



Archived at the Flinders Academic Commons:

<http://dspace.flinders.edu.au/dspace/>

‘This is the peer reviewed version of the following article:
Short, M. A., & Weber, N. (2018). Sleep duration and risk-
taking in adolescents: A systematic review and meta-
analysis. *Sleep Medicine Reviews*, 41, 185–196. <https://doi.org/10.1016/j.smr.2018.03.006>

which has been published in final form at

<https://doi.org/10.1016/j.smr.2018.03.006>

© 2018 Elsevier Ltd. This manuscript version is made
available under the CC-BY-NC-ND 4.0 license:

<http://creativecommons.org/licenses/by-nc-nd/4.0/>

Accepted Manuscript

Sleep Duration and Risk-Taking in Adolescents: A systematic review and meta-analysis

Michelle A. Short, PhD, Nathan Weber, PhD

PII: S1087-0792(17)30207-1

DOI: [10.1016/j.smrv.2018.03.006](https://doi.org/10.1016/j.smrv.2018.03.006)

Reference: YSMRV 1101

To appear in: *Sleep Medicine Reviews*

Received Date: 1 December 2017

Revised Date: 9 March 2018

Accepted Date: 21 March 2018

Please cite this article as: Short MA, Weber N, Sleep Duration and Risk-Taking in Adolescents: A systematic review and meta-analysis, *Sleep Medicine Reviews* (2018), doi: 10.1016/j.smrv.2018.03.006.

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.



Sleep Duration and Risk-Taking in Adolescents: A systematic review and meta-analysis

Running head: Sleep duration and risk-taking in adolescents

Michelle A. Short, PhD*, & Nathan Weber, PhD

School of Psychology, Flinders University, Adelaide, South Australia

Conflicts of interest:

None

Corresponding author:

Michelle Short

GPO Box 2100

Adelaide S.A. 5001

Tel: +6182013877

Email: michelle.short@flinders.edu.au

SUMMARY

Risk-taking is associated with increased morbidity and mortality among adolescents, with insufficient sleep a potential factor contributing to heightened risk-taking propensity in this age group. A systematic review of the evidence examining the relationship between sleep duration and risk-taking in adolescents was conducted using PsycINFO, PubMed, Medline, Scopus, and CINAHL databases. These searches identified 26 studies including 579,380 participants, 24 of which were appropriate for meta-analysis. Pooled results indicated that insufficient sleep was associated with 1.43 [1.26, 1.62] times greater odds of risk-taking. This relationship was witnessed across diverse categories of risk-taking, including alcohol use, drug use, smoking, violent/delinquent behaviour, transport risk-taking/road safety, sexual risk-taking and trait risk-taking. Risk of bias analysis showed that the quality of the included studies was mixed. Further, few studies utilized either longitudinal or experimental designs, thus limiting causal conclusions. These findings highlight the importance of further research to examine the causal relationship between sleep duration and risk-taking and to elucidate the mechanisms that underpin this relationship.

Keywords: Risk-taking, decision making, sleep, sleep deprivation, adolescents, youth

Abbreviations

BART Balloon analogue risk task

DDT Delayed discounting task

HDI Highest density interval

ROPE Region of practical equivalence

TIB Time in bed

TST Total sleep time

INTRODUCTION

Risk-taking is endemic among adolescents, with risky behaviour such as drug and alcohol use, risky driving, unprotected sex, gambling, and petty crime prevalent in this age group (1-5). Adolescents are more likely to take risks than either children or adults (6). Resultantly, unintentional injury is a leading cause of death among adolescents worldwide, accounting for the largest number of adolescent deaths in the U.S. (7). Thus, it is imperative to understand factors that may help mitigate the detrimental consequences of risk-taking in this age group.

Sleep loss is one factor that may heighten risk-taking propensity (8). Extant empirical research supports a relationship between sleep loss and risk-taking propensity in adults (9, 10), with sleep loss associated with greater risk-taking on gambling tasks, whilst driving, in the workplace, and in relation to health behaviours including smoking, drug use, and alcohol intake (11-17). The means by which sleep loss is argued to heighten risk-taking is through its detrimental effects on brain regions important for risk-taking and decision making, such as the prefrontal cortex (18).

Compared with adults, less is known about the relationship between sleep loss and risk-taking in adolescents. Research including adolescent participants is crucial due to the prevalence of both risk-taking and insufficient sleep in this age group. Current recommendations suggest eight to 10 hours' sleep per night for adolescents (19-21), but the sleep of many adolescents falls well short. In countries such as Singapore, Korea and Taiwan, sleep durations of five to six hours per night are common (22-24), while in the U.S., the majority of adolescent obtain less than eight hours of sleep on school nights (25). In addition, there are several salient reasons why results from studies of adults cannot be generalised to adolescents: adolescents need more sleep than adults for optimal functioning ; they have a

different psychosocial milieu; they are exposed to more novel risk-taking decisions; and their brains are less developed, developing faster in regions related to heightened sensation seeking and risk-taking yet relatively underdeveloped in regions crucial to decision-making and inhibition of risk-taking (19, 26, 27).

One systematic review summarised studies examining the relationship between sleep and risk-taking in adolescents, finding that inadequate sleep was related to increased risk-taking (28). This study included a range of sleep variables, including sleep duration, sleep disturbance, sleep problems, daytime sleepiness, tiredness and insomnia, and did not meta-analyse studies. As aspects of sleep and daytime functioning are not unitary, they likely have differing relationships with risk-taking. In addition, the research attention given to this emerging field has grown substantially in recent years, with preliminary searches revealing that approximately half of all original research in this area was published within the last five years. Therefore, a review of the literature is timely and important. The present review updates and extends previous findings by examining sleep duration specifically, and meta-analysing results to identify the pooled effect size (and range of credible values) for this relationship. The meta-analytic approach confers several advantages, such as enabling more accurate conclusions by summarizing the overall effect size and allowing a more nuanced understanding of the relationship when statistically testing for factors that moderate this relationship. In the absence of meta-analysis, there is a tendency in some reviews to tally and compare the number of significant versus non-significant findings. Meta-analysis avoids the focus on results significance testing, which is affected by factors such as sample size and variability, rather focusing on effect size (29, 30).

Our systematic review identified, meta-analysed, and critically appraised literature examining the relationship between sleep duration and risk-taking in adolescents to answer the following questions: 1) Is there a relationship between sleep duration and risk-taking in

adolescents? 2) Does this relationship vary according to type of risk-taking behaviour, age, study design, country, or how sleep is operationalised? 3) What are the key areas for future research? This review conforms to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations (31).

METHODS

Relevant literature was sourced using PsycINFO, PubMed, Medline, Scopus, and CINAHL databases to include original research that spans psychology, medicine, social sciences, neuroscience, and education. The ancestry method was used to capture additional studies. Search terms included sleep* AND duration* OR depriv* OR loss OR total OR restrict* OR lack OR amount* OR insufficien* OR poor OR time OR hour OR short* OR impair* OR inadequate* OR debt* OR no sleep AND risk* AND take OR takers OR taker OR taking OR seek* OR decision* OR behavio* AND adolescen* OR teenager* OR teen OR teens OR youth*. Publications were included if they were primary peer-reviewed journal articles, articles in press, or academic theses, were published in English, examined the relationship between sleep duration and risk-taking, and included participants who were adolescents. Studies were deemed to include a measure of sleep duration if they assessed length of nightly sleep using measures such as total sleep time, sleep minutes, sleep period (time elapsed between sleep onset and offset), or time in bed. Risk-taking is defined as decision making, occurring prior to an action, which has the capacity to lead to negative outcomes (32). Thus, studies were included if they included a measure of risky decision-making. Adolescence is defined as the period from 10 to 19 years, as per the World Health Organisation definition (33). Studies examining clinical populations or pharmacological interventions were excluded. Searches were conducted on April 9, 2017. Exclusion criteria were not applied regarding the date of publication to capture all relevant published original research.

For each eligible study, data were extracted regarding authors, year of publication, location, age range, sample size, measures, study design, and effect size. As the majority of the studies identified utilised cross-sectional designs, study quality and risk of bias were assessed using key indicators of the three primary sources of bias for cross-sectional studies: selection bias, information bias, and confounding (34). Selection bias was assessed using three indicators: Were inclusion criteria given and applied uniformly? Did the sampling strategy achieve a sample representative of the target population? Was the response rate $\geq 80\%$? Information bias refers to the reliability and validity of study measures. As subjective measures contain a higher risk of bias due to factors such as social desirability responding and inaccuracy, information bias was assessed using two indicators: Was the IV(s) measured objectively? Was the DV(s) measured objectively? Finally, the risk of confounding variables was assessed using one indicator: Did the study assess and statistically adjust for confounding variables?

Statistical Analyses

We used a Bayesian meta-regression approach (35, 36) to meta-analyze the included studies (see the supplement s1 for full details of the model). As most studies reported odds ratios, we converted all effect sizes to log odds ratios¹ (37) for analysis. The effect sizes were coded to represent the odds of risk-taking behaviour in insufficient versus sufficient sleep; thus, higher values represent more risk-taking with less sleep. Each effect size was classified according to the category of the risk-taking measured used: drug use, alcohol use, smoking, sexual risk-taking, violent/delinquent behaviour, risk-taking related to transport/road safety, gambling, and trait risk-taking. We hierarchically modelled a separate log odds ratio for each

¹ For ease of interpretation we report odds ratios, but all analyses were conducted on log odds ratios.

category² with all drawn from an overarching normal distribution, the mean of which reflects the overall effect size estimate. Further, we included study as a random effect, allowing each category estimate to vary by study. Finally, we included age range as a covariate in all analyses. Specifically, the (mean centred) minimum and maximum ages were included as predictors. Where studies reported grades and not age, grades were converted to indicate age minimums from 13 to 17 years for grades eight to 12, respectively, and age maximums of 14 to 18. Coefficients for both were estimated for each category, but again these were drawn from an overarching normal distribution reflecting the overall impact of the age range bounds on the estimated effect size. We also created additional models to investigate the impact of potential moderators of the relationship between sleep duration and risk-taking. These models allowed the effect size estimate for each category to vary by levels of the moderator.

Unlike frequentist analyses, the result of a Bayesian analysis is a distribution of the plausible parameter values (the posterior distribution), not a single point estimate. We present the mean of the distribution as a summary of the most credible values (i.e., our best estimate of the relevant value) and represent uncertainty in the estimates with 95% Highest Density Intervals (HDI; presented in text inside []). HDIs are similar to frequentist confidence intervals, but have a number of properties allowing easier interpretation. Specifically, unlike confidence intervals, the 95% HDI represents a range of values that, given the data and modelling assumptions, we can be 95% confident contains the true value. Further, the HDI is calculated such that any value within the HDI is a more credible parameter value than all values outside. Thus, when the HDI does not include an odds ratio of 1, we can be 95% confident that the odds ratio differs from 1. However, comparison with an exact value is not a

² Due to the small number (and size) of studies reporting effect sizes for gambling, we were unable to estimate the gambling effect size with enough precision to make any sensible interpretations. Specifically, we could be 95% sure that the true gambling odds ratio in these studies is between .5 and 2. Consequently, we have excluded the gambling category from further results presentations, but it was still included in all analyses. Thus, the gambling results still contributed to our estimates of overall effect size and the overall impact of moderators.

good basis for inference, so we use the region of practical equivalence (ROPE; (38)) as a basis for inference regarding meaningful and negligible effects. Specifically, we identified a range of values such that we consider any effects within that range to be so small as to be considered negligible. We set the ROPE as log odds ratio of ± 0.2 (odds ratios: 0.82, 1.22). Thus, when the HDI is entirely outside the ROPE, we can be 95% confident that the effect size is meaningful. Similarly, and in contrast with frequentist analyses, when the HDI lies entirely inside the ROPE, we can be 95% confident that the effect is negligible. Finally, we can also examine the proportion of the posterior distribution that lies within or outside the ROPE to quantify our certainty that the true effect is negligible or meaningful, respectively. Thus, we use the term “meaningful” to an effect that has a 95% or greater probability of exceeding a negligible effect size.

For all models, we used Markov Chain Monte Carlo techniques programmed in R (39), JAGS (40), and runjags (41) to generate representative credible values from the joint posterior distribution on the model parameters. The four chains were burned in and checked for convergence graphically and using the Gelman-Rubin statistic (42), and run long enough to ensure a minimum effective sample size of 10,000 (43). The forest plot was created using the R package ggplot2 (44).

RESULTS

Insert figure 1 here

The PRISMA flow chart detailing the screening and identification of studies is shown in figure 1. Overall, 26 studies including 579,380 adolescent participants were identified. Twenty of the 26 studies were conducted in the United States, with two from Finland, two from Norway and one each from Taiwan and Ghana. Cross-sectional designs were used in 22 of the studies, longitudinal in two studies, and two were experimental. Sleep was measured using subjective self-report in 23 studies, often from a single survey item, while sleep diaries were used in two studies and actigraphy in one. A variety of measures were used to operationalize risk-taking, with most studies including more than one risk-taking variable. Overall, studies examined drug use (N = 16), alcohol use (N = 12), smoking (N = 10), sexual risk-taking (N = 7), violent/delinquent behaviour (N = 8), risk-taking related to transport/road safety (N = 10), gambling (N = 3), and trait risk-taking (N = 6). Twenty-three studies used subjective self-report measures of risk-taking, with two using both subjective and objective measures and one using objective measures only. Study summaries are provided in table 1. Of the 26 studies identified, five studies required further information from the authors to be included in the meta-analysis and this information was supplied for three (45-47). Risk of bias in the included studies is summarized in figure 2. Among the studies that control for confounding variables, on average, they included four covariates (range 2 – 9), with all controlling for sex, and the majority also controlling for socioeconomic indicators such as parental education. Other key covariates included age, school grade, depressed mood, and race/ethnicity.

Table 1. Summary of articles identified in the systematic review. Note: S = subjective, O = objective, P =prospective (i.e., sleep diaries), BART = balloon analogue risk task, DDT = delayed discounting task.

Author/Date	N	Country	Design	Sleep	S/P/O	Risk	S/O	Summary
<i>Ayres et al. 2016 (48)</i>	13,570	US	C	School night TST ≥ 8 h vs < 8 h	S	Non-medical use of prescription medication	S	Adolescents obtaining less than 8 h sleep on school nights were significantly more likely to report non-medical use of prescription medication than those obtaining ≥ 8 h
<i>Backman et al. 2015 (49)</i>	4,855	Finland	C	Weekly TST ≥ 7 vs < 7 h	S	Property crime, violent crime	S	Insufficient sleep (< 7 h on both school nights and weekends) was significantly associated with property and violent crime
<i>Bagley et al. 2012 (50)</i>	1,077	US	C*	Weekly TST (weeknight & weekend TST)	S	delinquency, sexual risk-taking, drug use, BART	S&O	TST per week was significantly negatively associated with general risk-taking, substance use, and sexual risk-taking, but not objective risk-taking on the BART
<i>Barnes & Meldrum 2017 (51)</i>	577	US	C	Typical TST	S	Self-control, violent delinquency, drug use (incl. alcohol and tobacco), non-violent delinquency	S	Typical TST and was significantly negatively associated with drug use and significantly positively associated with self-control, but not violent or non-violent delinquency
<i>Clinkinbeard et al. 2010 (52)</i>	14,382	US	C	Typical TST 8-10h (ref) vs 7h, 6h or ≤ 5 h	S	Violent delinquency, property delinquency	S	Adolescents typically sleeping ≤ 7 h per night reported significantly more property delinquency than those obtaining 8-10h, while those typically sleeping ≤ 5 h per night reported significantly more violent delinquency
<i>Daly et al. 2015 (53)</i>	573	US	C	School night TST ≥ 7 vs < 7 h	S	alcohol use, cigarette use, marijuana use	S	Adolescents sleeping ≤ 7 h on school nights were significantly more likely to report using alcohol, cigarettes and marijuana in the past 30 days

Sleep duration and risk-taking in adolescents

<i>Davis et al. 2013 (54)</i>	55	US	E	8.5h vs 4h sleep for one night prior to experiment	O	Pedestrian safety behaviours in a virtual environment	O	Adolescents crossed the road with less time before vehicle contact, had more virtual hits or close calls, looked left and right more often and took more time to initiate pedestrian crossings following 4h sleep compared to when they had 8.5h sleep
<i>Doku et al. 2013 (55)</i>	1,198	Ghana	C	School night TIB: ≥ 9 h vs < 9 h for 12-15-yrs, ≥ 8 h vs < 8 h for 16-18-yrs	S	Smoking, drunkenness, marijuana use, drug use	S	Adolescents who obtained sufficient sleep were significantly more likely to report marijuana or other drug use, and were more likely to have experienced drunkenness. There were no differences in the trying cigarettes or tobacco products between the two groups
<i>Hall Brown 2009 (56)</i>	35	US	E	School night TST vs weekend TST	P	Impulsivity, sensation seeking, BART, delayed discounting task	S&O	No significant within-subjects' differences were found for the BART, DDT, sensation seeking or impulsivity following 5 nights of weeknight sleep ($X = 6.92$ h, $SD = 1.05$) compared to following 2 nights of weekend sleep ($X = 8.65$ h, $SD = 1.33$)
<i>Hildenbrand et al. 2013 (57)</i>	14,782	US	C	School night TST ≥ 8 h vs < 8 h		Carrying weapons at school, physical fight at school	S	Adolescents with insufficient sleep were significantly more likely to report carrying weapons at school in the past 30 days and fighting at school in the last year
<i>McHale et al. 2011 (58)</i>	469	US	C	Weekly TST	P	Risky Behaviour Questionnaire	S	No significant relationship was found between weekly TST and risky behaviours
<i>McKnight-Eily et al. 2011 (59)</i>	12,154	US	C	School night TST ≥ 8 h vs < 8 h	S	Physical fighting, smoking, alcohol use, marijuana use, sexual activity	S	Adolescents with insufficient sleep were significantly more likely to report smoking cigarettes in the past 30 days, alcohol use, marijuana use or sexual activity in the past 3 months, and physical fighting in the past 12 months

Sleep duration and risk-taking in adolescents

<i>Meldrum et al.</i> 2014 (47)	11,641	US	C	School night TST ≥8h vs 7h, 6h, 5h & <5h	S	Drunk driving, weapon carrying, physical fighting, cigarette use, alcohol use, binge drinking, marijuana use, sexual risk- taking, texting while driving	S	Compared to adolescents obtaining ≥8h TST, adolescents obtaining ≤7h TST were more likely to smoke, use alcohol, binge drink, use marijuana and texting while driving in the past 30 days, while those obtaining ≤6h TST were more likely to report fighting in the past 12 months, and those obtaining ≤5h TST were more likely to carry weapons or drive drunk in the past 30 days. Finally, those obtaining <5h TST were significantly more likely not to use a condom at last sexual intercourse. Effects increased with shorter TSTs
<i>O'Brien & Mindell 2005</i> (60)	208	US	C	School night TST ≥8h15m vs ≤6h45m	S	Safety behaviours, violence, use of tobacco, alcohol, marijuana, drugs, sexual risk-taking	S	Adolescents obtaining less TST were significantly more likely to report using alcohol and sexual risk-taking. No significant differences were found for safety behaviours, violence, and tobacco, marijuana, or drug use
<i>Owens et al.</i> 2017 (46)	11,240	US	C	School night TST 9h vs 8h, 7h, 6h, 5h, ≤4h & ≥10h	S	Early initiation drug use, perceived risk of drug use, sensation seeking, gang involvement	S	Adolescents obtaining ≤7h TST were more likely to be at-risk for early initiation of drug use and sensation seeking, while those obtaining ≤6h TST were significantly more likely to perceive fewer risks with drug taking. Adolescents obtaining ≤4h TST were more likely to be involved with gangs
<i>Pasch et al.</i> 2010 (61)	242	US	C	School night TIB, weekend TIB	S	Smoking, alcohol use, drunkenness, marijuana use, school truancy	S	Longer school night TIB was associated with decreased odds of reporting alcohol use or drunkenness in the past month, but not smoking, marijuana use or truancy. Weekend TIB was not significantly associated with any risk-taking variables

Sleep duration and risk-taking in adolescents

<i>Pasch et al. 2012 (62)</i>	704	US	L	School night TIB, weekend TIB, weekly TIB	S	Tobacco use, alcohol use, marijuana use	S	Longer school night, weekend and weekly TIB at T1 predicted current cigarette use 2-years later. School night and weekly TIB, but not weekend TIB, at T1 significantly predicted marijuana use at T2. No relationship was found between T1 weekend TIB and risk-taking. Stronger relationships occurred between T1 substance use and T2 TIB
<i>Peach et al. 2013 (63)</i>	6,503	US	C	TST	S	Sensation seeking, delinquent behaviour	S	A significant negative relationship was found between sleep duration and delinquency, but not sensation seeking
<i>Reichenberger et al. 2015 (64)</i>	322	US	C	TIB	S	Use of cigarettes, chewing tobacco, alcohol, marijuana, other drug use, sexual risk-taking, seatbelt use	S	Adolescents who smoked, used alcohol, binge drank and used marijuana slept significantly less than those who did not. No differences in TIB were found for use of chewing tobacco, other illicit drugs, sexual risk-taking or seatbelt use
<i>Sivertsen et al. 2015 (45)</i>	9,328	Norway	C	School night TST 8-9h vs 7-8h, 6-7h, 5-6h, <5h, ≥9h	S	Alcohol use, drug use	S	Compared to adolescents obtaining 8-9h TST, adolescents with less sleep reported more alcohol use and drug use. Problematic drug and alcohol use was more prevalent when TST <7h while frequent intoxication was more prevalent when TST <6h. TST ≥9h was associated with high alcohol use and illicit drug use
<i>Stea et al. 2014 (65)</i>	2,432	Norway	C	School night TIB <8h vs ≥8h	S	Smoking, using snuff	S	Adolescents with insufficient sleep were more likely to report being a current smoker or a current snuff user

Sleep duration and risk-taking in adolescents

<i>Terry-McElrath et al. 2016 (66)</i>	379,901	US	C	Frequency of getting at least 7 hours of sleep	S	Use of alcohol, amphetamines, cigarettes, marijuana, narcotics	S	Significant negative associations were found between the frequency of getting ≥ 7 h sleep and use of cigarettes, alcohol, marijuana, amphetamines, and narcotics. Associations decreased with adolescent grade and over time (1991 to 2014)
<i>Wheaton et al. 2016 (67)</i>	50,370	US	C	School night TST 9h vs 8h, 7h, 6h, 5h, ≤ 4 h & ≥ 10 hours	S	Bicycle helmet use, seatbelt use, travelling with drink driver, drink driving, texting and driving	S	Adolescents with TST ≤ 8 h were more likely to drink drive and text while driving than those with 9h TST; adolescents with ≤ 7 h TST were more likely to not use bicycle helmets or seatbelts, or travel with a drink driver. Infrequent seatbelt use, riding with drinking driver, and drinking and driving was more likely when TST ≥ 10 h
<i>Winsler et al. 2014 (68)</i>	27,939	US	C	School night TST	S	Use of tobacco, alcohol, or marijuana, use of illicit/non-medical prescription drugs	S	Each hour of TST below 9h was associated with a increased likelihood of adolescents using either tobacco, alcohol or marijuana, or illicit/non-medical prescription drugs in the past 30 days
<i>Wong et al. 2015 (69)</i>	6,504	US	L	TST	S	Binge drinking, drink driving, sexual risk-taking, illicit drug use	S	TST was associated with concurrent binge drinking, drink driving, sexual risk-taking and illicit drug use at both T1 and T2. TST at T1 significantly predicted binge drinking and illicit drug use at T2
<i>Yen et al. 2010 (70)</i>	8,319	Taiwan	C	TST > 8 , 6-8h, < 6 h	S	Violence, alcohol use, illicit drug use, truancy, unprotected sex, theft	S	Compared to adolescents obtaining 6-8h TST, those obtaining either less <i>or</i> more sleep were more likely to report ever having unprotected sex, a conviction for theft or truancy. They were also more likely to report illicit drug use or violence in the previous year, or drunk alcohol every week

*cross-sectional data was drawn from time two of longitudinal study to include only adolescent participants.

Insert figures 2 and 3 here

Pooled results are shown in figure 3. Overall, there was a meaningful relationship between sleep duration and risk-taking, with insufficient sleep associated with 1.43 [1.26, 1.63] times greater odds of adolescent risk-taking. This relationship is deemed meaningful as the HDI lies entirely outside the ROPE of ± 0.2 . When this relationship is examined by risk-taking category, shorter sleep was associated with meaningfully greater odds of alcohol use, drug use, smoking, sexual risk-taking, and transport-related risk-taking. Although we can be 95% confident that violence/delinquency and trait risk-taking have odds ratios greater than 1, we can conclude meaningful effect sizes with only 94% and 79% confidence, respectively. The forest plot reflects similar odds ratio estimates across categories. We examined this homogeneity by calculating the estimated effect size difference (log odds ratio) for each pair of categories (see table 2). As none of the HDIs excluded 0, we have no evidence of intra-category differences in effect size. Further, 90% or more of the posterior distribution of pairwise differences between alcohol use, drug use, smoking, sexual risk-taking, and transport-related risk-taking were within the ROPE. Thus, we can conclude with 90% confidence that the difference in true effect size between these categories was negligible. There were insufficient data regarding violence/delinquency and trait risk-taking to allow confident conclusions. As shown in table 3, there was a trend for the relationship between sleep duration and risk-taking tended to be slightly stronger in studies including older adolescents. The combined effect of the coefficients for minimum and maximum age was 0.06 [-0.06, 0.16]. Thus, we can be confident that a one-year change in both minimum and maximum age is associated with a negligible change in the effect size and cannot conclude with 95% confidence that age is a meaningful covariate. However, there is weak evidence that larger increases in age range are associated with meaningfully larger effect sizes (e.g., we can be 66% confident of a meaningfully larger effect size in studies looking at oldest, 18-19,

versus youngest, 12-13, adolescents). Finally, there was no evidence that sleep duration cut-off (70% certainty of negligible difference) country of origin (80% certainty of negligible difference) or study design (62% certainty of negligible difference) affected the relationship between sleep duration and risk-taking.

Table 2. Log odds ratios (log OR) and 95% highest density intervals (HDI₉₅) of the difference in effect sizes between risk-taking categories, including the posterior proportion with the region of practical equivalence (ROPE).

Comparison	log OR Difference		Posterior Proportion within ROPE		
	Estimate	HDI ₉₅	Below	Within	Above
Violence - Transport	-0.09	[-0.26, 0.06]	.10	.90	.00
Violence - Trait	-0.02	[-0.24, 0.28]	.04	.89	.07
Violence - Sex	-0.10	[-0.29, 0.07]	.14	.86	.00
Violence - Drugs	-0.14	[-0.32, 0.04]	.25	.75	.00
Violence - Cigarettes	-0.11	[-0.27, 0.03]	.13	.87	.00
Violence - Alcohol	-0.16	[-0.32, 0.00]	.33	.67	.00
Transport - Trait	0.07	[-0.16, 0.39]	.01	.80	.20
Transport - Sex	-0.01	[-0.20, 0.19]	.03	.95	.02
Transport - Drugs	-0.04	[-0.25, 0.17]	.06	.93	.02
Transport - Cigarettes	-0.02	[-0.19, 0.16]	.02	.97	.01
Transport - Alcohol	-0.07	[-0.25, 0.12]	.07	.93	.00
Trait - Sex	-0.08	[-0.42, 0.18]	.23	.76	.01
Trait - Drugs	-0.12	[-0.43, 0.13]	.29	.71	.01
Trait - Cigarettes	-0.10	[-0.40, 0.14]	.22	.77	.01
Trait - Alcohol	-0.15	[-0.45, 0.10]	.34	.65	.00
Sex - Drugs	-0.03	[-0.25, 0.20]	.06	.91	.03
Sex - Cigarettes	-0.01	[-0.19, 0.18]	.02	.96	.02
Sex - Alcohol	-0.06	[-0.25, 0.14]	.07	.93	.01
Drugs - Cigarettes	0.02	[-0.18, 0.21]	.01	.95	.03
Drugs - Alcohol	-0.03	[-0.23, 0.18]	.05	.94	.01
Cigarettes - Alcohol	-0.05	[-0.22, 0.12]	.04	.96	.00

Note. The proportion of the posterior distribution within the ROPE represents the confidence we can have that the difference between categories is negligible.

Table 3. Odds ratios and 95% highest density intervals (HDI₉₅) for covariates of the relationship between sleep duration and risk-taking

Covariate and level	Odds Ratio	
	Estimate	HDI ₉₅
Age range (years)		
14-16	1.48	[1.27, 1.73]
15-17	1.56	[1.32, 1.85]
16-18	1.65	[1.30, 2.10]
17-19	1.74	[1.24, 2.40]
Sleep duration		
Continuous	1.48	[1.26, 1.76]
Cut-off = 7 h	1.49	[1.10, 1.97]
Cut-off = 8 h	1.62	[1.37, 1.98]
Cut-off = 9 h	1.26	[0.82, 1.73]
Study design		
Cross-sectional	1.49	[1.38, 1.61]
Other	1.45	[1.06, 1.99]
Country		
U.S.	1.46	[1.34, 1.58]
Other	1.62	[1.10, 2.49]

Inset Figures 4 and 5 here

Funnel plots were constructed for the total sample of studies, as well as for studies in each risk-taking category. These are shown in Figures 4 and 5. Visual inspection of the funnel plots reveal no systematic asymmetry. We used Egger's test (71) to quantify the asymmetry present in the overall funnel plot (see supplementary material for details of the analysis). We set a ROPE of ± 1 for the intercept parameter. We chose this value based on specific examples discussed by Egger et al. (71). Specifically, 1 is intermediate between the (i) the smallest absolute value of intercept estimates identified as reflecting asymmetry (1.19) and (ii) the largest absolute value of intercept estimates identified as reflecting symmetry (0.75). The analysis revealed an intercept of 0.50 [-0.87, 1.86] with 75% of the posterior lying within the ROPE. Thus, these data provide no evidence of asymmetry and consequently

no reason to suspect that the results of this meta-analysis have been distorted by publication bias.

DISCUSSION

The present review systematically reviewed the extant evidence for the relationship between sleep duration and risk-taking in adolescents. Results of the meta-analysis indicated a meaningful relationship between sleep duration and risk-taking. Despite the marked heterogeneity in how risk-taking was operationalized, the effect sizes were similar across different categories of risk-taking, including alcohol use, drug use, smoking, sexual risk-taking and risk-taking related to road/transport safety. The homogeneity suggests that the relationship between sleep duration and risk-taking is at the level of global risky decision making, rather than differentially affecting risk-taking constructs. On a practical level it shows that, if future research can garner stronger evidence that sleep plays a causal role in risk-taking, then interventions targeting specific risk behaviours, for example, promoting safe sex, or campaigns regarding drugs and alcohol use, will profit from targeting sleep as a means of harm minimisation and/or reduction.

While there was a trend for age to moderate the relationship between sleep duration and risk-taking, this relationship was weak. For country of origin, we have only weak evidence of no systematic variability between studies conducted in the U.S. versus other countries, however, there are caveats when considering these findings. First, there were few studies that were conducted outside of the U.S ($N = 5$) and these countries were heterogeneous (4 European and 1 African). There was no meaningful evidence that the relationship between sleep duration and risk-taking varied according to study design, or how sleep duration was operationalized. In regard to sleep duration operationalization, it must be noted that four of the meta-analysed studies had originally compared different sleep duration

categories against a reference category representing “ideal” sleep (45-47, 67), resulting in multiple effect sizes for each risk-taking variable. Comparing various sleep durations against an “optimal” sleep duration allows non-linear relationships to be observed, such as U-shaped relationships between sleep duration and risk-taking where both short and long sleep durations are associated with heightened risk-taking. It also does not obscure differences that may occur between individuals who obtain less than the ideal duration of sleep, but rather allows for dose-response effects to be observed, which are not seen when comparing sleep duration categories above and below a cut-off (47). Unfortunately, multiple effect sizes per risk-taking variable per study were not suitable for meta-analysis and these results needed to be dichotomised. Examining sleep as a continuous variable or dichotomising sleep duration may attenuate effect sizes if the relationship between sleep duration and risk-taking is non-linear. Thus, the current approach, while necessary for meta-analysis, could not include these studies in a separate category of sleep operationalization.

The primary limitation in this literature is the paucity of experimental and longitudinal research. In addition to experimental and longitudinal research, quasi-experimental designs - especially when quasi-experiments use more sophisticated data-analytic approaches such as propensity score matching- would also benefit this literature (72, 73). To date, the advancement of knowledge in this field has primarily relied upon large-scale cross-sectional surveys, with 85% of included studies using a cross-sectional design. While these studies have some major strengths, such as enabling the collection of data from over 500,000 adolescents, and assessing risk-taking behaviours that contribute to the leading causes of death and disability among adolescents, the major limitation of this approach is that causation cannot be established. This is a significant concern given that strong arguments could be made that, a) the direction of the effect may be opposite, with risk-taking propensity having a causal role in short sleep durations (i.e., risky decision making in terms of sleep), or b) both

risk-taking and sleep duration are likely impacted by third variables, such as family environment, or parent limit-setting.

Establishing causality is important before including sleep in potential intervention/prevention campaigns. Four studies used methodologies that allow causal conclusions and, together, they provide tentative support for sleep as a cause of risk-taking. Specifically, two longitudinal studies reported both concurrent and longitudinal associations between sleep duration and binge drinking, illicit drug use, and cigarette use (62, 69), with one also reporting significant bidirectional relationships (62). An experimental study by Davis and colleagues compared adolescents' performance in a virtual pedestrian environment after 8.5 hours sleep and 4 hours sleep. Adolescents made significantly more risky choices, which included allowing less distance between themselves and an oncoming car when crossing the road, and having more virtual hits or close calls, when sleep restricted compared to when they were well rested (54). The fourth study used naturalistic sleep restriction and extension to manipulate sleep duration (56). Specifically, adolescents' performance on two objective gambling tasks, and self-reported sensation seeking and impulsivity, were compared after 5 nights of weeknight sleep (sleep restriction, TST X = 6.92 h) and after 2 nights of weekend sleep (sleep extension, TST X = 8.65 h). No significant differences were found between any measures of risk-taking. However, these findings are limited by the imprecision of the naturalistic design and the inter-individual differences in the sleep obtained in both sleep restriction and extension conditions. Thus, while existing evidence suggests that sleep duration has a causal role in risk-taking, we need more evidence, particularly from experimental studies, to make strong causal attributions.

Future research would also profit from examining the mechanisms that explain any potential relationship between sleep duration and risk-taking. Neuroimaging studies support the notion that sleep duration may impact risk-taking behaviour through its effect on the

brain. For example, transient interference on right dorsolateral prefrontal cortex functioning resulted in heightened risk-taking among adults, aged 18 to 31 years, through failure to inhibit risky decisions, while increasing cortical excitability in this area resulted in diminished risk-taking (74, 75). Changes to prefrontal cortex functioning are similarly observed following sleep loss. In a series of experiments with young adults, Venkatraman and colleagues found that sleep loss resulted in a shift in risk-taking strategy away from defence against losses and towards greater reward-seeking. These strategic shifts were correlated with decreased orbitofrontal and insular cortical activation (reduced activation for losses) as well as increased activity in the right nucleus accumbens (heightened activation for rewards) (13, 76).

One adolescent imaging study recruited 58 early adolescents, aged 11 to 13 years, who monitored their sleep at home for four days using actigraphy and self-report prior to functional magnetic resonance image scanning while completing risk-taking task (77). Adolescents who obtained less sleep showed less activation in the caudate of the ventral striatum in anticipation of a reward. The authors suggest that adolescents who obtained less sleep had dampened reactivity of this reward-related brain region, thus requiring these adolescents to seek more exciting or risky rewards to experience reward circuitry activation (77). Thus, while extant evidence is promising, further research in this area is needed to better elucidate this relationship.

Risk of bias assessment indicates that the quality of the evidence for the identified studies is mixed. Common strengths of this literature included low risk of selection bias and low risk of bias due to confounding. The risk of selection bias could be further reduced by providing full descriptions of participant inclusion criteria and achieving higher response rates. The major risk of bias in the literature is information bias, with most studies including subjective measurement of both sleep duration and risk-taking. The use of subjective

measures exclusively has inherent risks, including inaccuracy and responding biases. As responding biases may operate similarly among self-report measure, associations between two subjective self-report measures can be inflated. There are two important points to note regarding the risk of bias assessment. First, while most of studies were deemed to have a low risk of bias due to confounding, this binary measurement of risk confounding is rudimentary, with studies being assessed as either including or not including covariates. While many studies did control for key confounders, such as sex, age, socioeconomic status, and race/ethnicity, other confounding factors, such as genetic predisposition to risk-taking (51), are typically not considered. Second, it is important to note that the use of objective measures of sleep and/or risk-taking often comes at a cost in terms of sample size. While ideal, the use of objective measures is frequently not feasible in large epidemiological studies, where thousands, and sometimes hundreds of thousands, of adolescents are recruited, thus a balance between large, epidemiological studies and smaller studies including objective measures is desirable.

In conclusion, empirical evidence obtained from over 500,000 adolescents shows an association between sleep duration and risk-taking in adolescents across domains of risk-taking such as drug use, alcohol use, smoking, transport/road safety, sexual risk-taking, violent/delinquent behaviour and trait risk-taking/sensation seeking. Due to limitations in the design of most studies, strong causal conclusions cannot be made. Research focusing on the elucidation of causal (including possibly bi-directional) relationships, and examining the mechanisms of action, deserve priority. If sleep loss leads to more risky decision making, this may begin a self-perpetuating cycle, with poor sleep leading to poor decision making about sleep, leading to poorer sleep, and so on. This is an important and timely issue, given the importance of risk-taking to adolescent well-being, morbidity and mortality, and the potential for simple interventions targeting sleep to have wide-ranging benefits.

Practice points

1. This systematic review examined the association between sleep duration and risk-taking in 579,380 adolescents from identified 26 studies, 24 of which were included the meta-analysis.
2. Pooled results indicated that shorter sleep was associated with increased odds of risk-taking behaviours, including the use of cigarettes, alcohol and drugs, sexual risk-taking, transport/road safety risk-taking and violence, but not gambling.
3. Studies including older adolescents tended to report stronger relationships between sleep duration and risk-taking, although this evidence was weak.
4. How sleep duration was operationalised, country of origin and study design did meaningfully moderate the effect of sleep duration on risk-taking.

Research agenda

1. While the extant evidence supports an association between sleep duration and risk-taking in adolescents, there is a clear need for more longitudinal and experimental studies to address the issue of causation and bidirectionality.
2. In addition to study design, the primary limitation of the current literature is the measurement of both sleep duration and risk-taking, which was almost exclusively measured by subjective self-report measures. Due to the risk of report biases and inflated associations derived from two self-report measures, the use of objective measures is advised, where possible.
3. Greater research attention is needed to elucidate the mechanisms of action that explain how insufficient sleep impacts risk-taking propensity.

REFERENCES

1. Maggs JL, Schulenberg JE. Initiation and Course of Alcohol Consumption among Adolescents and Young Adults. In: Galanter M, Lowman C, Boyd GM, Faden VB, Witt E, Lagressa D, editors. *Recent Developments in Alcoholism: Alcohol Problems in Adolescents and Young Adults*. Boston, MA: Springer US; 2005. p. 29-47.
2. Simons-Morton BG, Ouimet MC, Zhang Z, Klauer SE, Lee SE, Wang J, et al. Crash and Risky Driving Involvement Among Novice Adolescent Drivers and Their Parents. *American Journal of Public Health*. 2011;101(12):2362-7.
3. Kershaw TS, Ethier KA, Niccolai LM, Lewis JB, Ickovics JR. Misperceived risk among female adolescents: social and psychological factors associated with sexual risk accuracy. *Health Psychology*. 2003;22(5):523.
4. Gupta R, Derevensky JL. Adolescent gambling behavior: A prevalence study and examination of the correlates associated with problem gambling. *Journal of gambling studies*. 1998;14(4):319-45.
5. Moffitt TE. Adolescence-limited and life-course-persistent offending: A complementary pair of developmental theories. *Developmental theories of crime and delinquency*. 1997;7:11-54.
6. Gardner M, Steinberg L. Peer influence on risk taking, risk preference, and risky decision making in adolescence and adulthood: an experimental study. *Dev Psychol*. 2005;41(4):625-35.
7. Sleet DA, Ballesteros MF, Borse NN. A review of unintentional injuries in adolescents. *Annual review of public health*. 2010;31:195-212 4 p following
8. *Davis AL, Avis KT, Schwebel DC. The effects of acute sleep restriction on adolescents' pedestrian safety in a virtual environment. *The Journal of adolescent health : official publication of the Society for Adolescent Medicine*. 2013;53(6):785-90.
9. Womack SD, Hook JN, Reyna SH, Ramos M. Sleep loss and risk-taking behavior: a review of the literature. *Behavioral sleep medicine*. 2013;11(5):343-59.
10. Harrison Y, Horne JA. The impact of sleep deprivation on decision making: a review. *Journal of experimental psychology: Applied*. 2000;6(3):236.
11. Shingledecker CA, Holding DH. Risk and Effort Measures of Fatigue. *Journal of Motor Behavior*. 1974;6(1):17-25.
12. Killgore WDS, Grugle NL, Balkin TJ. Gambling When Sleep Deprived: Don't Bet on Stimulants. *Chronobiology international*. 2012;29(1):43-54.
13. Venkatraman V, Huettel SA, Chuah LY, Payne JW, Chee MW. Sleep deprivation biases the neural mechanisms underlying economic preferences. *Journal of Neuroscience*. 2011;31(10):3712-8.
14. Roehrs T, Greenwald M, Roth T. Risk-taking behavior: effects of ethanol, caffeine, and basal sleepiness. *Sleep*. 2004;27(5):887-93.
15. Schoenborn CA, Adams PF. Sleep duration as a correlate of smoking, alcohol use, leisure-time physical inactivity, and obesity among adults: United States, 2004-2006. Book *Sleep duration as a correlate of smoking, alcohol use, leisure-time physical inactivity, and obesity among adults: United States, 2004-2006*. 2008.
16. Vail-Smith K, Felts WM, Becker C. Relationship between sleep quality and health risk behaviors in undergraduate college students. *College Student Journal*. 2009;43(3):924-30.
17. Goel N, Rao H, Durmer JS, Dingus DF, editors. *Neurocognitive consequences of sleep deprivation*. Seminars in neurology; 2009: © Thieme Medical Publishers.
18. Thomas M, Sing H, Belenky G, Holcomb H, Mayberg H, Dannals R, et al. Neural basis of alertness and cognitive performance impairments during sleepiness. I. Effects of 24 h of sleep deprivation on waking human regional brain activity. *Journal of sleep research*. 2000;9(4):335-52.
19. Hirshkowitz M, Whiton K, Albert S, Alessi C, Bruni O, DonCarlos L, et al. National Sleep Foundation's sleep time duration recommendations: methodology and results summary. *Sleep Health*. 2015;1(1):40-3.
20. Paruthi S, Brooks LJ, D'Ambrosio C, Hall WA, Kotagal S, Lloyd RM, et al. Recommended Amount of Sleep for Pediatric Populations: A Consensus Statement of the American Academy of

- Sleep Medicine. *Journal of clinical sleep medicine : JCSM : official publication of the American Academy of Sleep Medicine*. 2016;12(6):785-6.
21. Short MA, Weber N, Reynolds C, Coussens S, Carskadon MA. Estimating Adolescent Sleep Need Using Dose-Response Modelling. *Sleep*. 2018:zsy011-zsy.
 22. Yang CK, Kim JK, Patel SR, Lee JH. Age-related changes in sleep/wake patterns among Korean teenagers. *Pediatrics*. 2005;115(1 Suppl):250-6.
 23. Lo JC, Ong JL, Leong RL, Gooley JJ, Chee MW. Cognitive performance, sleepiness, and mood in partially sleep deprived adolescents: The Need for Sleep study. *Sleep*. 2016;39(3):687-98.
 24. Chen M-Y, Wang EK, Jeng Y-J. Adequate sleep among adolescents is positively associated with health status and health-related behaviors. *BMC Public Health*. 2006;6:59-.
 25. Asarnow LD, McGlinchey E, Harvey AG. The effects of bedtime and sleep duration on academic and emotional outcomes in a nationally representative sample of adolescents. *Journal of Adolescent Health*. 2014;54(3):350-6.
 26. Romer D, Betancourt LM, Brodsky NL, Giannetta JM, Yang W, Hurt H. Does adolescent risk taking imply weak executive function? A prospective study of relations between working memory performance, impulsivity, and risk taking in early adolescence. *Developmental science*. 2011;14(5):1119-33.
 27. Romer D. Adolescent Risk Taking, Impulsivity, and Brain Development: Implications for Prevention. *Developmental psychobiology*. 2010;52(3):263-76.
 28. *Shochat T, Cohen-Zion M, Tzischinsky O. Functional consequences of inadequate sleep in adolescents: a systematic review. *Sleep Med Rev*. 2014;18(1):75-87.
 29. Stanley TD. Wheat from Chaff: Meta-Analysis as Quantitative Literature Review. *The Journal of Economic Perspectives*. 2001;15(3):131-50.
 30. Rosenthal R, DiMatteo MR. Meta-analysis: recent developments in quantitative methods for literature reviews. *Annual review of psychology*. 2001;52:59-82.
 31. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS medicine*. 2009;6(7):e1000097.
 32. Byrnes JP, Miller DC, Schafer WD. Gender differences in risk taking: A meta-analysis. American Psychological Association; 1999.
 33. Organization WH. Health for the World's Adolescents. A second chance in the second decade, 2014. URL: http://apps.who.int/adolescent/second-decade/files/1612_MNCAH_HWA_Executive_Summary.pdf [accessed 2015-09-09][WebCite Cache ID 6bPyeGf3i]. 2015.
 34. Yu IT, Tse SL. Workshop 6--sources of bias in cross-sectional studies; summary on sources of bias for different study designs. *Hong Kong medical journal = Xianggang yi xue za zhi*. 2012;18(3):226-7.
 35. Sutton AJ, Abrams KR. Bayesian methods in meta-analysis and evidence synthesis. *Statistical methods in medical research*. 2001;10(4):277-303.
 36. Sutton AJ, Welton NJ, Ades A, Cooper N, Abrams KR. Evidence synthesis for decision making in healthcare: John Wiley & Sons; 2012.
 37. Borenstein M, Hedges, L.V., Higgins, J.P.T. & Rothstein, H.R. . Introduction to Meta-Analysis: John Wiley & Sons, Ltd.; 2009.
 38. Kruschke JK. Doing Bayesian Data Analysis, 2nd Ed: A Tutorial with R, JAGS, and Stan. London, UK.: Academic Press.; 2015.
 39. R Core Development Team. R: A Language and Environment for Statistical Computing. Vienna, Austria: The R Foundation for Statistical Computing; 2011.
 40. Plummer M. JAGS version 4.3.0 user manual 2017.
 41. Denwood MJ. runjags: An R Package Providing Interface Utilities, Model Templates, Parallel Computing Methods and Additional Distributions for MCMC Models in JAGS. 2016. 2016;71(9):25.
 42. Gelman A, & Rubin, D. B. Inference from iterative simulation using multiple sequences. *Statistical Science*. 1992;7:457-47.

43. Kruschke JKaV, W. (2015). In: J. R. Busemeyer, Z. Wang, J. , editor. Bayesian estimation in hierarchical models. Oxford, UK: Oxford University Press.; 2015.
44. Wickham H. ggplot2: Elegant Graphics for Data Analysis. New York: Springer-Verlag.; 2009.
45. *Sivertsen B, Skogen JC, Jakobsen R, Hysing M. Sleep and use of alcohol and drug in adolescence. A large population-based study of Norwegian adolescents aged 16 to 19 years. *Drug and alcohol dependence*. 2015;149:180-6.
46. *Owens J, Wang G, Lewin D, Skora E, Baylor A. Association Between Short Sleep Duration and Risk Behavior Factors in Middle School Students. *Sleep*. 2017;40(1):01.
47. *Meldrum RC, Restivo E. The behavioral and health consequences of sleep deprivation among U.S. high school students: Relative deprivation matters. *Preventive medicine*. 2014;63:24-8.
48. Ayres CG, Pontes NM, Pontes MC. Understanding the Nonmedical Use of Prescription Medications in the U.S. High School Adolescents. *Journal of School Nursing*. 2016;11:11.
49. Backman H, Laajasalo T, Saukkonen S, Salmi V, Kivivuori J, Aronen ET. Are qualitative and quantitative sleep problems associated with delinquency when controlling for psychopathic features and parental supervision? *J Sleep Res*. 2015;24(5):543-8.
50. Bagley EJ. Exploring sources of the association between sleep and risk-taking from late-childhood into adolescence. *Dissertation Abstracts International: Section B: The Sciences and Engineering*. 2012;73(1-B):657.
51. *Barnes JC, Meldrum RC. The impact of sleep duration on adolescent development: a genetically informed analysis of identical twin pairs. *Journal of youth and adolescence*. 2015;44(2):489-506.
52. Clinkinbeard SS, Simi P, Evans MK, Anderson AL. Sleep and delinquency: does the amount of sleep matter? *Journal of youth and adolescence*. 2011;40(7):916-30.
53. Daly BP, Jameson JP, Patterson F, McCurdy M, Kirk A, Michael KD. Sleep duration, mental health, and substance use among rural adolescents: Developmental correlates. *Journal of Rural Mental Health*. 2015;39(2):108-22.
54. Davis AL, Avis KT, Schwebel DC. The Effects of Acute Sleep Restriction on Adolescents' Pedestrian Safety in a Virtual Environment. *Journal of Adolescent Health*. 2013;53(6):785-90.
55. Doku D, Koivusilta L, Rimpelä A. Sleep and Its Association With Socioeconomic Status, Health, and Risky Behaviors Among Ghanaian School Children. *Journal of Research on Adolescence*. 2013;23(4):706-15.
56. Hall Brown TS. The effects of natural sleep debt on current mood, working memory, and risk-taking propensity. *Dissertation Abstracts International: Section B: The Sciences and Engineering*. 2009;69(9-B):5778.
57. Hildenbrand AK, Daly BP, Nicholls E, Brooks-Holliday S, Kloss JD. Increased Risk for School Violence-Related Behaviors Among Adolescents With Insufficient Sleep. *Journal of School Health*. 2013;83(6):408-14.
58. McHale SM, Kim JY, Kan M, Updegraff KA. Sleep in Mexican-American Adolescents: Social Ecological and Well-Being Correlates. *Journal of youth and adolescence*. 2011;40(6):666-79.
59. McKnight-Eily LR, Eaton DK, Lowry R, Croft JB, Presley-Cantrell L, Perry GS. Relationships between hours of sleep and health-risk behaviors in US adolescent students. *Preventive medicine*. 2011;53(4-5):271-3.
60. O'Brien EM, Mindell JA. Sleep and risk-taking behavior in adolescents *Behavioral Sleep Medicine*. 2005;3(3):113-33.
61. Pasch KE, Laska MN, Lytle LA, Moe SG. Adolescent sleep, risk behaviors, and depressive symptoms: Are they linked? *American journal of health behavior*. 2010;34(1):237-48.
62. *Pasch KE, Latimer LA, Cance JD, Moe SG, Lytle LA. Longitudinal Bi-directional Relationships Between Sleep and Youth Substance Use. *Journal of youth and adolescence*. 2012;41(9):1184-96.
63. *Peach HD, Gaultney JF. Sleep, Impulse Control, and Sensation-Seeking Predict Delinquent Behavior in Adolescents, Emerging Adults, and Adults. *Journal of Adolescent Health*. 2013;53(2):293-9.

64. Reichenberger DA, Hilmert CJ, Irish LA, Secor-Turner M, Randall BA. Associations Between Sleep and Health-Risk Behaviors in a Rural Adolescent Population. *Journal of Pediatric Health Care*. 2016;30(4):317-22.
65. Stea TH, Knutsen T, Torstveit MK. Association between short time in bed, health-risk behaviors and poor academic achievement among Norwegian adolescents. *Sleep Medicine*. 2014;15(6):666-71.
66. Terry-McElrath YM, Maslowsky J, O'Malley PM, Schulenberg JE, Johnston LD. Sleep and Substance Use among US Adolescents, 1991–2014. *American journal of health behavior*. 2016;40(1):77-91.
67. *Wheaton AG, Olsen EO, Miller GF, Croft JB. Sleep duration and injury-related risk behaviors among high school students - United States, 2007-2013-
<https://www.cdc.gov/mmwr/volumes/65/wr/mm6513a1.htm> *Morbidity and Mortality Weekly Report*. 2016;65(13):337-41.
68. Winsler A, Deutsch A, Vorona RD, Payne PA, Szklo-Coxe M. Sleepless in Fairfax: the difference one more hour of sleep can make for teen hopelessness, suicidal ideation, and substance use. *Journal of youth and adolescence*. 2015;44(2):362-78.
69. *Wong MM, Robertson GC, Dyson RB. Prospective Relationship Between Poor Sleep and Substance-Related Problems in a National Sample of Adolescents. *Alcoholism: Clinical and Experimental Research*. 2015;39(2):355-62.
70. Yen CF, King BH, Tang TC. The association between short and long nocturnal sleep durations and risky behaviours and the moderating factors in Taiwanese adolescents. *Psychiatry Research*. 2010;179(1):69-74.
71. Egger M, Smith GD, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ*. 1997;315(7109):629-34.
72. Sung B. Analysis of the Relationship between Sleep Duration and Body Mass Index in a South Korean Adult Population: A Propensity Score Matching Approach. *Journal of Lifestyle Medicine*. 2017;7(2):76-83.
73. Boutwell BB, Beaver KM. Maternal cigarette smoking during pregnancy and offspring externalizing behavioral problems: a propensity score matching analysis. *Int J Environ Res Public Health*. 2010;7(1):146-63.
74. Knoch D, Gianotti LRR, Pascual-Leone A, Treyer V, Regard M, Hohmann M, et al. Disruption of Right Prefrontal Cortex by Low-Frequency Repetitive Transcranial Magnetic Stimulation Induces Risk-Taking Behavior. *The Journal of Neuroscience*. 2006;26(24):6469-72.
75. Fecteau S, Knoch D, Fregni F, Sultani N, Boggio P, Pascual-Leone A. Diminishing Risk-Taking Behavior by Modulating Activity in the Prefrontal Cortex: A Direct Current Stimulation Study. *The Journal of Neuroscience*. 2007;27(46):12500-5.
76. Venkatraman V, Chuah YM, Huettel SA, Chee MW. Sleep deprivation elevates expectation of gains and attenuates response to losses following risky decisions. *Sleep*. 2007;30(5):603-9.
77. Holm SM, Forbes EE, Ryan ND, Phillips ML, Tarr JA, Dahl RE. Reward-related brain function and sleep in pre/early pubertal and mid/late pubertal adolescents. *The Journal of adolescent health : official publication of the Society for Adolescent Medicine*. 2009;45(4):326-34.









