Published in final edited form as:

Prev Med. 2008 May ; 46(5): 439–444. doi:10.1016/j.ypmed.2007.11.008.

Sleep duration and obesity-related risk factors in the rural Midwest

Katherine A. Stamatakis¹ and Ross C. Brownson²

¹ Department of Epidemiology, Johns Hopkins University Bloomberg School of Public Health

² Division of Epidemiology and Prevention Research Center, Saint Louis University School of Public Health

Abstract

Objective—Habitual short sleep duration is a common practice linked to weight gain and risk of obesity. Our objective was to examine the association between sleep duration with other behaviors, such as physical activity and nutrition, which are important for obesity prevention efforts.

Methods—We used cross-sectional data from rural communities in Missouri, Tennessee and Arkansas (n=1,203). Controlling for covariates, we assessed the association between short sleep duration (<7 hours vs. 7-8 hours) and obesity, not meeting vigorous physical activity requirements, low fruit and vegetable consumption, high fat consumption and frequently eating at fast food restaurants.

Results—The proportion of participants with habitual sleep duration of <7 hours, 7-8 hours and 9 hours was 36.2%, 57.3%, and 6.4%, respectively. After multivariable adjustment, short sleep duration was associated with certain obesity-related behaviors, particularly lower physical activity and lower fruit and vegetable consumption.

Conclusions—Short sleep duration is associated with risk behaviors that are known to promote weight gain and obesity. Interventions aimed at promoting physical activity and improved nutrition may benefit by considering adequate sleep duration as a potentially modifiable behavior that may impact the effectiveness of efforts to prevent obesity.

Keywords

Sleep; sleep deprivation; obesity; risk factors; exercise; diet

Corresponding Author: Katherine A. Stamatakis, PhD, MPH, Department of Epidemiology, Johns Hopkins University Bloomberg School of Public Health, 5501 Hopkins Bayview Circle, Room 4B-50, Baltimore, Maryland 21224, Tel: 410-206-5017, Fax: 410-550-3374, kstamatakis@jhu.edu.

Publisher's Disclaimer: 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 citable 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.

Introduction

The apparent trend toward decreased sleep duration in accordance with the increasingly urgent obesity epidemic in the United States has bolstered research on the metabolic consequences of sleep deprivation (Knutson et al. 2007). Roughly 40% of US adults report usual weekday sleep duration of less than seven hours per night (National Sleep Foundation 2005), a proportion that has increased over all age groups from 1985-2004 (Centers for Disease Control and Prevention 2005). The growing obesity epidemic in the US (Flegal et al. 2002) throughout this time period is likely to be the result of a complex interaction of environmental, social, behavioral and genetic factors (Booth et al. 2001). As part of this picture, recent evidence indicates that short sleep duration may also act as one among other risk factors for weight gain and obesity in adults (Gangwisch et al. 2005; Hasler et al. 2004; Patel et al. 2006) as well as children (Agras et al. 2004; Reilly et al. 2005; Sugimori et al. 2004).

Since the concept of energy balance is fundamental to obesity prevention (*i.e.*, excess calories and inadequate activity) (World Health Organization 2000), understanding the impact of inadequate sleep duration on behaviors that influence caloric intake and activity levels could inform prevention efforts. Short-term experimental restriction of sleep in healthy, young adult subjects has led to alterations in glucose metabolism (Spiegel et al. 1999) and in hormones that regulate appetite, such as leptin and ghrelin (Dzaja et al. 2004; Mullington et al. 2003; Spiegel et al. 2004), in addition to increased craving for high caloric foods (Spiegel et al. 2004). Restriction of sleep also leads to increased daytime sleepiness (Aeschbach et al. 2001; Breslau et al. 1997; Klerman & Dijk 2005), which may hinder participation in activities requiring added physical effort or exertion, including physical activity, and preparation of healthful food, as opposed to purchasing pre-prepared and often less nutritionally optimal food options. Thus, it is plausible that inadequate sleep duration may impact weight gain by serving as a barrier to meeting nutrition and physical activity levels recommended for the maintenance of normal weight.

Epidemiologic data on the relationship between shortened sleep duration and obesity-related risk factors such as physical inactivity and poor nutrition are lacking. Understanding how sleep duration is associated with obesity-related behaviors could provide some insights as to its relevance to obesity prevention efforts. However, since sleep duration may be directly impacted (*i.e.*, either shortened or lengthened) by physical and mental illness, associations from observational, population-based studies must consider physical and psychosocial comorbidities as potential confounders. Many population-based studies with data on sleep duration, physical activity and other obesity-linked factors describe bivariate associations. There is scant literature quantifying the extent of the association between short sleep duration and obesity-related behaviors with adjustments for health status, and no studies have reported associations between short sleep duration and obesity-related behaviors in rural areas, a segment of the population with high levels of obesity. Therefore, the objectives of this study were to examine the associations between sleep duration with common obesity-related behaviors, including physical activity, fruit and vegetable consumption, high fat intake and frequency of eating fast food, and to assess the impact of adjustment for physical health and psychosocial characteristics on these patterns of association.

Methods

Study Population

The present study used cross-sectional data from an ongoing evaluation of a community walking trails intervention to promote physical activity in rural communities in Missouri, Tennessee and Arkansas (Brownson et al. 2005). Data were obtained from a telephone-administered questionnaire based on a modification of the Behavioral Risk Factor Surveillance System instrument. There were twelve communities of <20,000 residents (seven with <2,500 residents) included in the study, based on their previous participation in the Ozark Heart Health Project, presence of walking trails, a high rate of poverty relative to the rest of the state, and higher diabetes-related hospitalization and mortality rates compared to the state (Deshpande et al. 2005). Individuals residing in eligible households, which were identified as those situated within a 2-mile radius of walking trails, were contacted via a random-digit dialing procedure. Most of the twelve towns included in the walking trail intervention were completely encompassed within the 2-mile radius of the walking trail. Data for the current analysis was from the third phase of data collection July to September 2005, when information on sleep habits was included in the questionnaire (n=1,258, mean age = 54 (range 20-92)). The response rate for the interview was 65.2% as calculated using the method of the Council of American Survey Research Organizations (CASRO 1982).

Measures

Sleep Duration. Data on habitual sleep duration was assessed with the open-ended question “How many hours of sleep do you usually get at night (or your main sleep period) on weekdays or workdays?”, rounded to the nearest hour. Responses were then grouped into three categories: short sleep duration (<7 hours), long sleep duration (≥9 hours), and the reference group (7-8 hours). Similar sleep duration data obtained from the Sleep Habits Questionnaire of the Sleep Heart Health Study have been found to be moderately stable over time (correlation coefficient = 0.57 after 2.4 years), and exhibited face validity in cross-sectional associations with respect to diabetes status (Gottlieb et al. 2005) and hypertension (Gottlieb et al. 2006).

Obesity and Obesity-Related Behaviors. Body mass index (BMI) was computed from self-reported weight and height according to the formula $BMI = \text{weight (kg)} / \text{height}^2 \text{ (m)}$, and grouped into three categories: obese (BMI ≥30), overweight (BMI 25 to <30), and normal (BMI 18.5 to <25). Individuals classified as underweight (BMI < 18.5) were excluded from the analyses (n = 22). Physical activity status was determined by the self-reported duration and frequency of vigorous physical activities, including running, aerobics, heavy yard work, or anything else that causes large increases in breathing or heart rate. Vigorous physical activity requirements were considered met for those who participated in vigorous physical activities at least 20 minutes per day, 3 days per week. Participating in moderate physical activities, including brisk walking, bicycling, vacuuming, gardening or anything that causes small increases in breathing or heart rate, was also examined, but since meeting weekly recommended levels of moderate physical activity was not strongly associated with sleep duration we focused instead on vigorous physical activities. Fruit and vegetable consumption were reported separately as average daily servings consumed over the past

month, which were subsequently summed and grouped into three categories of average daily fruit and vegetable servings: 1-2 servings, 3-4 servings, and 5 or more servings. High fat consumption was determined by self-reported assessment of diet being high, medium or low in fat. Frequent fast food consumption was defined for those who reported “often” going to a fast food restaurant when they eat out, versus “never”, “occasionally” or “sometimes”.

Other Covariates

Additional characteristics were assessed as potential confounders and/or mediators of the relationship between sleep duration and obesity-related behaviors in multivariable models (Bauman et al. 2002). Sociodemographic factors included age, gender, race (white vs. non-white), marital status (married or member of an unmarried couple; divorced, separated or never married; widowed), employment status (employed; out of work, homemaker or student; retired; unable to work), annual household income level (<\$20,000, \$20,000 to <\$35,000, \$35,000 to <\$75,000, \$75,000), and highest achieved level of education (8th grade or less/some high school; high school diploma/tech or vocational school; some college; college graduate/post graduate degree). Smoking status was defined as never, former, or current. Current health status was assessed in categories of self-reported health status (excellent/very good, good/fair, poor). Subjects were categorized as having depressed mood if they reported little interest or pleasure in doing things or feeling down, depressed or hopeless for at least half of the days in the previous two weeks. Finally, other sleep-related characteristics included having difficulty falling asleep, maintaining sleep, or waking too early in the morning (five or more times in the past month), and current snoring (three or more nights per week). To ensure similar comparisons across models with separate groups of covariates, a total of 55 individuals (4.4%) with missing values for any covariate (or classified as underweight, as defined above) were excluded from the analysis, resulting in a final sample size of 1,203 for the analyses.

Statistical Methods

Statistical tests of bivariate associations were based on chi-square distribution (d.f. = 2), with sleep duration modeled as a three-category, nominal response variable. Power calculations indicated limited power (<0.80) in detecting associations in the feasible range (OR = 1.5 – 2.5) between long sleep duration (≥ 9 hours) and obesity-related behaviors. Therefore, only results for short sleep duration are displayed in tables.

The relationship between short sleep duration and four obesity-related behaviors – not meeting vigorous physical activity requirements (*vs.* meeting vigorous physical activity requirements), low fruit and vegetable consumption (1-2 *vs.* ≥ 5 servings per day), high fat diet (*vs.* medium or low fat diet), and frequently eating fast food (*vs.* never, occasionally or sometimes eating fast food)– was assessed in separate logistic regression models, with each of the four obesity-related behaviors modeled as separate outcomes. Since associations (and distribution across sleep duration categories) based on a weighted average of weekday and weekend sleep duration were nearly identical to those based on weekday sleep duration alone, we report results only for weekday short sleep duration.

Odds ratios (with 95% confidence intervals) for the associations between short sleep duration (compared to the reference 7-8 hours sleep duration group) and the four obesity-related behaviors were adjusted for groups of covariates in four nested models to assess the impact of age (Model 1), and then subsequently, sociodemographic characteristics (Model 2), physical and mental health status (Model 3) and other sleep-related characteristics (Model 4, *i.e.*, full covariate adjustment model) (SAS Institute Inc., Carey, NC, version 9.0). Potential interactions between obesity status (obese vs. non-obese) and sleep duration were also assessed by including a multiplicative interaction term (sleep duration * obesity status) in logistic regression models for each obesity-related behavior.

Results

The proportion of the study population sleeping <7 hours per night (short sleep duration), 7-8 hours per night, and 9 hours per night (long sleep duration) was 36.2%, 57.3%, and 6.4%, respectively. Shorter sleep duration was associated with younger mean age. Several characteristics were more common among both short and long sleepers (Table 1), including inability to work, household income < \$35,000 per year, education level less than college graduate, current smoking, less than excellent/very good health status, having depressed feelings, and obesity. Obesity-related behaviors such as not meeting vigorous physical activity requirements, low fruit and vegetable consumption, and high fat diet were also more common among both short and long sleepers. Often eating at fast food restaurants and frequent insomnia were more common among the short sleep duration group.

In age-adjusted models, short sleep duration (<7 hours) was associated with not meeting vigorous physical activity requirements, low fruit and vegetable consumption, high fat diet, and often eating fast food (Table 2). The strongest age-adjusted associations were found for not meeting physical activity requirements and low fruit and vegetable consumption. Subsequent adjustment for sociodemographics somewhat reduced these associations, with adjustment for physical and mental health and other sleep characteristics leading to only minor further reductions in the associations. Results from multivariable adjustment of models with high fat diet and frequent fast food consumption as outcomes were less statistically robust, although the consistency of the point estimates with each subsequent adjustment seem to indicate that loss of statistical significance may have been due to variance inflation and not confounding. It is interesting to note that while we lacked adequate power to assess associations for habitually short sleep duration of <6 hours, we found some evidence for a dose-response relationship with stronger associations for all four obesity-related behaviors among this shorter sleep duration group (results not shown).

Age-adjusted associations for obesity-related behaviors were generally stronger for the short sleep duration group when restricted to non-obese subjects (Table 3). This was particularly true for the association between short sleep duration and high fat diet in the non-obese stratum, which exhibited a stronger association in the stratified model even after multivariable adjustment. Associations in the obese stratum were generally weaker and statistically unstable. The exception to this pattern was often eating fast food, which was more strongly associated with short sleep duration in the obese stratum.

Discussion

These results describe the relationship between sleep duration and some common obesity-related behaviors, including reduced physical activity, low fruit and vegetable consumption, high fat diet, and frequently eating fast food, in a rural population residing in three Midwestern states. Short sleep duration was associated with certain obesity-related behaviors even after multivariable adjustment for sociodemographic characteristics and physical and mental health status. When assessing the association between sleep duration and obesity-related behaviors stratified by obesity status, associations were generally similar or stronger among non-obese. These patterns support the hypothesis that habitually short sleep duration is associated with behaviors that impact net energy balance and that may eventually lead to weight gain.

There are sparse available data describing the relationship between sleep duration and obesity-related behaviors in other populations. In a study among adolescents in Taiwan, short sleep duration on most weeknights was associated with lower physical activity and worse nutritional habits (Chen et al. 2006). Another study found that European youth who were not regularly physically active were less likely to sleep the 'optimal' seven to eight hours per night, although short sleep and long sleep were grouped into a single 'suboptimal' category (Stepptoe et al. 1997). These cross-sectional data, as well as our own, are unable to provide evidence that short sleep duration has a causal impact on other obesity-related behaviors. It is possible that the inverse is true, and that obesity-related behaviors may influence duration of sleep. In fact, the results of a moderate-intensity physical activity intervention among postmenopausal women found that, among those women with improved physical condition after 12 months of the intervention, sleep duration increased and sleep quality was improved (Tworoger et al. 2003). A more comprehensive scenario is that the relationship between sleep and obesity-related behaviors is bidirectional, whereby sleep and obesity-related behaviors may have reciprocal effects on each other.

In prospective studies that have examined the relationship between sleep duration and subsequent obesity or weight gain in non-obese groups, findings have consistently shown shorter sleep duration predicted increasing weight (Agras et al. 2004; Gangwisch et al. 2005; Hasler et al. 2004; Patel et al. 2006; Reilly et al. 2005; Sugimori et al. 2004). In the Nurses Health Study, those who habitually slept less than seven hours per night were more likely to gain weight and become obese in subsequent years (Patel et al. 2006). Similar findings were reported from the National Health and Nutrition Examination Study (Gangwisch et al. 2005). Likewise, three prospective studies on weight gain and incident obesity in young children have found that shorter sleep duration was consistently associated with worsening status (Agras et al. 2004; Reilly et al. 2005; Sugimori et al. 2004). Cross-sectional studies in children and adolescents have also shown a consistent dose-response relationship between shorter sleep duration and higher prevalence of obesity (Eisenmann et al. 2006; Knutson 2005; Sekine et al. 2002; Von Kries et al. 2002). In adults, cross-sectional results have been more varied, with sleep duration exhibiting a linear, negative association with obesity (Vioque et al. 2000) and BMI (Gangwisch et al. 2005) in some studies, while in another study, sleep duration had a U-shaped relationship with obesity, with higher prevalence at short and long ends of the distribution (Ko et al. 2007). In a comparable study of a rural

adult population sample, sleep duration and BMI exhibited a negative, linear association (Kohatsu et al. 2006). The contrast between the consistency of results from prospective studies and the varied results from cross-sectional studies with respect to sleep duration and obesity emphasize the importance of distinguishing between pre-obese and obese states when studying behaviors that may be impacted by the state of obesity.

There are several relevant limitations of the current data, beginning with the use of self-reported data for sleep duration and covariates, including weight and height. Our measure of habitual sleep duration was not validated against any objective assessment of sleep habits in these data. However, our assessment of short sleep duration is consistent with that used in numerous other epidemiologic studies that reported associations between self-reported habitual sleep duration of <7 hours and long-term adverse health outcomes including all-cause mortality (Amagai et al. 2004; Heslop et al. 2002; Kojima et al. 2000; Kripke et al. 1979; Kripke et al. 2002; Patel et al. 2004; Tamakoshi & Ohno 2004; Wingard & Berkman 1983), incident cardiovascular disease (Ayas et al. 2003a), diabetes (Ayas et al. 2003b), and hypertension (Gangwisch et al. 2006). Since our sample was drawn from a rural population with a relatively higher proportion of poverty compared to the state as a whole these results may not be generalizable to urban or suburban populations. In addition, we were unable in these cross-sectional data to determine temporality in the associations between sleep duration and obesity-related risk factors. Finally, our sample size limited our ability to examine associations at more extreme ends of the sleep duration distribution (<6 hours, 9 hours) and may have resulted in limited power for statistical tests of associations from multivariable adjustment and stratified models.

Regardless of the precise causal relationship between sleep duration and obesity-related behaviors, these results suggest that the path to weight gain via short sleep duration may operate through interrelationships with obesity-related behaviors that may act as mediators or moderators in the causal pathway (Kraemer et al. 2001). As we gain a better understanding of the relationship between sleep patterns and obesity-related behaviors, new intervention options may become available. For example, many public health campaigns now use tailored communications or mass media (Kahn et al. 2002; Kreuter et al. 2000). For obesity interventions, messages about achieving recommended levels of sleep may be incorporated in a variety of health communication materials and intervention approaches.

Conclusions

In our study, short sleep duration was associated with behaviors – low physical activity levels, poor nutrition – that are known to promote weight gain and obesity. While the focus of this study is on individual factors and behaviors, it may have broader implications for efforts to intervene and evaluate the success of efforts to promote physical activity and healthy eating at individual, social, policy, and environmental levels (Brownson et al. 2006). Interventions aimed at promoting physical activity and improved nutrition may benefit by considering adequate sleep duration as a potentially modifiable behavior that may impact energy balance.

Acknowledgements

This study was funded through the National Institutes of Health grants NIDDK #5 R18 DK061706, NHLBI F32 HL083640, and the Centers for Disease Control and Prevention contract U48/ DP000060 (Prevention Research Centers Program). The authors are grateful for the assistance on this project from Sarah Lovegreen, Laura Hagood and Drs. Mike Elliott, Debra Haire-Joshu, and Janet McGill.

This study was approved by the Saint Louis University Institutional Review Board.

References

- Aeschbach D, Postolache TT, Sher L, Matthews JR, Jackson MA, Wehr TA. Evidence from the waking electroencephalogram that short sleepers live under higher homeostatic sleep pressure than long sleepers. *Neuroscience*. 2001; 102(3):493–502. [PubMed: 11226688]
- Agras WS, Hammer LD, McNicholas F, Kraemer HC. Risk factors for childhood overweight: a prospective study from birth to 9.5 years. *J.Pediatr.* 2004; 145(1):20–25. [PubMed: 15238901]
- Amagai Y, Ishikawa S, Gotoh T, Doi Y, Kayaba K, Nakamura Y, Kajii E. Sleep duration and mortality in Japan: the Jichi Medical School Cohort Study. *J.Epidemiol.* 2004; 14(4):124–128. [PubMed: 15369129]
- Ayas NT, White DP, Manson JE, Stampfer MJ, Speizer FE, Malhotra A, Hu FB. A prospective study of sleep duration and coronary heart disease in women. *Arch Intern Med.* 2003; 163(2):205–9. [PubMed: 12546611]
- Ayas NT, White DP, Al-Delaimy WK, Manson JE, Stampfer MJ, Speizer FE, Patel S, Hu FB. A prospective study of self-reported sleep duration and incident diabetes in women. *Diabetes Care.* 2003; 26(2):380–4. [PubMed: 12547866]
- Bauman AE, Sallis JF, Dziewaltowski DA, Owen N. Toward a better understanding of the influences on physical activity: the role of determinants, correlates, causal variables, mediators, moderators, and confounders. *Am.J.Prev.Med.* 2002; 23(2 Suppl):5–14. [PubMed: 12133733]
- Booth SL, Sallis JF, Ritenbaugh C, Hill JO, Birch LL, Frank LD, Glanz K, Himmelgreen DA, Mudd M, Popkin BM, Rickard KA, St Jeor S, Hays NP. Environmental and societal factors affect food choice and physical activity: rationale, influences, and leverage points. *Nutr.Rev.* 2001; 59(3 Pt 2):S21–S39. [PubMed: 11330630]
- Breslau N, Roth T, Rosenthal L, Andreski P. Daytime sleepiness: an epidemiological study of young adults. *Am.J.Public Health.* 1997; 87(10):1649–1653. [PubMed: 9357347]
- Brownson RC, Hagood L, Lovegreen SL, Britton B, Caito NM, Elliott MB, Emery J, Haire-Joshu D, Hicks D, Johnson B, McGill JB, Morton S, Rhodes G, Thurman T, Tune D. A multilevel ecological approach to promoting walking in rural communities. *Prev.Med.* 2005; 41(5-6):837–842. [PubMed: 16256183]
- Brownson RC, Haire-Joshu D, Luke DA. Shaping the context of health: a review of environmental and policy approaches in the prevention of chronic diseases. *Annu.Rev.Public Health.* 2006; 27:341–370. [PubMed: 16533121]
- Centers for Disease Control and Prevention. QuickStats. *MMWR.* 2005; 54:933.
- Chen MY, Wang EK, Jeng YJ. Adequate sleep among adolescents is positively associated with health status and health-related behaviors. *BMC Public Health.* 2006; 6
- Deshpande AD, Baker EA, Lovegreen SL, Brownson RC. Environmental correlates of physical activity among individuals with diabetes in the rural midwest. *Diabetes Care.* 2005; 28(5):1012–1018. [PubMed: 15855559]
- Dzaja A, Dalal MA, Himmerich H, Uhr M, Pollmacher T, Schuld A. Sleep enhances nocturnal plasma ghrelin levels in healthy subjects. *Am.J.Physiol Endocrinol.Metab.* 2004; 286(6):E963–E967. [PubMed: 14871884]
- Eisenmann J, Ekkekakis P, Holmes M. Sleep duration and overweight among Australian children and adolescents. *Acta Paediatrica, International Journal of Paediatrics.* 2006; 95(8):956–963.
- Flegal KM, Carroll MD, Ogden CL, Johnson CL. Prevalence and trends in obesity among US adults, 1999–2000. *JAMA.* 2002; 288(14):1723–1727. [PubMed: 12365955]

- Gangwisch JE, Malaspina D, Boden-Albala B, Heymsfield SB. Inadequate sleep as a risk factor for obesity: Analyses of the NHANES I. *Sleep*. 2005; 28(10):1289–1296. [PubMed: 16295214]
- Gangwisch JE, Heymsfield SB, Boden-Albala B, Buijs RM, Kreier F, Pickering TG, Rundle AG, Zammit GK, Malaspina D. Short sleep duration as a risk factor for hypertension: Analyses of the first National Health and Nutrition Examination Survey. *Hypertension*. 2006; 47(5):833–839. [PubMed: 16585410]
- Gottlieb DJ, Punjabi NM, Newman AB, Resnick HE, Redline S, Baldwin CM, Nieto FJ. Association of sleep time with diabetes mellitus and impaired glucose tolerance. *Arch.Intern.Med*. 2005; 165(8):863–867. [PubMed: 15851636]
- Gottlieb DJ, Redline S, Nieto FJ, Baldwin CM, Newman AB, Resnick HE, Punjabi NM. Association of usual sleep duration with hypertension: the Sleep Heart Health Study. *Sleep*. 2006; 29(8):1009–1014. [PubMed: 16944668]
- Hasler G, Buysse DJ, Klaghofer R, Gamma A, Ajdacic V, Eich D, Rössler W, Angst J. The association between short sleep duration and obesity in young adults: A 13-year prospective study. *Sleep*. 2004; 27(4):661–666. [PubMed: 15283000]
- Heslop P, Smith GD, Metcalfe C, Macleod J, Hart C. Sleep duration and mortality: The effect of short or long sleep duration on cardiovascular and all-cause mortality in working men and women. *Sleep Med*. 2002; 3(4):305–14. [PubMed: 14592192]
- Kahn EB, Ramsey LT, Brownson RC, Heath GW, Howze EH, Powell KE, Stone EJ, Rajab MW, Corso P. The effectiveness of interventions to increase physical activity. A systematic review. *Am.J.Prev.Med*. 2002; 22(4 Suppl):73–107. [PubMed: 11985936]
- Klerman EB, Dijk DJ. Interindividual variation in sleep duration and its association with sleep debt in young adults. *Sleep*. 2005; 28(10):1253–1259. [PubMed: 16295210]
- Knutson KL. Sex differences in the association between sleep and body mass index in adolescents. *Journal of Pediatrics*. 2005; 147(6):830–834. [PubMed: 16356441]
- Knutson KL, Spiegel K, Penev P, Van Cauter E. The metabolic consequences of sleep deprivation. *Sleep Med.Rev*. 2007; 11(3):163–178. [PubMed: 17442599]
- Ko GTC, Chan JCN, Chan AWY, Wong PTS, Hui SSC, Tong SDY, Ng SM, Chow F, Chan CLW. Association between sleeping hours, working hours and obesity in Hong Kong Chinese: The ‘better health for better Hong Kong’ health promotion campaign. *International Journal of Obesity*. 2007; 31(2):254–260. [PubMed: 16718283]
- Kohatsu ND, Tsai R, Young T, VanGilder R, Burmeister LF, Stromquist AM, Merchant JA. Sleep duration and body mass index in a rural population. *Archives of Internal Medicine*. 2006; 166(16):1701–1705. [PubMed: 16983047]
- Kojima M, Wakai K, Kawamura T, Tamakoshi A, Aoki R, Lin Y, Nakayama T, Horibe H, Aoki N, Ohno Y. Sleep patterns and total mortality: a 12-year follow-up study in Japan. *Journal of Epidemiology*. 2000; 10(2):87–93. [PubMed: 10778032]
- Kraemer HC, Stice E, Kazdin A, Offord D, Kupfer D. How do risk factors work together? Mediators, moderators, and independent, overlapping, and proxy risk factors. *Am.J.Psychiatry*. 2001; 158(6):848–856. [PubMed: 11384888]
- Kreuter, MW.; Farrell, D.; Olevitch, L.; Brennan, L. Tailoring health messages: customizing communication with computer technology. L. Erlbaum; Mahwah, N.J.: 2000.
- Kripke DF, Simons RN, Garfinkel L, Hammond EC. Short and long sleep and sleeping pills. Is increased mortality associated? *Arch Gen Psychiatry*. 1979; 36(1):103–16. [PubMed: 760693]
- Kripke DF, Garfinkel L, Wingard DL, Klauber MR, Marler MR. Mortality associated with sleep duration and insomnia. *Arch Gen Psychiatry*. 2002; 59:131–6. [PubMed: 11825133]
- Mullington JM, Chan JL, Van Dongen HP, Szuba MP, Samaras J, Price NJ, Meier-Ewert HK, Dinges DF, Mantzoros CS. Sleep loss reduces diurnal rhythm amplitude of leptin in healthy men. *J Neuroendocrinol*. 2003; 15(9):851–4. [PubMed: 12899679]
- National Sleep Foundation. 2005 Sleep in America Poll: Summary Findings. 2005
- Patel SR, Ayas NT, Malhotra MR, White DP, Schernhammer ES, Speizer FE, Stampfer MJ, Hu FB. A prospective study of sleep duration and mortality risk in women. *Sleep*. 2004; 27(3):440–444. [PubMed: 15164896]

- Patel SR, Malhotra A, White DP, Gottlieb DJ, Hu FB. Association between reduced sleep and weight gain in women. *American Journal of Epidemiology*. 2006; 164(10):947–954. [PubMed: 16914506]
- Reilly JJ, Armstrong J, Dorosty AR, Emmett PM, Ness A, Rogers I, Steer C, Sherriff A. Early life risk factors for obesity in childhood: Cohort study. *British Medical Journal*. 2005; 330(7504):1357–1359. [PubMed: 15908441]
- Sekine M, Yamagami T, Handa K, Saito T, Nanri S, Kawaminami K, Tokui N, Yoshida K, Kagamimori S. A dose-response relationship between short sleeping hours and childhood obesity: Results of the Toyama birth cohort study. *Child: Care, Health and Development*. 2002; 28(2):163–170.
- Spiegel K, Leproult R, Van Cauter E. Impact of sleep debt on metabolic and endocrine function. *The Lancet*. 1999; 354:1435–39.
- Spiegel K, Tasali E, Penev P, Van Cauter E. Brief communication: Sleep curtailment in healthy young men is associated with decreased leptin levels, elevated ghrelin levels, and increased hunger and appetite. *Ann Intern Med*. 2004; 141(11):846–50. [PubMed: 15583226]
- Steptoe A, Wardle J, Fuller R, Holte A, Justo J, Sanderman R, Wichstrom L. Leisure-time physical exercise: prevalence, attitudinal correlates, and behavioral correlates among young Europeans from 21 countries. *Prev.Med*. 1997; 26(6):845–854. [PubMed: 9388797]
- Sugimori H, Yoshida K, Izuno T, Miyakawa M, Suka M, Sekine M, Yamagami T, Kagamimori S. Analysis of factors that influence body mass index from ages 3 to 6 years: A study based on the Toyama cohort study. *Pediatrics International*. 2004; 46(3):302–310. [PubMed: 15151547]
- Tamakoshi A, Ohno Y. Self-reported sleep duration as a predictor of all-cause mortality: results from the JACC study, Japan. *Sleep*. 2004; 27(1):51–54. [PubMed: 14998237]
- Twoogor SS, Yasui Y, Vitiello MV, Schwartz RS, Ulrich CM, Aiello EJ, Irwin ML, Bowen D, Potter JD, McTiernan A. Effects of a yearlong moderate-intensity exercise and a stretching intervention on sleep quality in postmenopausal women. *Sleep*. 2003; 26(7):830–6. [PubMed: 14655916]
- Vioque J, Torres A, Quiles J. Time spent watching television, sleep duration and obesity in adults living in Valencia, Spain. *International Journal of Obesity*. 2000; 24(12):1683–1688. [PubMed: 11126224]
- Von Kries R, Toschke AM, Wurmser H, Sauerwald T, Koletzko B. Reduced risk for overweight and obesity in 5- and 6-y-old children by duration of sleep - A cross-sectional study. *International Journal of Obesity*. 2002; 26(5):710–716. [PubMed: 12032757]
- Wingard DL, Berkman LF. Mortality risk associated with sleeping patterns among adults. *Sleep*. 1983; 6(2):102–7. [PubMed: 6878979]
- World Health Organization. Obesity: preventing and managing the global epidemic. World Health Organization; Geneva: 2000.

Table 1

Distribution of covariates across sleep duration categories: Rural Midwest, 2005 (n = 1,203)

	< 7 hours n=436	7 to 8 hours n=689	9 hours n=78	p-value
Mean Age (years)	51.9	55.2	57.7	<.01
Female	77.3	75.9	78.2	.81
Non-white race/ethnicity	5.8	3.6	5.1	.24
Married	62.2	68.4	51.3	<i>ref</i>
Divorced	22.5	18.0	29.5	<.01
Widowed	15.4	13.6	19.2	.11
Employed	49.8	45.6	19.2	<i>ref</i>
Non wage-earner	14.0	17.4	18.0	.01
Retired	22.0	27.3	32.0	<.01
Unable to work	14.2	9.7	30.8	<.01
Income <\$20,000	32.2	23.9	31.6	<.01
Income \$20 to <\$35,000	21.6	17.9	34.2	<.01
Income \$35 to <\$75,000	29.5	34.4	17.1	.30
Income \$75,000+	16.7	23.9	17.1	<i>ref</i>
< HS education	12.4	10.2	25.6	<.01
HS grad/Tech school	34.9	32.8	38.5	.01
Some college	24.8	20.4	15.4	.02
College grad or more	28.0	36.7	20.5	<i>ref</i>
Never smoker	53.0	54.7	47.4	<i>ref</i>
Former smoker	24.1	29.0	28.2	.58
Current smoker	22.9	16.3	24.4	.03
Excellent/very good health	40.4	49.4	26.9	<i>ref</i>
Good health	30.0	27.6	29.5	.03
Fair/poor health	29.6	23.1	43.6	<.01
Depressed	25.2	15.7	29.5	<.01
Frequent Snoring	26.4	27.4	25.6	.89
Insomnia	62.6	30.8	28.2	<.01
Normal BMI	37.8	38.3	32.0	<i>ref</i>
Overweight	30.3	35.3	21.8	.47
Obese	31.9	26.4	46.2	.02
Not vigorously active	82.8	75.6	85.9	<.01
5+ servings F&V	38.3	45.6	44.9	<i>ref</i>
2-4 servings F&V	41.1	40.8	39.7	.39
<2 servings F&V	20.6	13.6	15.4	<.01
Consume high fat diet	14.2	8.4	12.8	<.01
Often eat fast food	18.4	12.6	7.8	<.01

* two-tailed *p*-values based on chi-square distribution with d.f. = 2.

Table 2

Odds ratios (95% confidence interval) for not meeting physical activity requirements, low fruit and vegetable consumption, high fat diet and often eating fast food among those with short sleep duration (vs. 7-8 hour sleep duration): Rural Midwest, 2005 (n = 1,125) ^{*}.

Modeled Outcome	Model 1	Model 2	Model 3	Model 4
Not Meet Physical Activity Requirements				
6 Hours	1.74 (1.28, 2.38)	1.62 (1.16, 2.25)	1.57 (1.12, 2.21)	1.52 (1.07, 2.17)
7 to 8 Hours	1.00	1.00	1.00	1.00
Low Fruit & Vegetable Consumption				
6 Hours	1.75 (1.24, 2.47)	1.59 (1.08, 2.33)	1.49 (1.01, 2.21)	1.44 (0.96, 2.16)
7 to 8 Hours	1.00	1.00	1.00	1.00
High Fat Diet				
6 Hours	1.63 (1.11, 2.40)	1.47 (0.97, 2.22)	1.38 (0.90, 2.11)	1.32 (0.84, 2.06)
7 to 8 Hours	1.00	1.00	1.00	1.00
Often Eat Fast Food				
6 Hours	1.38 (0.98, 1.94)	1.34 (0.93, 1.91)	1.31 (0.91, 1.89)	1.29 (0.88, 1.89)
7 to 8 Hours	1.00	1.00	1.00	1.00

Model 1: Age-adjusted

Model 2: Model 1 + gender, race/ethnicity, marital status, employment status, household income, and education.

Model 3: Model 2 + physical health status, obesity status, smoking status and depressed mood.

Model 4: Model 3 + snoring frequency and insomnia.

^{*} Excludes long sleepers (n = 78)

Table 3

Odds ratios (95% confidence interval) for four obesity-related behaviors among those with short sleep duration (compared to 7-8 hour sleep duration group), stratified by obesity status: Rural Midwest, 2005 (n = 1,125)^{*}

	Non-obese (n = 804)		Obese (n = 321)	
	Age-adjusted	Covariate-adjusted ^{**}	Age-adjusted	Covariate-adjusted ^{**}
Not Meet Physical Activity Requirements				
6 Hours	1.78 (1.26, 2.53)	1.60 (1.09, 2.35)	1.37 (0.65, 2.85)	1.12 (0.50, 2.48)
7 to 8 Hours	1.00	1.00	1.00	1.00
Low Fruit & Vegetable Consumption				
6 Hours	1.80 (1.18, 2.75)	1.37 (0.84, 2.23)	1.57 (0.85, 2.89)	1.57 (0.78, 3.13)
7 to 8 Hours	1.00	1.00	1.00	1.00
High Fat Diet				
6 Hours	2.35 (1.38, 3.99) [§]	1.78 (0.99, 3.21)	0.94 (0.52, 1.70)	0.89 (0.47, 1.69)
7 to 8 Hours	1.00	1.00	1.00	1.00
Often Eat Fast Food				
6 Hours	1.17 (0.76, 1.80)	1.09 (0.68, 1.76)	1.73 (0.98, 3.05)	1.66 (0.90, 3.05)
7 to 8 Hours	1.00	1.00	1.00	1.00

^{*} Excludes long sleepers (n=78).

^{**} Adjusted for age, gender, race/ethnicity, marital status, employment status, household income, education, physical health status, obesity status, smoking status, depressed mood, snoring frequency, and insomnia.

[§] $p < 0.05$ for interaction term (short sleep duration * obesity status).