Published in final edited form as:

Sleep Med. 2012 December ; 13(10): 1261–1270. doi:10.1016/j.sleep.2012.08.005.

Sleep Duration versus Sleep Insufficiency as Predictors of Cardiometabolic Health Outcomes

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Abstract

Objective—The objective of the present study was to investigate the relationship between sleep insufficiency and sleep duration, particularly regarding negative cardiometabolic health outcomes already considered to be affected by reduced sleep time.

Methods—A total of N=30,934 participants from the 2009 Behavioral Risk Factor Surveillance System (BRFSS) answered questions about their sleep duration as well as subjective feelings of sleep insufficiency. Outcomes included body mass index (BMI), obesity (BMI ≥ 30), and history of hypertension, diabetes, hypercholesterolemia, heart attack, and stroke. Linear and logistic regression models examined whether cardiometabolic outcomes were associated with (1) sleep duration alone, (2) sleep insufficiency alone, and (3) the combined effect of sleep duration and sleep insufficiency.

Results—Results indicated that, when examined alone, sleep duration <5 hours (vs 7 hours) was related to BMI (B=2.716, p<0.01), obesity (B=2.080, p<0.000001), diabetes (B=3.162, p<0.000001), hypertension (B=2.703, p<0.000001), hypercholesterolemia (B=1.922, p<0.000001), heart attack (B=4.704, p<0.000001), and stroke (B=4.558, p<0.000001), and sleep insufficiency (days per week, continuous) was related to BMI (B=0.181, p<0.01), obesity (B=1.061, p<0.000001), and hypercholesterolemia (B=1.025, p<0.01). All of these relationships remained significant after adjustment for covariates, except for diabetes and sleep duration. Also, after adjustment, a significant relationship between insufficient sleep and hypertension emerged (B=1.039, p<0.001). When evaluated together, after adjustment for covariates, significant

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The authors report no conflicts of interest.

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relationships remained between sleep duration <5 hours (vs 7 hours) and BMI ($B=1.266$, $p<0.05$), obesity ($B=1.389$, $p<0.05$), hypertension ($B=1.555$, $p<0.01$), heart attack ($B=2.513$, $p<0.01$) and stroke ($B=1.807$, $p<0.05$). It should be noted that relationships between sleep duration >9 hours (vs 7 hours) were seen for heart attack ($B=1.863$, $p<0.001$) and stroke ($B=1.816$, $p<0.01$). In these models, sleep insufficiency was associated with hypercholesterolemia ($B=1.031$, $p<0.01$) and hypertension ($B=1.027$, $p<0.05$).

Conclusions—These analyses show that both sleep duration and insufficiency are related to cardiometabolic health outcomes, and that when evaluated together, both variables demonstrate unique effects.

Keywords

Sleep; Obesity; Cardiovascular Disease; Diabetes; Hypertension

INTRODUCTION

Short sleep duration and insufficient sleep are common in the general population and have many effects on the biological and physiological processes in a body, causing metabolic dysfunction [1–8]. Several epidemiologic studies have documented that self-reported short and/or long sleep duration and insufficient sleep due to sleep difficulties are associated with adverse health outcomes including obesity, cardiovascular disease, and mortality [6, 9–12], but remarkably few studies have investigated individual differences in both response to insufficient sleep and physiologic sleep need and their association with adverse health outcomes [6]. There are likely natural short sleepers or natural long sleepers who have lower/longer basal sleep need and, hence, would not suffer adverse consequences. However, it is uncertain whether the established negative effects of sleep duration (particularly short sleep) on cardiometabolic health relate at least partially to unmet sleep need, in addition to sleep duration.

Sleep duration and insufficient sleep likely represent overlapping, though separate, constructs [6, 13]. It is possible that these two influences exert different or combined effects on health. For example, it may be the case that even if an individual feels sufficiently rested after six hours of sleep, the body may not have had the time required to complete sleep-specific processes. In this case, sleep duration effects would be present in the absence of perceived insufficient sleep effects. On the other hand, a person may be experiencing a situation in which restorative processes associated with sleep are hindered by competing processes (e.g., chronic inflammation) and is able to recognize sleep insufficiency, despite adequate duration. If these situations were associated with negative outcomes, then it would be an effect of insufficient sleep separate from short sleep duration. While many studies have shown associations of sleep duration or insufficient sleep with cardiometabolic outcomes separately, few studies compared sleep duration versus sleep insufficiency as predictors of cardiometabolic health outcomes until now.

The question of sleep insufficiency attempts to indicate healthy sleep more directly than with a measure of sleep duration, which may exclude important individual differences in sleep need. The preponderance of studies find that the sleep duration associated with lowest risk for adverse outcomes in adults is between 7–8 hours [12, 14–16]. Inter-individual differences in response to sleep deprivation have been demonstrated in controlled environments [17]. However, it has been challenging to capture differences in sleep need at the population level. The experimental studies suggest the pertinence of addressing the role of sleep sufficiency/insufficiency as a risk factor for cardiometabolic outcomes. Despite this, very few studies have specifically addressed health effects of unmet sleep need independent of sleep duration. Shankar and colleagues [18] explored the effects of perceived insufficient

sleep on cardiometabolic disease. This study found a negative association between unmet sleep need and cardiometabolic health. Earlier studies also found a significant positive correlation between perceived sleep insufficiency and reported poor general health, functional deficits [1] and increased cortisol secretion and abnormal growth hormone metabolism [19].

It should be noted that this is a global issue. Studies from many countries and multiple continents have shown that sleep duration is associated with overall health and mortality, as well as specific cardiovascular and/or metabolic disorders. Findings from Australia[20–23], Brazil[24], China[25], Finland[26–28], Germany[29], Italy[30], Japan[31–36], Korea[37], the Netherlands[38], Sweden[39–41], Taiwan[42, 43], the UK[44, 45], and many other countries. Multinational studies have been conducted across Europe[46–48] as well.

The present study examines the separate and combined relationship of both self-reported sleep duration and self-reported sleep insufficiency to self-reported health outcomes. We hypothesize that (1) self-reported sleep duration will be significantly associated with adverse cardiometabolic health outcomes, (2) perceived insufficient sleep will also be significantly associated with adverse cardiometabolic health outcomes, and (3) when self-reported sleep duration and perceived insufficient sleep are evaluated simultaneously, one variable will remain significantly associated, while the other variable will no longer be significantly associated. In this case, the effect of one variable will be explained by the other.

METHODS

Data from the 2009 Behavioral Risk Factor Surveillance System (BRFSS) were used [49]. The BRFSS is an annual, state-based, random-digit-dialed telephone interview survey of adults aged 18 years from all over the United States. It is conducted by the Centers for Disease Control and Prevention and it is designed to monitor health-related behaviors in the general population. For the present analyses, data from 6 states were included, representing states from the West (Hawaii and Wyoming), South (Georgia and Louisiana), and Midwest (Illinois and Minnesota); no states from the Northeast provided data. Response rates ranged from 45.6% (Hawaii) to 59.7% (Minnesota), and cooperation rates ranged from 68.9% (Hawaii) to 83.9% (Georgia)[50].

All analyses are adjusted to remove bias in the sample. To do this, BRFSS assigns a weight to each participant to account for differences in selection probability, lack of coverage or response, number of residential telephone lines in the home of each participant, and number of adults in the household. This increases generalizability of results by accounting for factors of location and accessibility, and characteristics such as age, sex, and ethnicity. A more detailed description can be located within BRFSS documentation [50].

Outcomes included body mass index (BMI; computed from self-reported height and weight), obesity (BMI ≥ 30), and self-reported history of hypertension, diabetes, hypercholesterolemia, heart attack, and stroke. Although the accuracy of self-reported BMI may be somewhat unreliable due to reporting bias, these data have demonstrated their utility and have been accepted in other studies [51–55].

Hypertension was assessed with the question, “Have you ever been told by a doctor, nurse, or other health professional that you have high blood pressure?” Diabetes, hypercholesterolemia, myocardial infarction and stroke were assessed using similar questions, substituting “you have high blood pressure” for “you have diabetes,” “your blood cholesterol is high,” “you had a heart attack,” and “you had a stroke,” respectively. Follow-up questions for hypertension and diabetes ruled out these conditions if they only existed during pregnancy. Responses were characterized as either “yes” or “no.”

Self-reported habitual sleep duration was assessed using the question, “On average, how many hours of sleep do you get in a twenty-four hour period? Think about the time you actually spend sleeping or napping, not just the amount of sleep you think you should get.” Hours of sleep were entered in whole numbers. Responses were categorized as <5, 5–6, 7 [reference], 8–9, and 10 hours. Perceived sleep insufficiency was assessed using the question, “During the past thirty days, for about how many days have you felt you did not get enough rest or sleep?” Responses were transformed to number of days per week (by dividing by 4.285) for improved clarity in interpretation.

Covariates included in analyses were age, sex, race/ethnicity (white, black, Hispanic, other, multiracial), education (less than high school, high school graduate, some college, college graduate), income (<\$10,000, \$10,000–\$15,000, \$15,000–\$20,000, \$20,000–\$25,000, \$25,000–\$35,000, \$35,000–\$50,000, \$50,000–\$75,000, and \$75,000), employment (employed, retired, homemaker, student, unemployed, unable to work), marital status (married, divorced, widowed, separated, never married, living with partner), Census region (west, midwest, south; no subjects from the northeast), minutes of exercise (sum of minutes of moderate and vigorous activity), any exercise in past month (yes or no), alcohol intake (drinks/month), heavy drinking (yes or no), smoking status (yes or no), and healthy diet (quantity of fruits and vegetables consumed), household size (number of adults plus children in household). Overall health was assessed with the item, “Would you say that in general your health is:” with the choices of excellent, very good, good, poor, or very poor. Physical health was assessed as days of poor physical health in the past 30 days, and mental health was assessed as days of poor mental health in the past 30 days. BMI was included as a covariate for analyses examining diabetes, hypertension, hypercholesterolemia, heart attack and stroke. These variables were chosen a priori, as previous studies have found that these variables were related to sleep[12, 56].

Statistical Analyses

Complete case analysis was implemented for both sleep duration and sleep insufficiency, such that only participants who provided complete data were included for each analysis. Categorical variables were expressed as percentages while continuous variables were expressed in terms of mean ($\pm$ SD). To assess unadjusted associations between each dependent variable and all covariates, Rao-Scott Chi-square and logistic regression were used for the categorical data and multivariable linear regression was used for continuous data. For each dependent outcome, three separate models were subsequently built by adding the sleep-related parameter as follows; 1) sleep duration alone; 2) sleep insufficiency alone; and 3) sleep duration and sleep insufficiency together. All significantly associated covariates were also added into the final model.

Regression results for BMI are reported as Unstandardized B coefficients. These numbers reflect the raw change in the outcome variable (i.e. BMI), given a 1-unit change in the predictor variable. In the case of insufficient sleep, these results could be interpreted as, “For every 1 day of insufficient sleep per month, an increase in B units of BMI would be predicted.” Similarly, in the case of sleep duration, results could be interpreted as, “This sleep duration category was associated with a BMI of B points higher than the reference group (7 hours).” This way, the results are directly interpretable. Regression results for binary outcomes (i.e., history of disease conditions) are represented as Odds Ratios (ORs). These values reflect the difference in probability of endorsing an outcome, relative to a reference. Therefore, for insufficient sleep, ORs can be interpreted as, “For every 1 more night of insufficient sleep, the likelihood of having this outcome increases by (OR-1)%.” So if the OR=1.01, the likelihood increases by 1% for each night of insufficient sleep (i.e., likelihood is 10% for those with 10 nights versus 0 nights). For sleep duration, these values can be interpreted similarly, as “Being in this sleep duration group is associated with a

(OR-1)% increased likelihood of having this condition, as compared to the reference group (7 hours).”

The multivariable model was built with only sleep duration and only sleep insufficiency to evaluate if either one of them or both were significantly associated with the primary outcomes. The model with both sleep duration and sleep insufficiency was used to explore relationships in the context of any unknown correlation between these two predictors. In the case that both variables were significant in the single-predictor model, adding both variables to the third model would aid in detecting the stronger predictor because the stronger one would diminish the association between the weaker predictor and the outcome. McFadden’s Pseudo- R^2 is reported as a measure of relative strength of the associations in the models. McFadden’s Pseudo- R^2 is calculated as the ratio of the log likelihood of the fit model to the log likelihood of the intercept only model. Pseudo R^2 values are dissimilar from R^2 values resultant from least squares regression and should not be interpreted as proportion of variance explained, but rather as a measure of model fit relative to other models of the same dependent variable.

This sample of greater than 30,000 individuals represents a population of approximately 21 million. As a result, we have the power to detect significance for extremely small effect sizes. Indeed, even for the least prevalent outcome (stroke 2.4%) we are powered at >90% for an Odds Ratio of 1.002, and at 100% power for Odds Ratios larger than 1.003 for the Sleep Insufficiency predictor. As the prevalence of the outcome increases (as it does for the other outcomes), our power is further increased at increasing small effect sizes. Indeed, this is a strength of population-based studies, such that small effects may be easily detected. Ultimately, these effects must be viewed in the context of their clinical relevance. We have mentioned how the power of this study affects the statistical significance in the discussion and have further emphasized the importance of examining the size and subsequent relevance of the estimates that show statistical significance.

A two-tailed P-value of <0.05 was considered significant. All statistical calculations were performed using STATA/SE version 11.1 (STATA Corp, College Station TX).

RESULTS

Subject Characteristics

The response rate to the sleep items was 98%. Of the 31,358 initial participants, 604 did not respond to the sleep duration/insufficiency items, resulting in a total of 30,934 adults aged 18 that were included in this study. They were asked questions about their race, education, income level, general health, food and exercise habits, marital status, employment status, household size, and census region. Subject characteristics are reported in Table 1. The states which provided data on sleep duration included Georgia, Hawaii, Illinois, Louisiana, Minnesota, and Wyoming. Subject characteristics are reported in Table 1, which contains both weighted and unweighted sample characteristics. Caution should be applied to interpreting the unweighted data, as the disregard for the sampling scheme will lead to incorrect distributional conclusions. Further, we investigated response versus non-response to sleep items and found no relevant differences between groups. This has been attached as Supplementary Data.

Sleep Duration Effects

Sleep duration effects were examined using Model 1 (sleep duration alone). Unadjusted and adjusted analyses for BMI are reported in Table 2, which presents unstandardized β coefficients, so that the results may be interpreted as the increase in BMI points associated with each sleep duration category or each increased day of insufficient sleep. Unadjusted

analyses for cardiometabolic outcomes are reported in Table 3, and analyses adjusting for covariates are reported in Table 4. Unadjusted analyses for the association between sleep duration and cardiometabolic outcomes demonstrated significant and incremental relationships. Specifically, the shortest sleep duration category (<5hrs) was associated with the highest odds for obesity, diabetes, hypertension, and hypercholesterolemia. Also, both the shortest (<5hrs) and the longest (≥10hrs) was associated with the highest odds for myocardial infarction, and stroke. These relationships were somewhat attenuated after adjustment for covariates. In adjusted analyses, sleep duration of <5 hours was associated with increased BMI and risk for obesity, hypertension, hypercholesterolemia, heart attack, and stroke, relative to 7- hour sleepers. Sleep duration of 5–6 hours was associated with hypertension and hypercholesterolemia. Sleep duration of 8–9 hours was associated with decreased BMI, with no significant results as related to any negative cardiometabolic health outcomes. Sleep duration of ≥10 hours was associated with heart attack and stroke.

Insufficient Sleep Effects

Sleep insufficiency effects were examined using Model 2 (sleep insufficiency alone). BMI results are presented in Table 2. Unadjusted and adjusted analyses for other variables are reported in Tables 3 and 4, respectively. In unadjusted analyses, significant positive relationships were found for BMI, obesity, and hypercholesterolemia, demonstrating that increased risk was associated with greater reported insufficient sleep. In adjusted analyses, significant positive relationships were found for BMI, obesity, hypertension, and hypercholesterolemia.

Sleep Duration vs. Insufficient Sleep

The combination of sleep duration and sleep insufficiency was evaluated in Model 3. As above, BMI results are reported in Table 2, results from unadjusted analyses of other variables are reported in Table 3 and results of adjusted analyses are reported in Table 4. A graphical representation of the sleep duration results can be found in Figure 1.

In unadjusted analyses, BMI was positively associated with sleep duration of <5, 5–6, and ≥10 hours, and a significant positive effect of sleep insufficiency was also found, suggesting that both sleep duration and insufficiency contribute unique variance explanation of BMI. Obesity was also positively associated with sleep duration of <5, 5–6, and ≥10 hours, and similarly demonstrated a significant positive effect of sleep insufficiency. For diabetes, a significant positive relationship was found for <5, 5–6, 8–9 and ≥10 hours of sleep duration, though no positive relationship was found for sleep insufficiency. Increased risk of both hypertension and hypercholesterolemia were associated with sleep duration of <5, 5–6, and ≥10 hours, with no significant relationship for sleep insufficiency. Increased risk for heart attack and stroke were both associated with <5, 5–6, 8–9, and ≥10 hours of sleep duration, and no significant relationship for sleep insufficiency was found.

These relationships were attenuated in adjusted analyses. In adjusted analyses, there was a significant positive relationship between BMI and sleep duration of <5 hours, as well as a significant negative relationship between BMI and sleep duration of 8–9 hours. No significant effect for sleep insufficiency was found. Similarly, obesity showed a significant positive relationship with sleep duration of <5h, and no significant effect for sleep insufficiency. Diabetes no longer demonstrated a significant positive relationship for sleep duration or sleep insufficiency. Risk of hypertension was positively associated with sleep duration of <5 and 5–6 hours, and a significant effect for sleep insufficiency was present as well, suggesting that both short sleep duration and insufficient sleep contribute unique variance explanation. Hypercholesterolemia no longer showed a significant association with sleep duration, though a significant association with sleep insufficiency was found, such that

increased risk was associated with more frequent insufficient sleep. Increased risk of heart attack and stroke were significantly associated with sleep duration of <5 hours and 10 hours, with no significant sleep insufficiency effects.

DISCUSSION

The present study describes an analysis of the 2009 BRFSS data, investigating the associations between sleep duration and/or sleep insufficiency and cardiometabolic health outcomes. Further, the analysis attempts to specify whether cardiometabolic outcomes are more directly linked to sleep duration or insufficient sleep. Our hypotheses were partially confirmed. When sleep duration was examined alone, significant associations were found with all outcomes (BMI, obesity, diabetes, hypertension, hypercholesterolemia, heart attack, and stroke). When sleep insufficiency was examined separately, significant associations were found for BMI, obesity, hypertension, and hypercholesterolemia. When sleep duration and sleep insufficiency were examined together, the following were observed: (1) both sleep duration and sleep insufficiency contributed unique variance explanation of hypertension risk, (2) sleep insufficiency alone accounted for risk of hypercholesterolemia, and (3) sleep duration alone accounted for risk of BMI and obesity (short sleep duration), as well as heart attack and stroke (both short and long sleep duration).

Our results indicated that sleep duration, when examined alone, was significantly associated with all cardiometabolic health variables investigated. Similar results were obtained in several other studies attempting to link sleep duration to similar health outcomes. For example, a study [57] found both short and long sleep duration (<5 hours or >9 hours) to be at increased risk of higher BMI, diabetes, and hypertension. In a recent meta-analysis, short and long sleep duration (<5–6 hours and >8–9 hours) were associated with a greater risk of developing or dying of stroke[58]. Risk for hypercholesterolemia decreased with each additional hour of sleep for females [15]. These findings also support others, from a number of research groups, who found that sleep duration is associated with obesity[12, 20–22, 35, 48, 59], diabetes[16, 19, 25, 27, 41–43], and cardiovascular disease[15, 24, 26, 31, 34, 36–38, 40]. The current study extends these findings, exploring an alternative measurement for sleep (sleep insufficiency) and comparing it alongside and against sleep duration.

Sleep insufficiency effects, examined alone, demonstrated significant associations with increased BMI and risk for obesity, hypertension, and hypercholesterolemia. A study by Shankar, Syamala, and Kalidindi [18] indicated similar results in their investigation of insufficient rest or sleep in relation to cardiovascular disease, diabetes, and obesity. They found an overall positive association in both age/sex-adjusted and multivariable-adjusted models. Further, they analyzed sleep insufficiency separately in relation to coronary heart disease, stroke, diabetes, and obesity, all of which demonstrated a significant positive association in both models. The question of sleep insufficiency attempts to indicate healthy sleep more directly than with a measure of sleep duration, which may exclude important individual differences in sleep need.

When weighed against each other, effects of sleep duration and insufficiency differed among cardiometabolic health outcomes. Sleep duration explained increased BMI and risk for obesity on its own, suggesting that sleep duration, rather than differences in perceived sleep need, regulates weight. Although the mechanism of this effect is unknown, short sleep has previously been associated with altered metabolic hormones (leptin and ghrelin)[60–62], energy balance[63, 64], time available to eat[63], and timing of meals [65, 66]. Previous studies have also shown that short sleep duration is associated with a higher consumption of high-calorie foods [65, 67, 68].

Hypercholesterolemia was solely explained by sleep insufficiency, suggesting that short sleep duration may not be directly linked to higher cholesterol levels. This contradicts studies mentioned above. However, it may be explained by the results of a study by Mackiewicz et al. [69] that found cholesterol metabolism to be an overrepresented category of genes that increased expression during sleep, and decreased representation during sleep deprivation. This may suggest that a more direct route for detecting sleep-related effects of hypercholesterolemia would be to measure sleep insufficiency rather than short sleep duration.

Both sleep duration and sleep insufficiency maintained significant effects on hypertension. This suggests that there are separate effects of sleep duration and perceived insufficiency. To more clearly understand this relationship, it should be explored in further studies. Perhaps the independent effects of short sleep duration reflect the body's inability to perform basic processes, whereas the independent effects of perceived insufficiency reflect the psychophysiological stress of perceived unmet needs despite adequate duration.

Regarding model fit, across models, the combined effects of Sleep Insufficiency and Sleep Duration (Model 3) produce the greatest model fit. However, this is largely due to the predictive power of Sleep Duration. Within a given model, covariate adjustment dramatically increases the model fit, suggesting that the set of covariates investigated are greater risk factors for the outcomes than Sleep Duration and Insufficiency. The persistence of significant effects for both Sleep Duration and Sleep Insufficiency after covariate adjustment suggests that, while their contribution to the explanation of cardiometabolic disease is low, it is meaningful. As it pertains to model fitness, Cohen[70] attributes R^2 values <0.09 as low fit, $0.09-0.25$ as medium fit, and >0.25 as high fit. For pseudo- R^2 values, these limits are typically relaxed, with pseudo- R^2 values >0.20 considered to be high fit. While our adjusted models for BMI ($R^2=0.131$), Obesity (pseudo- $R^2=0.083$), and Hypercholesterolemia (pseudo- $R^2=0.101$) indicate a medium model fit, all of the other models show a high level of model fit (pseudo- $R^2>0.20$).

This study adds to the literature in several relevant ways. First, it is the first study to evaluate, at the population level, whether the elevated risk of adverse health outcomes associated with sleep duration is explained by perceived insufficient sleep. Put simply, this study explores the role of perceived unmet sleep need in the relationship between sleep duration and health. Although insufficient sleep was associated with adverse outcomes, our data show that the variance explained is not greater than or separate from that explained by sleep duration, in most cases. Second, this study documents a population-level association between sleep duration/insufficiency and cardiometabolic disease, using a population-weighted dataset, adjusting for a very wide array of potential confounders. The cardiometabolic endpoints investigated represent some of the leading causes of death (e.g., myocardial infarction and stroke), or major risk factors for those events (e.g., obesity, hypertension, hypercholesterolemia). Third, this study documents that among habitual short sleepers, two sub-groups emerge: the "short" sleepers who are more populous, and the rarer "very short" sleepers, who report <5 hours per night. We find large differences in risk profiles between these groups. Though other studies have found different risk profiles in different sleep durations, this has not been investigated before in this way.

Limitations

Although this study has many qualities that strengthen its validity, some limitations should be noted. First, the sleep duration and sleep insufficiency questions may be problematic. Both of these sleep variables (though sleep insufficiency to a lesser degree) may not take sleep quality into account. Second, the feeling of obtaining insufficient "rest or sleep" may not necessarily be an accurate measurement of sleep insufficiency. This compound question

conflates “rest” with “sleep,” such that responses may not completely represent a perceived lack of sleep, rather a perceived lack of rest. Also, perceived insufficient sleep may be biased by perceived normative standards, such that individuals may subjectively feel sufficiently rested, but, knowing that the normative amount of sleep is approximately 8 hours, may report “insufficient sleep” based on this knowledge rather than personal experience. This study is cross-sectional and therefore inferences regarding direction of relationships and/or causality are not possible. A further limitation includes not adjusting for sleep disorders: sleep apnea and insomnia have both been shown to be associated with cardiometabolic health risks, and the findings from the present study may partially represent these relationships. Adjusting for mental illness, body mass index may have captured a proportion of insomnia and sleep apnea respectively. Further, a measurement of sleep insufficiency cannot account for possible effects of excessive sleep.

These data are limited in that they are self-reported values obtained through surveys that have not been validated relative to objective and/or prospective methods of assessing sleep. These values could be biased by a number of factors, such as the desire to appear “normal” or the desire to express dissatisfaction, confusion as to whether estimates should include time in bed awake and/or napping during the day, recall biases, etc. This is a problem with all such surveys, and results should be interpreted with appropriate caution.

Telephone interviews are associated with limitations. Accuracy of reporting depends largely on the honesty and comprehension of the participant. The procedure is impersonal and it is more difficult to ascertain the accuracy and specificity of responses than during an in-person interview or with the use of a more specific set of questions. However, a study by Zallek et al. [71] found that a single question about sleepiness, “Please measure your sleepiness on a typical day” (scale of 0–10), was just as accurate as the Epworth Sleepiness Scale of 8 questions in predicting the likelihood of falling asleep during a variety of activities. Also, although the BRFSS specific weighting procedures reduce bias in this sample, it is possible that non-response to the sleep duration and/or sleep insufficiency items is disproportionately represented by certain groups. When respondents included in analysis were compared to those that were not included, few (and mostly minor) differences were found. Since only 1.9% of the sample did not respond to the sleep-related items, even in the case that certain groups were more likely to be non-responders, this should minimally affect statistical outcomes, as there is still a sufficient number of responses for reliable inferences.

The main strength of asking for information over 30 days is that it allows for the assessment of a typical pattern, rather than assessing the past few nights, which may or may not be representative. In this way, it may better approximate long-term sleep curtailment. However, there is no empirically validated way of assessing this, and the item used in the present study has unknown validity as an indicator of insufficient sleep over the long term. Another issue is that this does not allow for a differentiation of workdays and weekends, nor does it differentiate those with stable sleep schedule from those with variable schedules that include sleep loss and subsequent recovery. In particular, recent data on the concept of Social Jetlag highlights the relevance of this, as does recent data showing that laboratory-based sleep curtailment in the presence of circadian misalignment is associated with elevated obesity and diabetes risk factors.

Because all of the data in the present study were collected at the same time, no inferences regarding causality can be drawn; it may be the case that sleep is a contributing factor to cardiometabolic disease, but it may also be the case that cardiometabolic disease impacts on sleep. Existing evidence supports both directions, so this may be a reciprocal relationship. Also, although the presence of a large array of potential confounders was adjusted for in the present analyses, it is possible that the relationships are sufficiently non-linear that the

variance accounted for by these covariates is misestimated. Further, other unmeasured factors may have confounded the relationships between sleep and health outcomes.

Conclusions

The present study explored self-reported sleep duration alone, perceived sleep insufficiency alone, and the combined effects of these two variables on a number of cardiometabolic health outcomes, including BMI, obesity, hypertension, hypercholesterolemia, diabetes, heart attack, and stroke. Sleep duration was associated with all outcomes. Sleep insufficiency was associated with BMI, obesity, hypertension, and hypercholesterolemia. When sleep duration and sleep insufficiency were examined together, the sleep duration effects alone remained for BMI, obesity, heart attack and stroke; sleep insufficiency effects alone remained for hypercholesterolemia, and both variables contributed significant variance explanation of hypertension.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This work was supported by T32HL007713. Also, we wish to thank the Centers for Disease Control and Prevention for collecting this data and making it available, as well as the BRFSS participants. We also wish to thank Allan Pack MB ChB PhD, and Karen Teff, PhD, for guidance and support.

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Figure 1.

Odds Ratios of risk of cardiometabolic outcomes associated with sleep duration categories, relative to 7 hours of sleep, after adjustment for covariates. Values represent adjusted analyses of Model 3, which included sleep duration and adjusted for sleep insufficiency, age, sex, race/ethnicity, education, income, employment, marital status, census region, minutes of exercise, any exercise in past month, alcohol intake, heavy drinking, smoking status, healthy diet, household size, overall health, physical health, and mental health. BMI was included as a covariate for all outcomes except obesity. White asterisks indicate Odds Ratios significant at the $p < 0.05$ level. Black asterisks indicate that Odds Ratios were significant in Model 1 (without adjusting for sleep insufficiency) but not in Model 3.

Table 1

Subject Characteristics

Variable	Category	Weighted Distribution	Un-Weighted Distribution
Age	Mean [Median] (SD)	45.73 [44.00] (16.68)	54.80 [55.00] (15.92)
Body Mass Index	Mean [Median] (SD)	27.73 [26.68] (5.79)	27.68 [26.66] (5.94)
Drinks/Month	Mean [Median] (SD)	11.90 [1.00] (44.56)	10.92 [1.00] (35.29)
Days Poor Physical Health	Mean [Median] (SD)	3.31 [0.00] (7.44)	3.96 [0.00] (8.33)
Days Poor Mental Health	Mean [Median] (SD)	3.15 [0.00] (7.15)	3.11 [0.00] (7.30)
Household Size	Mean [Median] (SD)	3.20 [3.00] (1.59)	2.48 [2.00] (1.43)
Sex	Male (%)	48.93%	38.62%
	Female (%)	51.07%	61.38%
Race/Ethnicity	White (%)	68.56%	73.70%
	Black (%)	15.87%	9.69%
	Hispanic (%)	7.12%	3.64%
	Other (%)	6.48%	8.18%
	Multiracial (%)	1.96%	4.79%
Education	College (%)	38.75%	37.34%
	Less Than High School (%)	6.82%	6.76%
	High School Graduate (%)	26.27%	27.46%
	Some College (%)	28.16%	28.44%
Income	<\$10,000 (%)	3.69%	4.23%
	\$10–15,000 (%)	3.78%	5.04%
	\$15–20,000 (%)	6.22%	6.86%
	\$20–25,000 (%)	7.94%	8.68%
	\$25–35,000 (%)	9.90%	11.20%
	\$35–50,000 (%)	14.55%	15.89%
	\$50–75,000 (%)	17.45%	17.58%
	>\$75,000 (%)	36.48%	30.51%
General Health	Excellent (%)	21.47%	18.61%
	Very Good (%)	35.25%	33.46%
	Good (%)	29.20%	30.40%
	Poor (%)	10.51%	12.57%
	Very Poor (%)	3.57%	4.95%
Marital Status	Married (%)	63.74%	59.01%
	Divorced (%)	7.95%	13.36%
	Widowed (%)	5.22%	12.29%

Variable	Category	Weighted Distribution	Un-Weighted Distribution
	Separated (%)	1.76%	1.70%
	Never Married (%)	18.15%	11.65%
	Living with Partner (%)	3.18%	1.98%
Employment Status	Employed (%)	62.85%	55.44%
	Retired (%)	14.04%	26.17%
	Homemaker (%)	6.43%	6.76%
	Student (%)	4.89%	1.54%
	Unemployed (%)	7.54%	4.86%
	Unable to work(%)	4.25%	5.24%
Diet (# of Fruits/Vegetables)	5 per day (%)	22.29%	23.54%
	<1 per day (%)	4.94%	4.49%
	1–3 per day (%)	37.07%	35.02%
	3–5 per day (%)	35.70%	36.95%
Census Region	West (%)	5.44%	33.03%
	Midwest (%)	56.75%	31.87%
	South (%)	37.80%	35.10%
Any Exercise	No (%)	21.67%	24.08%
	Yes (%)	78.33%	75.92%
Heavy Drinker	No (%)	94.97%	94.83%
	Yes (%)	5.03%	5.17%
Smoking	Never (%)	57.66%	53.20%
	Current Daily (%)	12.24%	11.93%
	Current Sometimes (%)	5.96%	4.56%
	Former (%)	24.14%	30.31%
Health Insurance	Insured (%)	86.11%	90.35%
	Uninsured (%)	13.89%	9.65%
Obesity	No (%)	71.67%	71.83%
	Yes (%)	28.33%	28.17%
Diabetes	No (%)	91.77%	88.78%
	Yes (%)	8.23%	11.22%
Hypertension	No (%)	71.36%	62.48%
	Yes (%)	28.64%	37.52%
Hypercholesterolemia	No (%)	63.48%	57.35%
	Yes (%)	36.52%	42.65%
Heart Attack	No (%)	96.45%	94.68%
	Yes (%)	3.55%	5.32%

Variable	Category	Weighted Distribution	Un-Weighted Distribution
Stroke	No (%)	97.60%	96.30%
	Yes (%)	2.40%	3.70%
Sleep Insufficiency (days/week)	Mean [Median] (SD)	1.97 [1.00] (2.39)	1.77 [1.00] (2.38)
Sleep Duration	<5 Hours (%)	2.59%	3.09%
	5–6 Hours (%)	32.96%	30.42%
	7 Hours (%)	30.60%	29.94%
	8–9 Hours (%)	30.49%	32.79%
	10+ Hours (%)	3.35%	3.76%

Table 2

Unadjusted and Adjusted Regression Results (Unstandardized B Coefficients) and 95% Confidence Intervals (CI) for Associations Between Body Mass Index (BMI) and (1) Sleep Duration alone, (2) Sleep Insufficiency alone, and (3) Sleep Duration and Sleep Insufficiency Combined.

Sleep Variable	Model 1		Model 2		Model 3	
	B	95% CI	B	95% CI	B	95% CI
N = 30,934						
Unadjusted		$R^2=0.012$		$R^2=0.006$		$R^2=0.013$
Sleep Insufficiency			0.181 ^b	(0.129 – 0.233)	0.097 ^c	(0.039 – 0.155)
<5 Hours	2.716 ^b	(1.610 – 3.822)			2.359 ^d	(1.245 – 3.473)
5–6 Hours	0.780 ^b	(0.484 – 1.076)			0.615 ^d	(0.301 – 0.929)
7 Hours		Reference				Reference
8–9 Hours	–0.255	(–0.539 – 0.029)			–0.200	(–0.486 – 0.086)
10+ Hours	1.523 ^b	(0.439 – 2.607)			1.525 ^b	(0.443 – 2.607)
Adjusted		$R^2=0.131$		$R^2=0.129$		$R^2=0.131$
Sleep Insufficiency			0.080 ^b	(0.028 – 0.132)	0.035	(–0.023 – 0.093)
<5 Hours	1.368 ^b	(0.384 – 2.352)			1.266 ^a	(0.268 – 2.264)
5–6 Hours	0.268	(–0.012 – 0.548)			0.217	(–0.077 – 0.511)
7 Hours		Reference				Reference
8–9 Hours	–0.323 ^a	(–0.589 – –0.057)			–0.303 ^a	(–0.573 – –0.033)
10+ Hours	0.410	(–0.658 – 1.478)			0.421	(–0.649 – 1.491)

^a $p<0.05$,^b $p<0.01$,^c $p<0.001$,^d $p<0.0001$

Table 3

Unadjusted Odds Ratios (OR) and 95% Confidence Intervals (CI) for Associations Between Categorical Cardiometabolic Variables and (1) Sleep Duration alone, (2) Sleep Insufficiency alone, and (3) Sleep Duration and Sleep Insufficiency Combined.

Sleep Variable	Model 1		Model 2		Model 3	
	OR	95% CI	OR	95% CI	OR	95% CI
N = 30,934						
Obesity		R ² =0.007		R ² =0.004		R ² =0.008
sleep insufficiency			1.061 ^f	(1.041 – 1.081)	1.034 ^b	(1.010 – 1.058)
<5 Hours	2.080 ^f	(1.508 – 2.652)			1.840 ^d	(1.314 – 2.366)
5–6 Hours	1.332 ^e	(1.172 – 1.492)			1.257 ^c	(1.099 – 1.415)
7 Hours		Reference				Reference
8–9 Hours	0.949	(0.835 – 1.063)			0.967	(0.849 – 1.085)
10+ Hours	1.650 ^c	(1.172 – 2.128)			1.652 ^c	(1.176 – 2.128)
Diabetes		R ² =0.010		R ² =0.005		R ² =0.010
sleep insufficiency			1.005	(0.975 – 1.035)	0.993	(0.961 – 1.025)
<5 Hours	3.162 ^f	(2.142 – 4.182)			3.247 ^f	(2.151 – 4.343)
5–6 Hours	1.253 ^a	(1.031 – 1.475)			1.268 ^b	(1.040 – 1.496)
7 Hours		Reference				Reference
8–9 Hours	1.520 ^e	(1.238 – 1.802)			1.514 ^e	(1.232 – 1.796)
10+ Hours	2.357 ^f	(1.707 – 3.007)			2.357 ^f	(1.709 – 3.005)
Hypertension		R ² =0.006		R ² =0.005		R ² =0.006
sleep insufficiency			1.009	(0.991 – 1.027)	0.989	(0.969 – 1.009)
<5 Hours	2.703 ^f	(1.997 – 3.409)			2.817 ^f	(2.043 – 3.591)
5–6 Hours	1.283 ^e	(1.143 – 1.423)			1.308 ^e	(1.158 – 1.458)
7 Hours		Reference				Reference
8–9 Hours	1.279 ^e	(1.139 – 1.419)			1.270 ^d	(1.130 – 1.410)
10+ Hours	1.720 ^e	(1.304 – 2.136)			1.719 ^e	(1.305 – 2.133)
Hypercholesterolemia		R ² =0.003		R ² =0.001		R ² =0.003
Sleep Insufficiency			1.025 ^b	(1.005 – 1.045)	1.008	(0.986 – 1.030)

Sleep Variable	Model 1		Model 2		Model 3	
	OR	95% CI	OR	95% CI	OR	95% CI
N = 30,934						
<5 Hours	1.922 ^e	(1.386 – 2.458)			1.860 ^d	(1.320 – 2.400)
5–6 Hours	1.208 ^c	(1.072 – 1.344)			1.190 ^b	(1.050 – 1.330)
7 Hours	Reference				Reference	
8–9 Hours	1.093	(0.973 – 1.213)			1.099	(0.979 – 1.219)
10+ Hours	1.422 ^b	(1.062 – 1.782)			1.422 ^b	(1.060 – 1.784)
Myocardial Infarction		R ² =0.020		R ² <0.0005		R ² =0.020
Sleep Insufficiency			1.008	(0.960 – 1.056)	0.988	(0.940 – 1.036)
<5 Hours	4.704 ^f	(2.642 – 6.766)			4.923 ^f	(2.585 – 7.261)
5–6 Hours	1.312 ^a	(0.976 – 1.648)			1.340 ^a	(1.006 – 1.674)
7 Hours	Reference				Reference	
8–9 Hours	1.653 ^c	(1.179 – 2.127)			1.642 ^c	(1.172 – 2.112)
10+ Hours	4.097 ^f	(2.741 – 5.453)			4.095 ^f	(2.741 – 5.449)
Stroke		R ² =0.022		R ² <0.0005		R ² =0.022
Sleep Insufficiency			1.015	(0.965 – 1.065)	0.997	(0.947 – 1.047)
<5 Hours	4.558 ^f	(2.286 – 6.830)			4.615 ^f	(2.269 – 6.961)
5–6 Hours	1.327 ^a	(0.953 – 1.701)			1.335 ^a	(0.967 – 1.703)
7 Hours	Reference				Reference	
8–9 Hours	1.632 ^c	(1.180 – 2.084)			1.628 ^c	(1.168 – 2.088)
10+ Hours	4.869 ^f	(2.839 – 6.899)			4.868 ^f	(2.840 – 6.896)

^a p<0.05,^b p<0.01,^c p<0.001,^d p<0.0001,^e p<0.00001,^f p<0.000001

Table 4

Adjusted Odds Ratio (OR) and 95% Confidence Intervals (CI) for Associations Between Cardiometabolic Variables and (1) Sleep Duration alone, (2) Sleep Insufficiency alone, and (3) Sleep Duration and Sleep Insufficiency Combined.

Sleep Variable	Model 1		Model 2		Model 3	
	OR	95% CI	OR	95% CI	OR	95% CI
N = 30,934						
Obesity		R ² =0.083		R ² =0.082		R ² =0.083
Sleep Insufficiency			1.024 ^a	(1.002 – 1.046)	1.007	(0.981 – 1.033)
<5 Hours	1.419 ^a	(1.023 – 1.815)			1.389 ^a	(0.987 – 1.791)
5–6 Hours	1.129	(0.987 – 1.271)			1.117	(0.971 – 1.263)
7 Hours		Reference				Reference
8–9 Hours	0.907	(0.793 – 1.021)			0.911	*(0.795 – 1.027)
10+ Hours	1.150	(0.796 – 1.504)			1.152	(0.798 – 1.506)
Diabetes		R ² =0.206		R ² =0.205		R ² =0.206
Sleep Insufficiency			0.991	(0.961 – 1.021)	0.991	(0.957 – 1.025)
<5 Hours	1.396	(0.896 – 1.896)			1.436	(0.900 – 1.972)
5–6 Hours	1.045	(0.847 – 1.243)			1.059	(0.855 – 1.263)
7 Hours		Reference				Reference
8–9 Hours	1.210	(0.960 – 1.460)			1.205	(0.955 – 1.455)
10+ Hours	1.118	(0.794 – 1.442)			1.115	(0.791 – 1.439)
Hypertension		R ² =0.217		R ² =0.217		R ² =0.218
Sleep Insufficiency			1.039 ^c	(1.015 – 1.063)	1.027 ^a	(1.001 – 1.053)
<5 Hours	1.686 ^c	(1.206 – 2.166)			1.555 ^b	(1.097 – 2.013)
5–6 Hours	1.181 ^b	(1.037 – 1.325)			1.135 ^a	(0.991 – 1.279)
7 Hours		Reference				Reference
8–9 Hours	1.062	(0.926 – 1.198)			1.077	(0.939 – 1.215)
10+ Hours	0.887	(0.625 – 1.149)			0.894	(0.628 – 1.160)
Hypercholesterolemia		R ² =0.101		R ² =0.101		R ² =0.101
Sleep Insufficiency			1.042 ^d	(1.020 – 1.064)	1.031 ^b	(1.007 – 1.055)
<5 Hours	1.364 ^a	(0.962 – 1.766)			1.241	(0.865 – 1.617)

Sleep Variable		Model 1		Model 2		Model 3			
N = 30,934		OR	95% CI	OR	95% CI	OR	95% CI		
5–6 Hours		1.141 ^a	(1.007 – 1.275)			1.091	(0.957 – 1.225)		
7 Hours		Reference				Reference			
8–9 Hours		0.956	(0.848 – 1.064)			0.972	(0.860 – 1.084)		
10+ Hours		0.979	(0.691 – 1.267)			0.988	(0.698 – 1.278)		
Myocardial Infarction		R ² =0.254		R ² =0.250		R ² =0.254			
Sleep Insufficiency				1.018	(0.966 – 1.070)	1.001	(0.947 – 1.055)		
<5 Hours		2.521 ^b	(1.079 – 3.963)			2.513 ^b	(0.969 – 4.057)		
5–6 Hours		1.185	(0.871 – 1.499)			1.184	(0.872 – 1.496)		
7 Hours		Reference				Reference			
8–9 Hours		1.207	(0.847 – 1.567)			1.208	(0.850 – 1.566)		
10+ Hours		1.863 ^c	(1.211 – 2.515)			1.863 ^c	(1.207 – 2.519)		
Stroke		R ² =0.217				R ² =0.215		R ² =0.218	
Sleep Insufficiency						0.974	(0.924 – 1.024)	0.965	(0.913 – 1.017)
<5 Hours		1.617 ^a	(0.835 – 2.399)					1.807 ^a	(0.883 – 2.731)
5–6 Hours		1.084	(0.764 – 1.404)	1.143	(0.809 – 1.477)				
7 Hours		Reference		Reference					
8–9 Hours		1.139	(0.817 – 1.461)	1.121	(0.801 – 1.441)				
10+ Hours		1.840 ^b	(1.040 – 2.640)			1.816 ^b	(1.030 – 2.602)		

^a p<.05,^b p<.01,^c p<.001,^d p<0.0001