ages 10–19 y), found that sleep disturbance in the context of negative life events was implicated in future aggressive acts, such as carrying/using a gun, even after controlling for age, gender and trauma-related stress.[63] These data may not reflect normative risk taking behaviors in teens and thus may not generalize to adolescent populations living outside the U.S., where gun access is more heavily controlled.

Several cross-sectional studies have also attempted to quantify sufficient or insufficient sleep in light of risky behavior or risk for injury.[62,72,78,85–91] A seminal study on this issue by O'Brien and Mindell[78] found that high school students, 14–19 y, living in urban and suburban areas, who received less than 6:75 h of sleep per night, reported greater alcohol use and sexual activity than those sleeping at least 8:25 h. Similarly, another study of 1429 adolescents (ages 13–17 y), living in an urban province of China, found that sleeping less than 7 h per night (vs. ≥7 h/night) was consistent with an increased susceptibility to multiple unintentional injuries

Table 4
Descriptive prospective and cross sectional studies assessing relationships between sleep and risk behaviors measures.

Risk behaviors							
Authors & year	Design	N	Location	Tools	Age/grade	Sleep measure	Outcome measures
Catrett & Gaultney, 2009[83]	Prospective	4353	USA	Self-report	7–12 grades	Insomnia	Risk behaviors (smoking, drinking & driving, safety violations, delinquency, violence)
Goldstein et al., 2008[95]	Prospective	271	USA	Self-report	13–19 y	Insomnia, sleep duration	Suicide
Johnson & Breslau, 2001[94]	Cross sectional	13,831	USA	Self-report	12–17 y	Sleep problems	Cigarettes, alcohol, illicit drugs use
Lam & Yang, 2007[85]	Cross sectional	1429	China	Self-report, interview	13–17 y	Sleep duration	Unintentional Injuries
Lee et al., 2012[90]	Cross sectional	8530	Korea	Self-report	7–11 grades	Sleep duration,	Suicidal ideation, depression
Mak et al., 2010[92]	Cross sectional	29,397	Hong Kong	Self-report	12–18 y	Sleep disorders, insomnia	Cigarette smoking
Mak et al., 2012[73]	Cross sectional	22,678	Hong Kong	Self-report	12–18 y	Sleep patterns & problems	Academic performance smoking, alcohol use
McKnight-Eily et al., 2011[86]	Cross sectional	12,154	USA	Self-report	9–12 grades	Sleep duration	Health risk behaviors (cigarettes, marijuana alcohol, sexual activities, suicide ideation)
O'Brien & Mindell, 2005[78]	Cross sectional	388	USA	Self-report	14–19 y	Sleep patterns	Risk behaviors, day time functioning and academic performance
Pasch et al., 2010[62]	Cross sectional	242	USA	Self-report	10–16 y	Sleep patterns, sleep duration	Depression, truancy, alcohol and substance use
Pasch et al., 2012[84]	Prospective	704	USA	Self-report, weight & height measured	10–17 y	Sleep duration, sleep patterns	Tobacco, alcohol, marijuana use
Patten et al., 2000[52]	Prospective	7960	USA	Self-report, telephone interview	12–18 y	Sleep problems	Cigarette smoking, depressive mood
Pérez et al., 2010[93]	Cross sectional	4901	Texas-Mexico	Self-report	9 grade	Sleep patterns and problems	Cigarette smoking, alcohol and marijuana use
Pizza et al., 2010[96]	Cross sectional	339	Italy	Self-report	11–12 grades	Sleep quality, sleepiness	Motor vehicle crashes, tobacco, alcohol, drugs use
Postel et al., 2009[72]	Cross sectional	1551	China	Self-report	Middle school	Sleep problems, sleep duration	Work related injuries, school performance
Roberts et al., 2001[53]	Cross sectional	5423	USA	Self-report	10–17 y	Sleep disturbances	Mood, fatigue, suicide ideation
Roberts et al., 2008[82]	Prospective	4175	USA	Self-report	11–17 y	Insomnia (DSM-IV)	Somatic & mental health, substance use interpersonal, activities
Roberts et al., 2009[21]	Prospective	4175	USA	Self-report	11–17 y	Sleep duration (<6 h)	Somatic, interpersonal, psychological functioning
Stallones et al., 2006[88]	Cross sectional	262	USA	Self-report	13–18 y	Sleep patterns, sleep duration, sleepiness	Risk of injuries
Tynjala et al., 1997[89]	Cross sectional	4187	Finland	Self-report	11,13,15 y	Tiredness, sleep habits	Psychoactive substances
Umlauf, 2011[63]	Prospective	20,716	USA	Self-report	9.75–18 y	Sleep problems	Risk behaviors, aggressive behavior, worry, socioemotion
Vignau et al., 1997[91]	Cross sectional	763	France	Self-report	14–18 y	Sleep disturbances	Risk behaviors, family and personal variables
Yen et al., 2010[87]	Cross sectional	8319	Taiwan	Self-report	7–12 grades	Sleep duration	Risk behaviors

(OR 2.2) but not to a single injury.[85] A more far-reaching result was found by a recent large representative survey of risk behavior in over 12,000 9–12th graders across the U.S. which showed that less than 8 h of sleep per night was associated with higher odds for 10 out of 11 health risk behaviors, including current smoking, alcohol, marijuana use, sexual activity, physical violence, and serious suicidal ideation.[86] Moreover, short weekday sleep may be more predictive of risk taking than weekend sleep, even if longer weekend sleep is present,[62] suggesting that weekend "catch-up" sleep may not be sufficient to protect adolescents from the behavioral outcomes resulting from cumulative weekly sleep loss. One study of 8300 Taiwanese junior high and high school students classified as ultra-short (<6 h), short (6–8 h), and long sleepers (>8 h) may best reflect the above findings.[87] Results from this study show that short and ultra-short sleepers were more likely to engage in risk taking, including substance use (OR 3.6), alcohol intake (OR 3.1), delinquency (e.g., theft) (OR 1.8), unprotected sexual activity (OR 1.7), violence (OR 1.5), and truancy (OR 1.4) when compared to long sleepers.[87] Interestingly, ultra-short sleepers were not more likely to engage in risk behaviors than short sleepers, with the exception of suicidal ideation, for which 6–8 h of sleep was protective, when compared to <6 h sleep duration.

Similar findings have been reported in two studies of adolescents living in rural areas in the U.S. and China, demonstrating increased proneness to work and non-work related injury for those who attained less than the needed sleep amounts.[72,88] Specifically,[88] U.S. adolescents getting less than 8.5 h of nightly sleep (on school nights, weekend nights, or a combination of both) were at a greater risk of injury than those getting more hours of sleep, with younger adolescents (ages 13–15 y; OR 1.8–3.7) being significantly more susceptible to injury than older adolescents (ages 16–18 y; OR 0.5–1.7). Similar data were shown among 1187 Chinese middle school students and farm-workers in a rural adolescent population, who were found to suffer from a greater incidence of injuries (OR = 2.4) if they slept less than 7 h per school night or went to bed after midnight at least one night per week (OR = 2.0), even after

adjusting for age, gender, and number of days worked per month.[72] Similar results have been found in a wide range of international studies, including Korean,[90] French[91] and Finnish[89] high school populations.

Cross-sectional data in adolescents have also attempted to connect sleep difficulties and/or insomnia with a tendency for engaging in risky behaviors, with mixed results.[53,73,86,92–94] The 1994–1996 US National Household Survey of Drug Abuse, one of the first reports linking adolescent sleep and risk behavior, suggested a link between sleep problems, alcohol/drug use and emotional or behavior problems in close to 14,000 adolescents (ages 12–17 y).[94] Self-reported frequent sleep problems in the past six months were associated with increased reports of smoking cigarettes (OR 1.5–3.2), drinking alcohol (OR 2.4–3.7) and using drugs (OR 2.6–3.7), even after controlling for age, gender, race, and socioeconomic factors. Importantly, the relationship between substance use and sleep was attenuated when externalizing and internalizing problems were included in the model, once again suggesting that adolescent sleep disturbances and co-occurring substance abuse may in part be a function of emotional or behavioral problems, but may also occur independently of them. Interestingly, findings from the only retrospective study comparing 140 adolescents, ages 13–19 y, who committed suicide to 131 matched controls, suggest that after controlling for depressive symptom severity, parental/family reports of their child's insomnia (in the week prior to the suicide) increased the risk for completed suicide.[95]

Other studies have found conflicting results.[92,93] For example, in a study of close to 30,000 7–12th graders (ages 12–18 y) in Hong Kong, regular current smokers were less likely to suffer from insomnia than "experimental" smokers (used only a few cigarettes in their lifetime) and non-smokers.[92] Results remained consistent after controlling for symptoms of depression and anxiety. A study of 5570 Hispanic adolescents (median age 15 y), primarily of low income families living on the Texas-Mexico border, found that smoking cigarettes (OR 1.9) and drinking alcohol (≥six days) in past month) (OR 2.6), increased the risk for insomnia.[93] Interestingly several other risk behaviors, including lifetime cocaine use, nonconsensual sex, suicidal ideation, and down mood, did not increase susceptibility for insomnia.[93] These mixed results reflect the need for additional research to better elucidate the links between insomnia, risk behaviors, and internalizing and externalizing conditions in adolescence.

Sleepiness, one of the main byproducts of insufficient sleep, may also predispose teens to accidents and subsequent injury. In study of 339 older Italian adolescents (ages 18–21 y), 40% endorsed drowsy driving and 24% reported being involved in a car accident, of which 15% indicated they believed the main cause was sleepiness.[96] Furthermore, those teens who reported being involved in a least one car accident, were more likely to be male (OR 3.3), use tobacco (OR 3.2), drive while sleepy (OR 2.1), and suffer from poor sleep (OR 1.9).[96]

In sum, ample evidence suggests strong causal connections between sleep loss, insomnia and a wide range of health and other risk taking behaviors. Notably, these links may be weakened by competing influences such as emotional status, psychosocial functioning and other negative life events.

Discussion

Developmental changes in sleep patterns during adolescence are well characterized. Based on accumulated scientific investigation, it has been established that bio-regulatory systems controlling sleep, as well as environmental and psychosocial factors are involved in these observed changes.[97–99] Delays in both circadian and homeostatic sleep mechanisms have been shown to underlie one of the hallmarks of adolescent development, i.e., a shift to a later sleep phase,[9,99,100] characterized by a tendency towards delayed bed and wake-up times. Superimposed environmental factors further promote the observed gap between weekday and weekend sleep timing and reduction in sleep duration in this population.[1,98] Thus, during weekends and holidays, adolescents naturally prefer later bed and wake times and extended sleep duration; whereas during weekdays they are required to considerably advance their wake times, thereby artificially shortening their sleep times, and often leading to increased reports of daytime sleepiness and fatigue.

Early school start times have been implicated as a major contributing factor to curtailed sleep during the weekday, sleep deprivation, and daytime sleepiness; and this relationship seems to be strengthened with age from early to late adolescence.[8,70,101,102] Other contributing environmental factors include growing academic workload,[70] less parental influence on bedtime,[8,70,103] and increased "screen time", e.g., television viewing and internet use.[27,104,105] Individual behavioral and psychosocial factors which have also been associated with poor sleep patterns and daytime sleepiness include stress, depressed mood, excess weight and obesity, alcohol use, caffeine intake and cigarette smoking.[1,8,36,69,105,106] However, it is currently not known whether these features constitute a cause or a consequence of poor and insufficient sleep in this age group.

The present systematic review attempts to tease apart several main health and functional correlates of inadequate sleep in the adolescent population, and to attempt to determine some of the causal directions of these associations. The main strengths of this comprehensive review are that it is based on observational studies in culturally diverse naturalistic settings and that it includes both prospective and cross sectional surveys of large sample sizes. Taken together, these strengths provide us with a deeper understanding of adolescents' subjective experiences of both their sleep and wake behaviors, and increase the external validity of the findings, allowing wide cross cultural generalizability to be achieved.

Few investigations have followed sleep and related outcomes prospectively. The available data provide mixed evidence suggesting that inadequate sleep may lead to direct or indirect harmful consequences for adolescents. Most physical health outcomes, including self perceived health and excessive weight gain were considerably attenuated when controlling for background variables, whereas pain was a significant consequence of inadequate sleep but only in females.

Causal relationships were more pronounced between sleep and psychosocial health outcomes. Specifically, mounting evidence supports bi-directional causal relationships between inadequate sleep and depression or depressive symptoms. Notably, long sleep was also associated with depression in two cross-sectional studies, an association that may have been overlooked in the prospective studies. Other consequent mental health issues implicated as causal to inadequate sleep include low self esteem, social support and life satisfaction, and poor perceived mental health.

Major behavioral consequences of insufficient sleep may include reduced academic achievement, particularly in older adolescents; however, due to the very limited number of prospective studies, these results should be interpreted cautiously. Furthermore, sleep loss and sleep problems seem to increase future engagement in certain health related risk behaviors, particularly use of psychoactive substances, such as nicotine and marijuana intake and driving while intoxicated.

Accumulating evidence from numerous cross-sectional investigations support the presence of co-morbid or reciprocal

relationships between inadequate sleep and several health and functional outcomes. Co-morbid somatic health outcomes include poor self perceived general health, weight gain and pain, as well as increased cardiovascular and cardiometabolic risks. Co-morbid psychosocial health outcomes include depression and anxiety, inattention, withdrawal, tiredness and aggression. Risky behaviors that appear co-morbid with inadequate or poor sleep include a wide range of risky health behaviors (e.g., alcohol and illicit substance use, unprotected sexual activity, and physical injury), violence and suicidal ideation.

Reciprocal associations have also been indicated. For example, while inadequate sleep may lead to depression, depression and anxiety are strong predictors of poor sleep, thus creating a vicious cycle. Similarly, somatic complaints such as pain may appear consequent to inadequate sleep, and may in turn lead to sleep disturbance. Behavioral outcomes showing reciprocal relationships with inadequate sleep are prominently the use of psychoactive substances; teens may use alerting substances to mask the effects of inadequate or poor sleep (i.e., daytime sleepiness and fatigue), but in turn, regular use may also result in chronic inability to get sufficient or adequate sleep, which may further lead to use of depressants to induce sleep when needed.

Mediating and moderating variables that appeared throughout the review included age, gender, chronotype and psychosocial variables such as attention, stress and lifestyle. These variables reflect some of the main areas that undergo significant changes in the course of adolescent development.[1,10] For example, age, gender and chronotype all appear to moderate the impact of inadequate sleep on overweight and obesity during adolescence, whereas lifestyle factors such as excessive screen time, diet and lack of physical activity likely mediate this relationship. Furthermore, moderating trait characteristics such as evening chronotype and male gender, and mediating psychosocial variables such as negative affect, compromised attention and behavioral problems, may explain the relationships between inadequate sleep and intellectual abilities, school performance and risk taking behaviors.

Study limitations

This review aimed to encompass major areas of health and functioning in adolescents which have been investigated in association to sleep. Areas not reviewed here include environmental, cultural and lifestyle factors such as socioeconomic status, parental styles, electronic media exposure and school start times, all of which have been associated with sleep disparities in this population (e.g.,[1,4,105]). These areas were not considered for the systematic review as they are more often implicated as causes of poor sleep rather than outcomes. Nevertheless, the authors are aware that some of these variables, particularly lifestyle, likely show a bi-directional relationship with sleep. Further longitudinal research is needed to clarify the nature of these relationships.

Additional limitations refer to instrumentation issues that include reliance on self-report and on global surveys or measures, which often include only a few constricted sleep questions, and the lack of standardized measurement. These methodological drawbacks result in a limited ability to accurately distinguish between adequate and inadequate sleep. For example, based on self-report data alone it is difficult to distinguish between sleep-onset insomnia/difficulties with waking up in the morning and an evening preference. As there is no standardized definition regarding optimal sleep quota, different studies measure sleep duration as a continuous, ordinal or dichotomous variable, using various cutoffs for ordinal and dichotomous scales. Additional research using more accurate and standardized assessment of sleep quality and quantity is highly needed.

Future directions

Given the paucity of longitudinal investigations, additional prospective and outcomes research is needed in order to better understand underlying mechanisms, direction of causality and mediating factors, as well as inform the development of targeted interventions that can be widely implemented. As evidence regarding the serious outcomes associated with inadequate sleep is mounting, targeted intervention studies with long term follow up should examine whether early sleep-related interventions for inefficient and inadequate sleep may protect teens from negative physiological, psychological, and behavioral outcomes. Such intervention studies may in turn increase our understanding regarding the direct and indirect effects of inadequate sleep on these and other outcomes.

It is clear from the above literature that attempts to quantify sufficient and insufficient sleep are currently not well founded. We suggest that *sleep need* is an elusive concept that deserves reevaluation. Further systematic research is warranted to establish optimal sleep quotas in the adolescent population, taking into consideration individual factors such as age, gender and chronotype, as well as cohort, cultural, environmental and other possible factors that have been demonstrated as moderators and mediators of these relationships.

Moreover, attempts to define optimal sleep need may be complicated by mere selection and definition of the outcomes variables investigated. Specifically, how a single optimal outcome is defined, and whether various health and functional outcomes are comparable in their requisites of sleep quotas to reach their respective optimal outcomes, are questions that need to be considered. For example, what may be considered optimal school performance, and is the amount of sleep necessary for such performance the same as that necessary for optimal physical or emotional health? The answers to these questions are far from straightforward, and are likely biased by cultural values, norms and priorities. Nevertheless, such an evaluation may provide for a clearer public health message regarding the appropriate sleep requirements in the adolescent population.

Conclusion

This systematic review provides ample evidence to demonstrate that inadequate sleep has significant consequences on various key aspects of adolescent health and functioning, including somatic and psychosocial health, academic performance and risk taking behavior. The evidence collectively supports the premise that sleep plays an important role in this crucial period of development, and indicates that the pervasive effects of chronic sleep debt have become a serious worldwide public health issue.

The conclusions of this review have important clinical implications. Sleep insufficiency and inadequacy have become ubiquitous in western societies, and adolescence is no exception. Inadequate sleep may be considered a marker or a prodrome of a wide spectrum of poor health and functional outcomes. Not unlike other areas of health related outcomes research, these sleep-related negative outcomes may accompany young individuals in their transition from adolescence to adulthood, and may cause more extensive long term damage. However, in as far as inadequate sleep is pervasive it is also amenable to prevention and treatment, for which at present, research is sorely needed.

Practice points

- Sleep plays an important role in healthy adolescent development.
- Inadequate sleep, both in quantity and in quality, is pervasive in adolescents.
- Inadequate sleep is associated with significant negative consequences in everyday aspects of adolescent health and functioning including somatic and psychosocial health, academic performance and risk taking behavior.
- Clinicians, educators, parents and policymakers should acknowledge that the pervasive effects of chronic sleep debt in adolescents have become a serious public health issue.
- Sleep clinicians and researchers should design and implement targeted social interventions aimed at both at increasing sleep quantity and improving sleep quantity in adolescents while assessing possible effects on functional outcomes in this population.

Research agenda

- To develop longitudinal observational studies following sleep patterns and daytime functional outcomes in naturalistic settings.
- To conceptualize underlying causal pathways and mechanisms linking inadequate sleep and negative health and functional outcomes.
- To develop standard instrumentation for evaluating sleep patterns in the adolescent population.
- To develop and implement behavioral interventions designed to promote balanced sleep practices in adolescents.
- To establish standardized appropriate sleep quota requirements, based on relevant individual and environmental factors.

Conflict of interest

The authors report no conflicts of interest

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