HHS Public Access

Author manuscript

*J Sleep Res*. Author manuscript; available in PMC 2021 December 01.

Published in final edited form as:

*J Sleep Res*. 2020 December ; 29(6): e12955. doi:10.1111/jsr.12955.

# Stressor Reactivity to Insufficient Sleep and its Association with Body Mass Index in Middle-Aged Workers

**Taylor F. D. Vigoureux**[1], **Soomi Lee**[1,*], **Orfeu M. Buxton**[2,3,4], **David M. Almeida**[5]

[1]School of Aging Studies, University of South Florida

[2]Department of Biobehavioral Health, Pennsylvania State University

[3]Division of Sleep Medicine, Harvard Medical School

[4]Division of Sleep and Circadian Disorders, Departments of Medicine and Neurology, Brigham and Women's Hospital

[5]Department of Human Development and Family Studies, Pennsylvania State University

## Summary

There is evidence that insufficient sleep and more stressors are individually associated with poor metabolic health outcomes. Examining sleep and stressors jointly may account for greater variability in health outcomes; however, we know little about the combined effect of both insufficient sleep and more stressors on metabolic health. This study examined whether experiencing more stressors in response to insufficient sleep ("stressor reactivity to insufficient sleep"; SRIS) was associated with body mass index (BMI) in middle-aged workers. 127 participants ($M_{age}$ = 45.24 ± 6.22) reported nightly sleep characteristics and daily stressors on 8 consecutive days. We collected height and weight measurements to calculate BMI (kg/m$^2$). On average, workers reported more stressors following nights with shorter-than-usual sleep duration or poorer-than-usual sleep quality (negative slope means higher SRIS). When examining SRIS with insufficient sleep represented by shorter-than-usual sleep duration, compared to those with average SRIS (within ± ½ *SD*; reference), workers with high SRIS (≤ −½ *SD*) had higher BMI ($B$ = 3.24, $p < .05$). The BMI of these workers fell in the obese range. There was no difference in BMI between workers with low SRIS (≥ + ½ SD) and the reference group. When examining SRIS with insufficient sleep represented by poorer-than-usual sleep quality, SRIS was not significantly associated with BMI. Results suggest that middle-aged workers with higher stressor reactivity to insufficient sleep duration may be at greater risk for obesity. Results may inform future studies on interventions for improving sleep and reducing stress in middle-aged workers.

*Corresponding Author: Soomi Lee, PhD., Assistant Professor, School of Aging Studies, University of South Florida, 4202 E. Fowler Avenue, MHC 1344, Tampa, FL 33620, soomilee@usf.edu, Phone: +1 813-974-9912.

Author Contributorship

S. Lee initiated this study and developed the study concept and an analysis plan. T. F. D. Vigoureux conducted statistical analyses and drafted the manuscript. O. M. Buxton, D. M. Almeida, and the Work Family and Health Network designed the research study; O. M. Buxton, D. M. Almeida contributed to data collection. All authors contributed to the revision of the manuscript and approved the final submitted version.

**Keywords**

insufficient sleep; stress; body mass index; daily diary; reactivity; workers

Sleep and stress are closely and dynamically related. For example, acute sleep deprivation causes highly reactive physiological responses to stressors (Guyon et al., 2014; Mezick, Matthews, Hall, Jennings, & Kamarck, 2014; Minkel et al., 2014; van Dalfsen & Markus, 2018; Vargas et al., 2017). The adverse effects of sleep loss are also observed in real world settings. Daily diary studies have shown that having insufficient sleep predicts experiencing more psychosocial and cognitive stressors the following day (Lee, Crain, McHale, Almeida, & Buxton, 2017; Lee, Buxton, Andel, & Almeida, 2019). The extent to which sleep is linked to next-day stressors may differ by individuals. For example, some may be more likely than others to appraise daily events that occur after nights with insufficient sleep as stressors. This individual difference represents *stressor reactivity to insufficient sleep* (SRIS). This study examined the association of SRIS with body mass index (BMI), an important indicator of metabolic health.

According to the stress-health model (Benham, 2010), both sleep and stress contribute to allostatic load and ultimately, adverse health outcomes. This suggests that considering both insufficient sleep and stressors may account for more variability in BMI rather than each alone. Yet, dynamic linkage between insufficient sleep and stressors and how it is associated with BMI have not been examined. In prior literature, insufficient sleep and more stressors are both individually associated with higher BMI (Buxton, Broussard, Zahl, & Hall, 2014; Jean-Louis et al., 2014; Kiecolt-Glaser et al., 2015; Nishiura, Noguchi, & Hashimoto, 2010). In general, perceiving more stressors can result in lower resting metabolism, lower fat oxidation, and higher insulin rates after a meal; these metabolic changes may be associated with weight gain (Kiecolt-Glaser et al., 2015). Our concept of SRIS captures the combined influence of insufficient sleep and stressors and is expected to be associated with BMI more strongly than insufficient sleep or stressors alone.

Supporting this idea, prior literature on daily stress highlights the importance of individual reactivity to negative events for health outcomes. For example, higher affective reactivity (i.e., more negative affect in response to stressful events) predicts future chronic health conditions, depression, and even mortality, while event exposure lacks association with these same outcomes (Charles, Piazza, Mogle, Sliwinski, & Almeida, 2013; Mroczek et al., 2015; Piazza, Charles, Sliwinski, Mogle, & Almeida, 2013). Our construct of SRIS captures individual reactivity to the incidence of insufficient sleep or how individuals differ in their psycho-cognitive appraisal of daily events after nights with insufficient sleep. In the literature on sleep, sleep reactivity (i.e., a propensity for sleep disruption following stressful events) has been often examined as a risk factor for incidence insomnia and depression (Drake, Pillai, & Roth, 2014). While these previous studies have addressed affective or sleep responses to stressors, the current study focuses on stressor perceptions following insufficient sleep (i.e., SRIS). Doing so is a way to explore the importance of sleep in daily lives and may guide future interventions targeting to improve sleep and stress; studies such as this are also critical to obtain more knowledge about allostatic load that may come from the combination of insufficient sleep and stressors, which damage many facets of health (McEwen, 2006a, 2006b).

The present study examined whether and how SRIS relates to BMI in a sample of middle-aged workers who are particularly prone to having less time for sleep and frequent exposure to daily stressors (Berkman et al., 2015; Buxton et al., 2016). Guided by the Stress-Health Model (Benham, 2010) and previous research on the importance of individual reactivity (Charles et al., 2013; Mroczek et al., 2015; Piazza et al., 2013), we hypothesized that higher SRIS (insufficient sleep operationalized as shorter duration or poorer quality than a participant's usual) would be associated with higher BMI (see Figure 1). In other words, individuals whose stressor perception is highly dependent on previous night's sleep were expected to have higher BMI. Considering potential non-linearity and possible differences in those who exhibit very low reactivity, we examined the hypothesized associations with high and low reactivity groups vs. the average reactivity group.

# Method

## Data

Data came from the Work, Family, and Health Study (WFHS), which investigates how work characteristics impact health and well-being in a sample of workers and their families (Bray et al., 2013). We used a sub-sample of employees in the WFHS who participated in an 8-day daily diary study. Our utilization of daily diary data allowed us to assess ecologically valid accounts of sleep and stressor variables (Gunthert & Wenze, 2012). Participants were employees in the information technology (IT) division of a U.S. Fortune 500 company in metropolitan areas.

Figure 2 is a flowchart showing how we came to our analytic sample. Of the 823 employees who completed a baseline sociodemographic interview at their workplace, 222 were eligible and invited to participate in a daily diary study. Eligibility criteria included having at least 1 child between the ages of 9 and 17 living at home (in order to recruit the child in the child daily diary study). Among these 222, 131 (59%) participated in a telephone daily diary study at baseline. Participants did not differ from individuals who were eligible but did not participate in the diary study on sociodemographic and work characteristics, with a few exceptions: compared to non-participants, diary participants were more likely to have older children, lower income, and were less likely to be a racial minority. Details of these comparisons can be found in a previous paper (Almeida et al., 2015). Four of the 131 participants were excluded for the following reasons: one completed only one diary day; two reported no stressors across the 8 days (could not calculate reactivity to insufficient sleep); one did not provide measured BMI data. The final analytic sample therefore included 127 workers. A majority (85%) of the sample completed all 8 days, 11% completed 7 days, and the rest completed 5-6 days.

## Procedure and Measures

Trained interviewers obtained informed consent and conducted baseline computer-assisted personal interviews with the employees at the workplace. During the workplace interview, interviewers collected height and weight measurements subsequently used to calculate BMI. Participants received $20 for participating in baseline workplace interviews. For the daily diary study, participants were telephoned on eight consecutive nights and asked about their daily experiences relating to sleep and daily stressful experiences. Each call lasted about 20 minutes and daily diary participation was compensated with an additional $150 per participant.

## Measured Body Mass Index (BMI)

Weight (in kilograms) was measured using a Health-O-Meter digital scale capable of weighing respondents up to 176.9 kilograms. Height (in centimeters) was measured using standard techniques and a Seca 214 stadiometer. BMI was calculated using the following formula: $\frac{(Weight \quad in\ kilograms)}{(Height\ in\ meters^2)}$

## Daily Diary Measures

**Sleep duration.—**Participants reported bedtime (i.e., "What time did you go to bed last night?") and wake time (i.e., "What time did you wake up this morning?") each day. We calculated nightly sleep duration as the interval (in hours) between bedtime and wake time. This variable indicates time in bed; however, we used this as an estimation of total time in sleep recovery following prior research (Lee et al., 2017). Additionally, in supplemental analyses, we used two other approximations of sleep duration: (a) the difference between calculated sleep and self-reported sleep latency ("how long did it take to fall asleep in minutes?") and (b) self-reported sleep hours.

**Sleep quality.—**We used one item adapted from the Pittsburg Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989) that reads "How would you rate (your/last night's) sleep quality overall?" Responses ranged from 1 (*very badly*) to 4 (*very well*). Previous studies have found that this single item was significantly associated with daily diary measures of wake after sleep onset, an indicator of sleep quality (Grandner, Kripke, Yoon, & Youngstedt, 2006), and this single item has been used as a measure of sleep quality in previous studies (Buxton et al., 2016; Lee et al., 2019, 2017).

**Daily stressors.—**To measure daily stressors, we used 10 items adapted from the Daily Inventory of Stressful Events (DISE; Almeida, Wethington, & Kessler, 2002). Participants reported any work- or home-related stressors from that day by responding *yes* (coded as "1") or *no* (coded as "0") to the following questions: "Since this time yesterday, (1) did you have an argument or disagreement with anyone at work, (2) did anything happen at your primary job that you could have argued about but you decided to let pass in order to avoid a disagreement, (3) did anything happen to a coworker or employee at your job that turned out to be stressful for you, (4) did you have demands placed on you at your job that were stressful, (5) other than what you have already mentioned, did anything else happen at your primary job that was stressful, (6) did you have an argument or disagreement with anyone outside of work, (7) did anything happen outside of work that you could have argued about but you decided to let pass in order to avoid a disagreement, (8) did you have demands placed on you at home that were stressful, (9) other than what you have already mentioned, did anything happen to a close friend or relative that turned out to be stressful for you, and (10) did anything else happen to you that was stressful for you?" We summed responses across all 10 items to calculate total frequency of daily stressors.

## Covariates

We controlled for sociodemographic characteristics related to BMI or sleep (Knutson, 2013; Office of Disease Prevention and Health Promotion, 2016). Included demographic covariates were age (in years, mean-centered), gender ("1" = *male*, "0" = *female*), race ("1" = *non-white*, "0" = *white*), married/partnered status ("1" = *not married or partnered,* "0" = *married or cohabiting*), and mean-centered household income. There were two household income variables: range and raw dollar amount. Two participants had missing data for range but reported their income in raw dollar amount. For those two participants, their range was determined and imputed from their reported raw dollar amount household income.

Given the potential associations of unhealthy lifestyles with sleep (Kanerva, Pietiläinen, Lallukka, Rahkonen, & Lahti, 2017), daily stress (Dalton & Hammen, 2018), and BMI (Wright & Aronne, 2012), we also considered variables indicative of unhealthy behaviors. Those include the frequency with which participants exercised for at least 20 minutes over the previous month, their weekly average frequency of fast food consumption, their weekly frequency of alcohol consumption, and the daily frequency with which they smoked tobacco cigarettes. Dichotomous variables were created for lack of exercise ("1" = *less than or equal to 4 times per month*, "0" = *greater than 4 times per month*), fast food consumption ("1" = *1 to 2 times per week or more*, "0" = *1 to 3 times per month or less*), alcohol consumption ("1" = *2 or more days per week*, "0" = *1 or fewer days per week*), and smoking ("1" = *every day or some days*, "0" = *not at all*).

## Data Analysis

**Modeling stressor reactivity to insufficient sleep.—**As a preliminary step, we computed a slope for stressor reactivity to insufficient sleep for each individual. Since repeated days were nested within each individual (i.e., 1016 total daily observations nested within 127 employees), we used multilevel models (Nezlek, 2012) to examine the extent to which perceptions of daily stressors change by previous night's insufficient sleep (i.e., SRIS). For example, the model for daily stressors predicted by previous night's sleep duration is expressed as:

$$Daily\ Stressors_{it} = \beta_{0i} + \ \beta_{1i} Previous\ Night\ Sleep\ Duration_{it} + e_{it} \quad (1)$$

where $\beta_{0i}$ represents each individual's intercept, and $\beta_{1i}$ represents each individual's reactivity to insufficient sleep slope with previous night sleep duration being centered at each individual's average sleep duration. Thus, $\beta_{1i}$ examines how stressor perceptions change as a function of previous night's sleep duration that is different from (or shorter than) the person's average (usual) sleep duration. Each individual's intercept and slope were modeled as follows:

$$\beta_{0i} = \gamma_{00} + \gamma_{01} Average\ Sleep\ Duration_i + u_{0i} \tag{2}$$

$$\beta_{1i} = \gamma_{10} + \gamma_{11} Average\ Sleep\ Duration_i + u_{1i} \tag{3}$$

where $\gamma_{00}$ and $\gamma_{10}$ being the sample mean of the intercept and slope, respectively, $u_{0i}$ and $u_{0i}$ denote random deviations of the person from those means, correlated with each other, and uncorrelated with the residual errors $e_{it}$. Controlling for average sleep duration ($\gamma_{11}$; centered at the sample mean) allows us to examine the within-person reactivity after controlling for the potential between-person association that individuals with shorter sleep duration than others in the sample may perceive more stressors, on average, across days. Reactivity to poorer-than-usual sleep quality was modeled in the same manner.

We used SAS PROC MIXED to fit the multilevel model to the data. In the total 1,016 daily observations, 1,012 days had no missing values on daily stressors and nightly sleep variables, and were thus used to output individual reactivity slopes. Intraclass correlation coefficients (ICCs) for daily stressors, sleep duration, and sleep quality were .29, .33, and .25, respectively, thus justifying the use of multilevel modeling (Nezlek, 2012). Figure 3 shows a spaghetti plot of individual participant and sample average reactivity slopes. On average, workers reported more stressors following nights with shorter sleep duration than their usual ($B = -0.15$, $SE = 0.03$, $p < .001$; negative slope means higher SRIS). Similarly, workers reported more stressors following nights with poorer sleep quality than their usual ($B = -0.13$, $SE = 0.06$, $p < .05$).

To be sure that the reactivity slope truly reflected the relationship between previous night's sleep and next day's stressor, we checked that this relationship remained significant after controlling for the previous day's stressors. The within-person slope remained significant after controlling for the previous day's stressors for reactivity to shorter-than-usual sleep duration ($B = -0.11$, $SE = 0.03$, $p < .001$) and poorer-than-usual sleep quality ($B = -0.22$, $SE = 0.06$, $p < .001$). We also examined whether acute changes in sleep could be a result of previous day's stressors by modeling the inverse of our reactivity (i.e., within-person association between daytime stressors and same-night sleep), and found this to not be true for sleep duration ($B = -0.05$, $SE = 0.04$, $p = .23$) or sleep quality ($B = 0.01$, $SE = 0.02$, $p = .60$).

For the sake of interpretability, reactivity to insufficient (shorter-than-usual) sleep (SRIS) was categorized into three groups (high SRIS: ≤ −½ SD, low SRIS: ≥ +½ SD, versus average SRIS [reference group]: −½ SD < slope < +½ SD). Reactivity to poorer-than-usual sleep quality slope was also categorized into three groups. In subsequent models, these categorical variables were used as predictors for body mass index. Given our goal to examine how difference from "typical" reactivity relates to BMI, and given that the low reactivity group was diverse with some slopes in the positive range, we used average reactivity as the reference group.

**Predicting BMI by SRIS slope.—**We used general linear modeling to predict BMI as a function of SRIS (duration and quality, respectively). In Model 1, we controlled for sociodemographic covariates including mean-centered age, gender, married/partnered status, race, mean-centered household income, average stressor frequency on days with usual sleep, and average sleep duration or quality. In Model 2, we additionally included the four unhealthy behavior variables (i.e., lack of exercise, fast food consumption, alcohol consumption, and smoking) to take into account their potential associations with BMI.

# Results

## Sample Characteristics

Table 1 shows characteristics of the whole sample and by stressor reactivity to insufficient (shorter-than-usual) sleep duration groups. Slightly more than half of the participants were men (54.3%). Most of the participants were married or partnered (86.6%), white (68.5%), and had completed at least a 4-year college degree (77.2%). Participants were on average 45 years old ($SD = 6$). For stressor reactivity to shorter-than-usual sleep duration, 28% of the sample was categorized as high, 35% as average, and 37% as low. There were no statistically significant differences by the reactivity group in sociodemographic, health-related, and sleep characteristics, except in BMI. For stressor reactivity to poorer-than-usual sleep quality, 25% of the sample was categorized as high, 39% as average, and 35% as low (Table S1). The high reactivity group was less likely to be married/partnered and had higher BMI and lower average sleep quality compared to the average and low reactivity groups.

## Predicting BMI from Stressor Reactivity to Shorter-than-Usual Sleep Duration

Table 2 shows results from a linear regression predicting BMI from stressor reactivity to shorter-than-usual sleep duration after controlling for sociodemographic covariates (Model 1) and after controlling for unhealthy behaviors (Model 2). Consistent with our hypothesis, individuals with high SRIS (≤ −½ SD) had a higher BMI ($B = 3.24$, $SE = 1.53$, $p < .05$) compared to the average SRIS group (within ± ½ SD; reference). This finding remained significant after controlling for unhealthy behaviors (i.e., lack of exercise, fast food and alcohol consumption, and smoking). The mean BMI of high SRIS workers fell within the obese range ($M = 30.44$). There were no differences in BMI between workers with low SRIS (≥ +½ SD) and the average SRIS group (see Figure 4). Table S3 contains results for analyses utilizing alternative approximations of sleep duration described in the Method section. These results were not significant; however, the effect was in the same direction with similar magnitude.

## Predicting BMI from Stressor Reactivity to Poorer-Than-Usual Sleep Quality

Stressor reactivity to poorer-than-usual sleep quality was not associated with BMI (see Table S1). Individuals with high SRIS (≤ −½ SD) tended to have a higher BMI compared to the average reactivity group (within ± ½ SD; reference); however, the estimate did not reach the statistical significance ($B = 3.05$, $SE = 2.02$, $p = .13$). There was no significant difference in BMI between lower reactivity and average reactivity groups ($B = -0.37$, $SE = 1.38$, $p = .79$). Thus, contrary to our hypothesis, stressor reactivity to poorer-than-usual sleep quality was not significantly associated with BMI.

## Discussion

Sleep is critical for many facets of health, including metabolic health (Buxton et al., 2014; Jean-Louis et al., 2014; Kiecolt-Glaser et al., 2015; Nishiura et al., 2010). This may be better understood through sleep's close relationship with stressor perception. This study found that perceiving more stressors after nights with shorter-than-usual sleep duration (i.e., stressor reactivity to insufficient sleep; SRIS) was associated with higher BMI in middle-aged workers. The result supports our research model showing that insufficient sleep predicts experiencing more stressors on a daily basis, which may be further associated with chronic load reactions of the metabolic system such as higher BMI (McEwen, 2006a, 2006b). Similarly, the results are in line with Benham's (2010) Stress-Health Model showing that the dynamic sleep-stress relationship may impact health through increased allostatic load. BMI was not associated with mean sleep duration or mean stressors per se, but with appraising more daily events as stressors after nights with shorter-than-usual sleep. Our use of a self-reported measure of daily stressors allowed us to capture appraisal, because in order to report that a stressor occurred, an individual has to first appraise the event as a stressor. This is parallel to previous findings that individual reactivity to a daily event is more important for health outcomes than event exposure itself (Charles et al., 2013; Mroczek et al., 2015; Piazza et al., 2013).

There is evidence that insufficient sleep is related to perceiving more psychosocial and cognitive stressors the following day (Lee, Buxton, Andel, & Almeida, 2019; Lee et al., 2017). However, there are individual differences in the strength of this relationship. This study examined how individual differences in SRIS relate to BMI. Previous researchers have urged the importance of examining sleep and stress simultaneously in health outcomes research (Benham, 2010), and our measure of SRIS allowed us to do so. The within-person slope of self-reported daily total stressors regressed on previous night's sleep duration (or sleep quality) indicates each individual's own reactivity to insufficient sleep that deviates from their usual sleep. This novel measure was significantly associated with BMI. Specifically, individuals with higher SRIS compared to average SRIS had higher BMIs falling in the obese range. This association remained significant after adjusting for potential differences in BMI due to sociodemographic variables. Thus, results highlight the potential importance of SRIS in predicting health, parallel to previous studies that suggested predictive effects of affective reactivity on chronic disease and mortality (Charles et al., 2013; Mroczek et al., 2015; Piazza et al., 2013). Additionally, the link between high SRIS and higher BMI existed independent of unhealthy behaviors (i.e., lack of exercise, fast food and alcohol consumption, and smoking) found to have significant associations with BMI in previous studies (Wright & Aronne, 2012). Taken together, our findings demonstrate that this new variable—SRIS—may be critical for identifying individuals at particular risk for adverse health outcomes (in this case, obesity).

Interestingly, the high reactivity-higher BMI relationship was not statistically significant for reactivity to poorer-than-usual sleep quality. However, the estimate for reactivity to poorer-than-usual sleep quality was of meaningful size and in the expected direction. Additionally, the unadjusted mean BMI was higher for the high reactivity group than for the low or average reactivity group (Table S1). It is possible that this estimate did not reach significance because our measure of sleep quality is on a 4-point Likert-type scale with a limited range of one to four and may not capture enough variability in sleep quality.

Strengths of this study include our novel conceptualization of SRIS. To the best of our knowledge, this study is the first to examine individual reactivity to insufficient sleep and its association with a metabolic health outcome (i.e., BMI). Additionally, our use of daily diary data allowed us to quantify within-person slopes of reactivity likely to occur in real life. Measures of nightly sleep and daily stressors were collected in participants' naturalistic settings, thus providing ecologically valid data (Gunthert & Wenze, 2012). The sample of middle-aged workers was also beneficial for our research question because they are prone to having insufficient sleep (Berkman et al., 2015; Buxton et al., 2016) and more opportunities to experience daily stressors (Almeida, 2005).

Although this study makes important contributions to the literature, a few limitations motivate future directions. While this study is the first to operationalize SRIS in this manner, it is both a strength and a hindrance because, though we have demonstrated one circumstance where this variable provides important insights into metabolic health, we cannot yet generalize to other health outcomes. One promising avenue for future research with SRIS is cardiovascular health, given that insufficient sleep (Sabanayagam & Shankar, 2010) and stress (Steptoe & Kivimaki, 2012) are both predictors of cardiovascular disease. Moreover, given the cross-sectional nature of our data, temporal order cannot be established; that is, we cannot determine whether BMI predicts reactivity or reactivity predicts BMI. However, it is important to note that establishing an association between two variables is a critical and necessary step for a seminal paper on a construct not previously operationalized. Future research could utilize longitudinal data to test the temporal order between the variables. Another limitation is that our sample was intentionally taken from an IT company and was well-educated and financially well-off. Therefore, the results may not generalize to other samples (e.g., workers from other industries with lower education and income). Also, we did not collect information on diagnosed sleep disorders. However, our measure of SRIS captures deviation from each individual's usual sleep duration or quality, and thus may be less relevant to individual differences in sleep problems. Still, future research could test whether sleep disorders play a role in the SRIS–BMI relationship. Additionally, only participants with children between the ages of 9 and 17 were eligible for the daily diary study. Individuals with children may be inherently different than those without children, especially in terms of the opportunities to experience daily stressors. Future research could test whether our findings are replicated in workers without children. Finally, although sleep and stressor information were collected daily with less chance for recall bias, the measures used may be imperfect. For example, the sleep duration variable we used indicates total time spent in bed (i.e., calculated as the difference between bedtime and wake time) and it may still involve errors around reported sleep timing and actual sleep onset/offset. Objective actigraphy- or polysomnography-assessed sleep would be ideal for future studies.

This study found that individuals whose stressor perception is more sensitive to shorter-than-usual sleep duration (high SRIS) were more likely to have a higher BMI that fell within the obese range. This was independent of unhealthy behaviors, sociodemographic characteristics, mean stressor frequency, and average sleep duration, indicating that reactivity has a potentially unique association with BMI. Our findings suggest that SRIS could be used as a screening tool for identifying individuals at risk for adverse metabolic health. Studies such as this are the groundwork for developing interventions to improve the sleep health of middle-aged workers, and by doing so, to reduce perception of stressors and promote overall worker health.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

## Acknowledgments

**Disclosure Statement:** The authors have indicated no financial conflicts of interest relevant to the current study. Outside of the current work, Orfeu M. Buxton received two subcontract grants to Penn State from Mobile Sleep Technologies (NSF/STTR #1622766, NIH/NIA SBIR R43AG056250), receives honoraria for Continuing Dental Education lectures at Tufts School of Dental Medicine, received honoraria for speaking at Boston College and Boston University, and receives an honorarium for his role as Editor-in-chief (designate) of Sleep Health sleephealthjournal.org. All other authors have no disclosures to report.

## References

Almeida DM, Davis KD, Lee S, Lawson KM, Walter KN, & Moen P (2015). Supervisor support buffers daily psychological and physiological reactivity to work-to-family conflict. Journal of Marriage and Family, 78(1), 165–179. 10.1111/jomf.12252 [PubMed: 26778857]

Almeida DM, Wethington E, & Kessler RC (2002). The Daily Inventory of Stressful Events: An interview-based approach for measuring daily stressors. Assessment, 9(1), 41–55. https://doi.org/10.1177%2F1073191102091006 [PubMed: 11911234]

Almeida David M. (2005). Resilience and vulnerability to daily stressors assessed via diary methods. Current Directions in Psychological Science, 14(2), 62–68.

Benham G (2010). Sleep: An important factor in stress-health models. Stress and Health, 26(3), 204–214. 10.1002/smi.1304

Berkman LF, Liu SY, Hammer LB, Moen P, Klein LC, Kelly E, … Buxton OM (2015). Work-family conflict, cardiometabolic risk and sleep duration in nursing employees. Journal of Occupational Health Psychology, 20(4), 420–433. 10.1037/a0039143 [PubMed: 25961758]

Bidulescu A, Din-Dzietham R, Coverson DL, Chen Z, Meng Y-X, Buxbaum SG, … Welch VL (2010). Interaction of sleep quality and psychosocial stress on obesity in African Americans: the Cardiovascular Health Epidemiology Study (CHES). BMC Public Health, 10(581). 10.1186/1471-2458-10-581

Bray J, Kelly E, Hammer L, Almeida D, Dearing J, King R, & Buxton OM (2013). An integrative, multilevel, and transdisciplinary research approach to challenges of Work, Family, and Health. Methods Report (RTI Press), 1–38. 10.3768/rtipress.2013.mr.0024.1303

Buxton OM, Broussard JL, Zahl AK, & Hall MH (2014). Effects of sleep deficiency on hormones, cytokines, and metabolism In *Impact of Sleep and Sleep Disturbances on Obesity and Cancer* (pp. 25–50). New York, NY: Springer 10.1007/978-1-4614-9527-7

Buxton OM, Lee S, Beverly C, Berkman LF, Moen P, Kelly EL, … Almeida DM (2016). Work-family conflict and employee sleep: Evidence from IT workers in the work, family and health study. Sleep, 39(10), 1911–1918. 10.5665/sleep.6172 [PubMed: 27450688]

Buysse DJ, Reynolds CF, Monk TH, Berman SR, & Kupfer DJ (1989). The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. Psychiatry Research, 28(2), 193–213. 10.1016/0165-1781(89)90047-4 [PubMed: 2748771]

Charles ST, Piazza JR, Mogle J, Sliwinski MJ, & Almeida DM (2013). The wear and tear of daily stressors on mental health. Psychological Science, 24(5), 733–741. 10.1177/0956797612462222 [PubMed: 23531486]

Dalton ED, & Hammen CL (2018). Independent and relative effects of stress, depressive symptoms, and affect on college students' daily health behaviors. Journal of Behavioral Medicine, 41, 863–874. 10.1007/s10865-018-9945-4 [PubMed: 29926314]

Drake CL, Pillai V, & Roth T (2014). Stress and sleep reactivity: A prospective investigation of the stress-diathesis model of insomnia. Sleep, 37(8), 1295–1304. 10.5665/sleep/3916 [PubMed: 25083009]

Grandner MA, Kripke DF, Yoon I, & Youngstedt SD (2006). Criterion validity of the Pittsburgh Sleep Quality Index: Investigation in a non-clinical sample. Sleep and Biological Rhythms, (4), 129–136. 10.1111/j.1479-8425.2006.00207.x [PubMed: 22822303]

Gunthert KC, & Wenze SJ (2012). Daily diary methods In Mehl MR & Conner TS (Eds.), Handbook of Research Methods for Studying Daily Life (pp. 144–159). New York, NY: The Guilford Press.

Guyon A, Balbo M, Morselli LL, Tasali E, Leproult R, L'Hermite-Balériaux M, … Spiegel K (2014). Adverse effects of two nights of sleep restriction on the hypothalamic-pituitary-adrenal axis in healthy men. Journal of Clinical Endocrinology and Metabolism, 99(8), 2861–2868. 10.1210/jc.2013-4254 [PubMed: 24823456]

Jean-Louis G, Williams NJ, Sarpong D, Pandey A, Youngstedt S, Zizi F, & Ogedegbe G (2014). Associations between inadequate sleep and obesity in the US adult population. BMC Public Health, 14(290), 1–17. [PubMed: 24383435]

Kanerva N, Pietiläinen O, Lallukka T, Rahkonen O, & Lahti J (2017). Unhealthy lifestyle and sleep problems as risk factors for increased direct employers' cost of short-term sickness absence. Scandinavian Journal of Work, Environment and Health, 38(6), 485–605. 10.5271/sjweh.3695

Kiecolt-Glaser JK, Habash DL, Fagundes CP, Andridge R, Peng J, Malarkey WB, & Belury MA (2015). Daily stressors, past depression, and metabolic responses to high-fat meals: A novel path to obesity. Biological Psychiatry, 77(7), 653–660. 10.1016/j.biopsych.2014.05.018 [PubMed: 25034950]

Knutson KL (2013). Sociodemographic and cultural determinants of sleep deficiency: Implications for cardiometabolic disease risk. Social Science & Medicine, 79, 7–15. 10.1016/j.socscimed.2012.05.002 [PubMed: 22682665]

Lee S, Buxton OM, Andel R, & Almeida DM (2019). Bidirectional associations of sleep with cognitive interference in employees' work days. Sleep Health, in press(March). 10.1016/j.sleh.2019.01.007

Lee S, Crain TL, McHale SM, Almeida DM, & Buxton OM (2017). Daily antecedents and consequences of nightly sleep. Journal of Sleep Research, 26(4), 498–509. 10.1111/jsr.12488 [PubMed: 28008673]

McEwen BS (2006a). Sleep deprivation as a neurobiologic and physiologic stressor: allostasis and allostatic load. Metabolism: Clinical and Experimental, 55(SUPPL. 2), 23–26. 10.1016/j.metabol.2006.07.008

McEwen BS (2006b). Stress, adaptation, and disease: Allostasis and allostatic load. Annals of the New York Academy of Sciences, 840(1), 33–44.

Mezick EJ, Matthews KA, Hall MH, Jennings R, & Kamarck TW (2014). Sleep duration and cardiovascular responses to stress in undergraduate men. Psychophysiology, 51(1), 88–96. 10.1111/psyp.12144 [PubMed: 24016263]

Minkel J, Moreta M, Muto J, Htaik O, Jones C, Basner M, & Dinges D (2014). Sleep deprivation potentiates HPA axis stress reactivity in healthy adults. Health Psychology, 33(11), 1430–1434. 10.1037/a0034219 [PubMed: 24818608]

Mroczek DK, Stawski RS, Turiano NA, Chan W, Almeida DM, Neupert SD, & Spiro A (2015). Emotional reactivity and mortality: Longitudinal findings from the VA normative aging study. Journals of Gerontology - Series B Psychological Sciences and Social Sciences, 70(3), 398–406. 10.1093/geronb/gbt107

Nezlek JB (2012). Multilevel modeling analyses of diary-style data In Mehl MR & Conner TS (Eds.), Handbook of Research Methods for Studying Daily Life (pp. 357–383). New York, NY: The Guilford Press.

Nishiura C, Noguchi J, & Hashimoto H (2010). Dietary patterns only partially explain the effect of short sleep duration on the incidence of obesity. Sleep, 33(6), 753–757. 10.1093/sleep/33.6.753 [PubMed: 20550015]

Office of Disease Prevention and Health Promotion. (2016). Nutrition and Weight Status. Retrieved from https://www.healthypeople.gov/2020/topics-objectives/topic/nutrition-and-weight-status

Piazza JR, Charles ST, Sliwinski MJ, Mogle J, & Almeida DM (2013). Affective reactivity to daily stressors and long-term risk of reporting a chronic physical health condition. Annals of Behavioral Medicine, 45(1), 110–120. 10.1007/s12160-012-9423-0 [PubMed: 23080393]

Sabanayagam C, & Shankar A (2010). Sleep duration and cardiovascular disease: Results from the National Health Interview Survey 2008. Sleep Medicine, 33(8), 1037–1042. 10.1093/sleep/33.8.1037

Steptoe A, & Kivimaki M (2012). Stress and cardiovascular disease. Nature Reviews Cardiology, 9, 360–370. 10.1038/nrcardio.2012.45 [PubMed: 22473079]

van Dalfsen JH, & Markus CR (2018). The influence of sleep on human hypothalamic–pituitary–adrenal (HPA) axis reactivity: A systematic review. Sleep Medicine Reviews, 39, 187–194. 10.1016/j.smrv.2017.10.002 [PubMed: 29126903]

Vargas I, Gencarelli A, Khader W, DiGuiseppe A, Boyle J, Muench A, & Lopez-Duran N (2017). Investigating the effect of acute sleep deprivation on hypothalamic-pituitaryadrenal-axis response to a psychosocial stressor. Psychoneuroendocrinology, 79, 1–8. 10.1016/j.psyneuen.2017.01.030 [PubMed: 28235691]

Wright SM, & Aronne LJ (2012). Causes of obesity. Abdominal Imaging, 37, 730–732. 10.1007/s00261-012-9862-x [PubMed: 22426851]

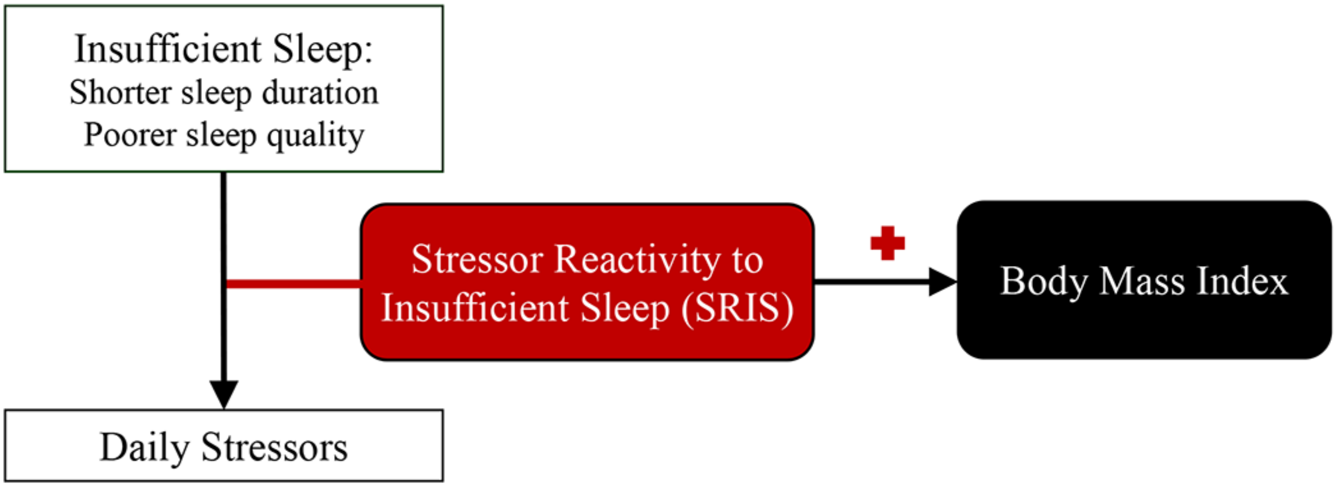


**Figure 1.**
Research model examining the link between stressor reactivity to insufficient sleep and metabolic health

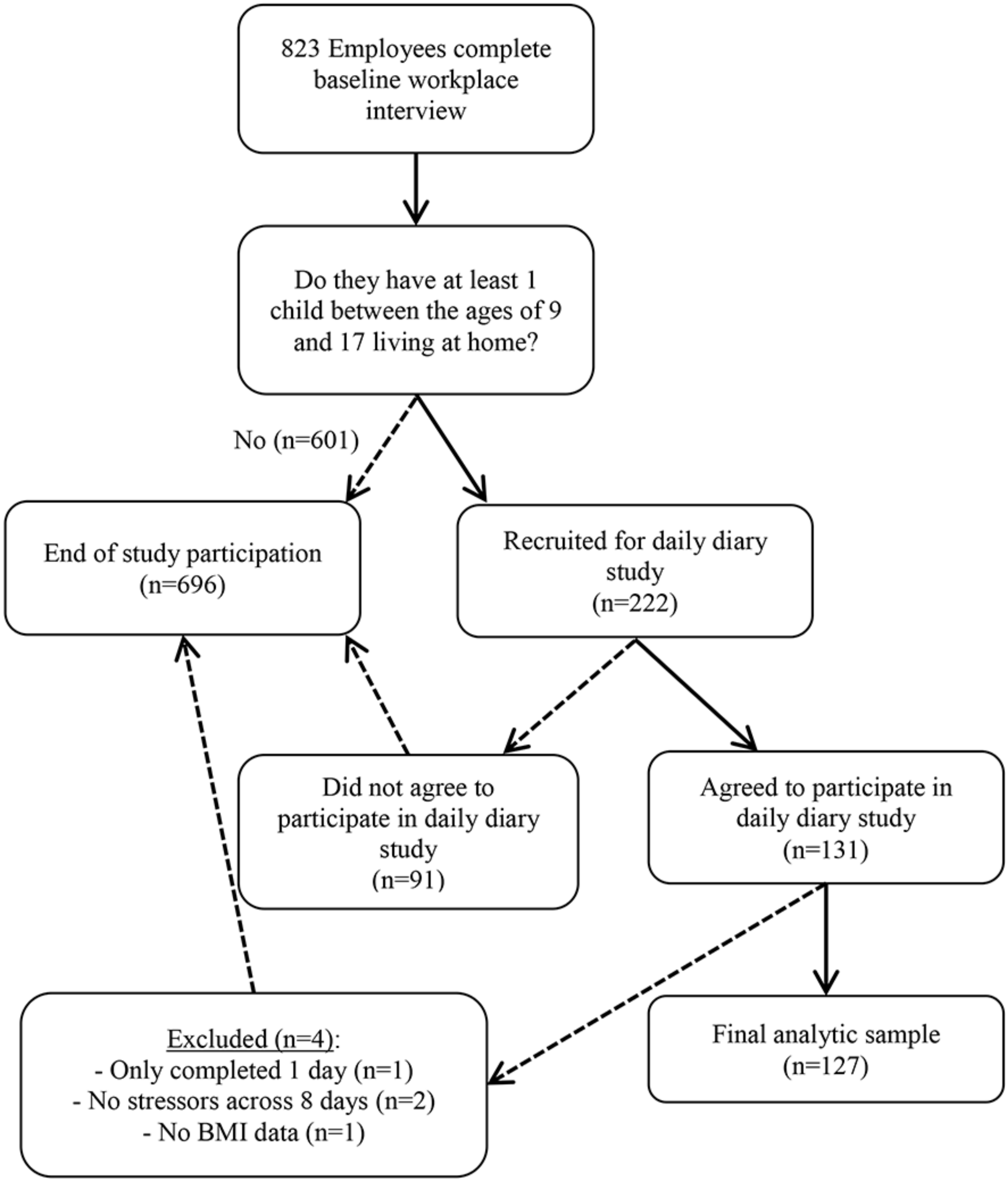


**Figure 2.**
Flowchart of daily diary sub-sample data collection

Author Manuscript

Author Manuscript

Author Manuscript

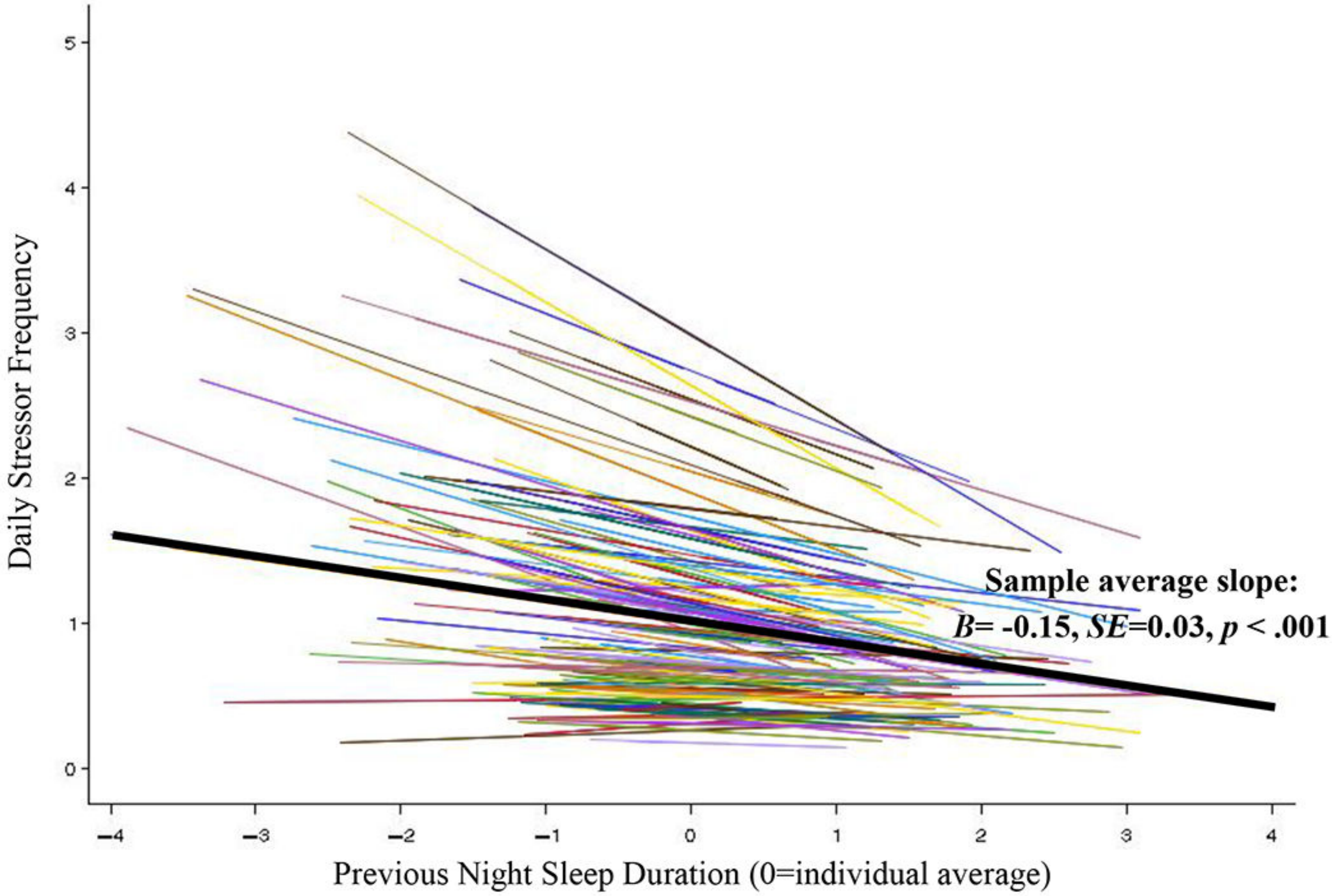


**Figure 3.**

Stressor reactivity to shorter-than-usual sleep duration random slopes. Each color line represents each individual's reactivity slope. The bolded black line shows the sample-level average reactivity slope.

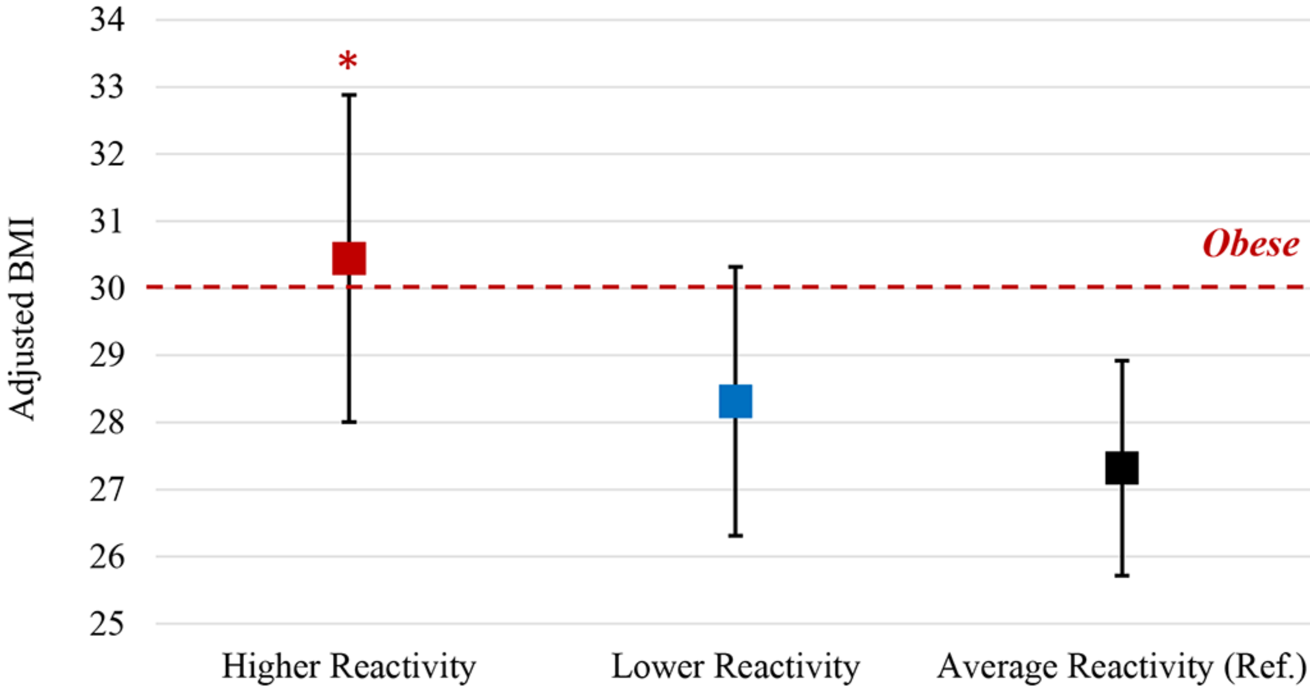


**Figure 4.**

Bar graph of adjusted mean BMI by stressor reactivity to insufficient sleep duration (SRIS) group after controlling for all covariates and unhealthy behaviors. Reactivity slopes for each SRIS group are as follows: higher reactivity slope ≤ −½ *SD*; lower reactivity slope ≥ + ½ SD; average reactivity slope within ± ½ *SD* (reference). The asterisk indicates an adjusted BMI that is significantly ($p < .05$) different from the reference group.

**Table 1.**

Descriptive statistics for total sample and by stressor reactivity to shorter-than-usual sleep duration category.

| Reactivity Category | Total (n = 127) | High Reactivity ≤ −½ SD (n = 36) | Average Reactivity (n = 44) | Low Reactivity ≥ +½ SD (n = 47) | Diff Tests |
|---|---|---|---|---|---|
| **Variable Name** | **M (SD) or %** | **M (SD) or %** | **M (SD) or %** | **M (SD) or %** | **$F/\chi^2$** |
| **Demographics** | | | | | |
| Sex, male (%) | 54.33 | 50.00 | 54.55 | 57.45 | 0.46 |
| Married/partnered (%) | 86.61 | 80.56 | 86.36 | 91.49 | 2.11 |
| Race, white (%) | 68.50 | 77.78 | 65.91 | 63.83 | 1.99 |
| Age | 45.24 (6.22) | 46.61 (6.12) | 44.98 (5.42) | 44.45 (6.91) | 1.30 |
| Education, college graduates (%) | 77.17 | 75.00 | 81.82 | 74.47 | 3.24 |
| Household income range[a] | 8.63 (2.94) | 8.42 (3.21) | 8.58 (2.74) | 8.85 (2.96) | 17.86 |
| **Health-related variables** | | | | | |
| Exercise frequency (%)[b] | 9.56 (8.66) | 8.33 (6.78) | 9.11 (9.42) | 10.91 (9.17) | 0.99 |
| Fast food consumption (3+ times/week, %) | 23.62 | 33.33 | 22.73 | 17.02 | 7.59 |
| Alcohol consumption (n/week) | 67 | 24 | 19 | 24 | 0.35 |
| # of Drinks/week[c] | 4.96 (5.90) | 4.33 (5.25) | 5.16 (5.22) | 5.42 (7.08) | 0.21 |
| Smoke tobacco cigarettes (%) | 5.51 | 5.56 | 9.09 | 2.13 | 2.50 |
| Body mass index | 28.60 (5.61) | † 30.71 (6.87) | § 27.51 (4.49) | †§ 27.90 (5.23) | **3.87** |
| **Sleep** | | | | | |
| Average sleep duration (minutes) | 433.2 (50.8) | 427.4 (54.13) | 442.59 (48.85) | 428.84 (49.76) | 1.16 |
| Average sleep quality (1-4) | 2.20 (0.81) | 2.36 (0.96) | 2.14 (0.70) | 2.15 (0.78) | 7.73 |

Note.

[a] Household income ranges: 7 = 100,000-109,999; 8 = 110,000-119,999; 9 = 120,000-129,999

[b] Exercise frequency: “How many times in the past 4 weeks did you exercise enough to break a sweat?”.

[c] Drinks per week was only computed for individuals who reported at least 1 drinking day per week.

[d] Stressor Intercept indicates the average stressor frequency on days with average sleep duration for the entire sample.

†,§ denote group differences. Groups with the same symbol do not differ. Groups with different symbols were significantly different from each other.

Bolded items were significant at $p < .05$

## Table 2.

Regression table examining the relationship between stressor reactivity to shorter-than-usual sleep duration and BMI.

| Variable Name | *b* | *SE* | *t* | *p* | 95% CI |
|---|---|---|---|---|---|
| **Model 1 - Reactivity to Shorter-Than-Usual Sleep Duration** | | | | | |
| High Reactivity to Shorter Sleep Duration (≤−½*SD*) | 3.24 | 1.53 | 2.12 | **0.04** | [0.21, 6.27] |
| Low Reactivity to Shorter Sleep Duration (≥+½*SD*) | 0.28 | 1.32 | 0.21 | 0.83 | [−2.34, 2.90] |
| Stressor Intercept | −0.77 | 1.42 | −0.55 | 0.59 | [−3.58, 2.03] |
| Sleep Duration | −0.00 | 0.01 | −0.17 | 0.87 | [−0.02, 0.02] |
| Age | −0.01 | 0.08 | −0.09 | 0.93 | [−0.17, 0.16] |
| Male | −0.44 | 1.07 | −0.42 | 0.68 | [−2.56, 1.67] |
| Nonmarried | 3.90 | 1.70 | 2.30 | **0.02** | [0.54, 7.26] |
| Nonwhite | −1.35 | 1.07 | −1.26 | 0.21 | [−3.47, 0.78] |
| Household Income | −0.18 | 0.19 | −0.95 | 0.34 | [−0.55, 0.19] |
| **Model 2 - Reactivity to Shorter-Than-Usual Sleep Duration Controlling for Unhealthy Behaviors** | | | | | |
| High Reactivity to Shorter Sleep Duration (≤−½*SD*) | 3.12 | 1.48 | 2.11 | **0.04** | [0.19, 6.06] |
| Low Reactivity to Shorter Sleep Duration (≥+½*SD*) | 0.99 | 1.30 | 0.76 | 0.45 | [−1.58, 3.57] |
| Stressor Intercept | −0.44 | 1.39 | −0.31 | 0.75 | [−3.19, 2.32] |
| Sleep Duration | −0.00 | 0.01 | −0.01 | 0.99 | [−0.02, 0.02] |
| Age | 0.01 | 0.08 | 0.13 | 0.90 | [−0.15, 0.17] |
| Male | −0.15 | 1.04 | −0.15 | 0.88 | [−2.21, 1.90] |
| Nonmarried | 3.79 | 1.65 | 2.30 | **0.02** | [0.52, 7.06] |
| Nonwhite | −1.67 | 1.08 | −1.54 | 0.13 | [−3.81, 0.48] |
| Household Income | −0.21 | 0.18 | −1.15 | 0.25 | [−0.57, 0.15] |
| Lack of Exercise | 1.39 | 1.01 | 1.38 | 0.17 | [−0.61, 3.40] |
| Fast Food | 2.33 | 0.97 | 2.41 | **0.02** | [0.42, 4.26] |
| Alcohol | −1.54 | 1.14 | −1.35 | 0.18 | [−3.81, 0.72] |
| Smoke | 1.19 | 3.18 | 0.38 | 0.71 | [−5.10, 7.48] |

*Note.* Average reactivity to shorter-than-usual sleep duration (within ± ½ *SD*) was used as the reference category. Stressor intercept represents the average number of stressors reported on days after average sleep duration. Age and household income are mean-centered. Items with bolded p-values were significant at $p < .05$.