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The association between sleep health and weight change during a 12-month behavioral weight loss intervention

Christopher E. Kline, Ph.D.¹, Eileen R. Chasens, Ph.D.², Zhadyra Bizhanova, M.B.Ch.B., MPH³, Susan M. Sereika, Ph.D.^{2,3,4}, Daniel J. Buysse, M.D.⁵, Christopher C. Imes, Ph.D.², Jacob K. Kariuki, Ph.D.², Dara D. Mendez, Ph.D.³, Mia I. Cajita, Ph.D.⁶, Stephen L. Rathbun, Ph.D.⁷, Lora E. Burke, Ph.D., MPH^{2,3}

¹Department of Health and Human Development, University of Pittsburgh, Pittsburgh, PA;

²School of Nursing, University of Pittsburgh, Pittsburgh, PA;

³Department of Epidemiology, University of Pittsburgh, Pittsburgh, PA;

⁴Department of Biostatistics, University of Pittsburgh, Pittsburgh, PA;

⁵Department of Psychiatry, University of Pittsburgh, Pittsburgh, PA;

⁶Department of Biobehavioral Health Science, University of Illinois, Chicago, IL;

⁷Department of Epidemiology & Biostatistics, University of Georgia, Athens, GA.

Abstract

Background: Prior research on the relationship between sleep and attempted weight loss failed to recognize the multidimensional nature of sleep. We examined the relationship between a composite measure of sleep health and change in weight and body composition among adults in a weight loss intervention.

Methods: Adults ($N=125$) with overweight or obesity (50.3 ± 10.6 years, 91% female, 81% white) participated in a 12-month behavioral weight loss intervention, with assessments of sleep, weight, fat mass, and fat-free mass at baseline, 6 months, and 12 months. Six sleep dimensions (regularity, satisfaction, alertness, timing, efficiency, and duration) were categorized as ‘good’ or ‘poor’ using questionnaires and actigraphy. A composite score was calculated by summing the number of

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Corresponding author: Christopher E. Kline, PhD, Physical Activity and Weight Management Research Center, Department of Health and Human Development, University of Pittsburgh, 32 Oak Hill Court, Room 227, Pittsburgh, PA 15261; Phone: 412-383-4027; chriskline@pitt.edu.

COMPETING INTERESTS

In the past 3 years, Dr. Buysse has served as a paid consultant to Bayer, BeHealth Solutions, Emmi Solutions, Weight Watchers International, and Pear Therapeutics. He has served as a paid consultant for professional educational programs developed by the American Academy of Physician Assistants, CME Institute, and Emmi Solutions, and received payment for a professional education program sponsored by Eisai. Dr. Buysse is an author of the Pittsburgh Sleep Quality Index, Pittsburgh Sleep Quality Index Addendum for PTSD (PSQI-A), Brief Pittsburgh Sleep Quality Index (B-PSQI), Daytime Insomnia Symptoms Scale, Pittsburgh Sleep Diary, Insomnia Symptom Questionnaire, and RU_SATED (copyright held by University of Pittsburgh). These instruments have been licensed to commercial entities for fees. He is also co-author of the Consensus Sleep Diary (copyright held by Ryerson University), which is licensed to commercial entities for a fee. No other authors report any conflicts of interest.

SUPPLEMENTARY INFORMATION

Supplementary information is available at the *International Journal of Obesity's* website.

'good' dimensions. Obstructive sleep apnea (OSA) was assessed in a subsample ($n=117$), using the apnea-hypopnea index (AHI) to determine OSA severity. Linear mixed modeling was used to examine the relationships between sleep health and outcomes of percent weight, fat mass, or fat-free mass change during the subsequent 6-month interval, adjusting for age, sex, bed partner, and race; an additional model adjusted for AHI.

Results: Mean baseline and 6-month sleep health was 4.5 ± 1.1 and 4.5 ± 1.2 , respectively. Mean weight, fat mass, and fat-free mass changes from 0–6 months were $-9.3\pm 6.1\%$, $-16.9\pm 13.5\%$, and $-3.4\pm 3.4\%$, respectively, and $0.4\pm 4.8\%$, $-0.3\pm 10.3\%$, and $0.7\pm 4.1\%$ from 6–12 months. Better sleep health was associated with greater subsequent weight loss ($P=.016$) and fat loss ($P=.006$), but not fat-free mass loss ($P=.232$). Following AHI adjustment, the association between sleep health and weight loss was attenuated ($P=.102$) but remained significant with fat loss ($P=.040$). Regularity, satisfaction, timing, and efficiency were each associated with weight and/or fat loss ($P .041$).

Conclusions: Better sleep health was associated with greater weight and fat loss, with associations attenuated after accounting for OSA severity. Future studies should explore whether improving sleep health, OSA, or the combination improves weight loss.

INTRODUCTION

Obesity continues to be a prevalent and disabling disease. Its prevalence is increasing worldwide,¹ and 42.4% of adults in the United States had obesity in 2017–2018.² Obesity imposes a significant public health burden given its association with cardiovascular disease, type 2 diabetes, and certain types of cancer.³ Globally, approximately 4.0 million deaths and 4.9% of disability-adjusted life-years are attributed to overweight and obesity annually.⁴

Lifestyle modification is the most common intervention for the treatment of obesity. The American College of Cardiology and American Heart Association recommend that individuals who have overweight or obesity participate in a comprehensive lifestyle program that uses behavioral strategies to support the adoption of a calorie-restricted diet and engagement in physical activity for at least 6 months.⁵ Adherence to a comprehensive lifestyle program results in clinically significant weight loss in those with obesity.⁶ However, the weight loss response to lifestyle modification is often variable and significant weight loss remains elusive for many adults.⁷ As a result, identifying factors that may impact the weight loss response could have important clinical implications.⁸

Sleep is increasingly recognized for its contribution to body weight regulation.⁹ The majority of research to date has focused on sleep duration; short sleep duration predicts greater obesity risk in prospective epidemiologic studies,¹⁰ while short-term laboratory studies involving sleep restriction have led to behavioral and physiological alterations (e.g., increased energy intake, reduced glucose tolerance) that predispose to obesity.¹¹ However, other dimensions of sleep have also been shown to be related to obesity, including poor sleep quality,¹² late sleep timing,¹³ low sleep efficiency,¹⁴ and irregular sleep patterns.¹⁵ Thus, multiple manifestations of poor sleep contribute to obesity risk.

Much less is known about how sleep may influence attempted weight loss, especially within the context of behavioral interventions. The available evidence is mixed. While disturbed sleep (e.g., short sleep duration, low sleep efficiency, or poor sleep quality) predicted blunted weight and/or fat loss following a weight loss intervention in some studies,^{16–20} other studies observed no association between sleep and weight loss.^{21–23} These studies are limited by their reliance upon self-reported sleep,^{17–19,21–23} assessment of sleep only at baseline,^{16,18,20} and/or inability to account for obstructive sleep apnea (OSA).^{16–23} These limitations are notable because self-reported sleep is often divergent from objectively assessed sleep,²⁴ sleep may improve following weight loss,¹⁹ and OSA may account for blunted weight loss.²⁵ Addressing these limitations may provide better insight into the influence of sleep in behavioral weight loss interventions.

This area of research has also been limited by its focus on individual sleep dimensions, which fails to account for the multidimensional nature of sleep.²⁶ The construct of sleep health emphasizes that the absence of a sleep disorder is not synonymous with healthy sleep and that multiple dimensions of sleep are associated with optimal health. The purpose of our investigation was to examine the relationship between sleep health and the outcomes of weight and body composition change in adults who participated in a 12-month behavioral weight loss intervention. To address prior limitations, we assessed sleep with both self-report and objective methods, assessed sleep at multiple time points, and accounted for OSA severity in sensitivity analyses. We hypothesized that better sleep health would be associated with greater subsequent weight and fat loss, but that these relationships would be attenuated following adjustment for OSA severity.

METHODS

Study Design and Sample

The parent study, EMPOWER, was a 12-month prospective observational study that included a behavioral weight loss intervention to provide the context for observing the triggers of lapses/relapses following intentional weight loss.²⁷ The study was approved by the University of Pittsburgh Institutional Review Board, and all participants provided written informed consent prior to participation.

Details about recruitment for EMPOWER are described elsewhere.²⁷ Inclusion criteria were: age ≥ 18 years, body mass index (BMI) >27 and <44 kg/m², no recent weight loss, and not receiving another weight loss treatment. Individuals were excluded if they had a condition requiring medical supervision of diet or exercise, were pregnant, had a psychiatric disorder, or consumed >4 alcoholic beverages per day. All participants received a standard behavioral weight loss treatment for 12 months, which included group sessions, daily dietary and weekly physical activity goals, and self-monitoring of dietary intake, physical activity, and weight.

A total of 151 adults were enrolled in EMPOWER. The present analyses were limited to 125 participants with complete sleep health data at baseline and/or 6 months. Excluded participants were older than those included (55.0±6.6 vs. 50.3±10.6 years; *P*=.033); however, the included and excluded sample did not differ on other baseline characteristics.

Measures

Unless otherwise noted, assessments were conducted at baseline, 6 months, and 12 months.

Sociodemographic data.—An investigator-developed self-report questionnaire collected information on age, sex, marital status, and race at baseline.

Weight and body composition.—Fasting body weight and body composition were measured using a digital body composition scale (TBF-300A; Tanita, Arlington Heights, IL) with participants wearing light clothing and no shoes. The scale has contact electrodes that deliver a constant current of 500 microA at 50 kHz to assess bioelectrical impedance from leg to leg, and provides measures of body weight, fat mass, and fat-free mass. For those missing weight data at the baseline, 6-month, or 12-month assessments, data were imputed using weight measurements (when available) from the group intervention sessions that corresponded with that time point (baseline: session 1; 6 months: session 18; 12 months: session 24). Six and 16 observations were imputed for weight at baseline and month 6, respectively. Change data for body weight, fat mass, and fat-free mass at 6 and 12 months were expressed as the percent change from the beginning of the interval (i.e., 0–6 months and 6–12 months).

Sleep health.—Six dimensions of sleep health were assessed, based upon an expanded operationalization of the SATED framework proposed by Buysse²⁶ and recent analyses examining sleep health:^{28–30} sleep regularity, sleep satisfaction, daytime alertness, sleep timing, sleep efficiency, and sleep duration. Table 1 summarizes these six sleep health dimensions, how they were measured, and the rationale for the values chosen to indicate ‘good’ sleep.^{26,31–39} Self-report questionnaires and actigraphy, each described below, were used to assess these dimensions. Each dimension was dichotomized as ‘good’ or ‘poor’ on the basis of clinically and/or scientifically relevant rationales. The number of ‘good’ dimensions were summed to provide a composite measure of sleep health, with higher values indicating better sleep health.

Sleep health dimensions of *satisfaction* and *alertness* were assessed with the ‘sleep quality’ item of the Pittsburgh Sleep Quality Index (PSQI)³³ and the Epworth Sleepiness Scale (ESS) total score,³⁴ respectively. Measures of *regularity*, *timing*, *efficiency*, and *duration* were assessed using actigraphy. Participants wore an accelerometer (Actiwatch 2; Philips Respironics, Bend, OR) on the wrist of their non-dominant hand for 7 consecutive nights, with concurrent completion of diaries to indicate bedtime, waketime, and watch removal times. Rest intervals (i.e., intervals from bedtime to waketime) were manually established following standardized procedures that considered multiple inputs (i.e., event markers, diaries, activity, light).⁴⁰ Sleep/wake status for each 30-second epoch was computed using manufacturer-provided software (Actiware v. 6.0; Philips Respironics) utilizing settings of 5 immobile minutes for sleep onset, 0 immobile minutes for sleep offset, and a wake threshold of 40 counts.^{40,41} The first 7 nights at each time point were used to obtain summary values for each actigraphic measure of sleep health. *Regularity* was operationalized as the standard deviation of waketime (i.e., the end time of each rest interval). *Timing* was based on the mean daily sleep midpoint, which was calculated as the time halfway between sleep onset

and offset. *Duration* was based on the mean daily amount of time scored as sleep between sleep onset and offset. *Efficiency* was calculated as the mean daily percentage of time scored as sleep between sleep onset and offset.

Sleep apnea.—In a subsample of participants, OSA was assessed over a single night at each time point using a home sleep testing device (ApneaLink Plus; ResMed, Inc.). This device records respiratory effort, oronasal airflow, and pulse oximetry to assess OSA.⁴² Participants with invalid recordings (e.g., <2 hours of recording time) were asked to wear the device an additional night. Recordings were analyzed using automated settings and default definitions for apneas and hypopneas incorporated into the manufacturer-supplied software (version 9.30). The apnea-hypopnea index (AHI) provided a summary measure of OSA severity; AHI was calculated as the sum of apneas and hypopneas divided by airflow recording time in hours. In this sample, we previously reported that OSA was associated with worse weight loss in the context of a behavioral weight loss intervention.²⁵ For these analyses, valid baseline or 6-month AHI data (i.e., ≥2 hours of recording time) were available for 117 participants.

Statistical Analyses

All analyses were performed using SAS software (v. 9.4; SAS Institute, Inc.; Cary, NC). Distributions of continuous variables were initially examined using histograms, Q-Q plots for normality, and scatter plots for outliers and extreme values.

The primary outcome for these analyses was percent weight change; secondary outcomes were percent changes in fat mass and fat-free mass. As noted previously, missing weight data were imputed using intervention session weights at the appropriate time points. Missing data for the predictors and covariates included in the adjusted models were imputed using multiple imputation (SAS PROC MI) with fully conditional specification. Categorical variables were imputed using multivariate logistic regression, while continuous variables were imputed using multiple linear regression models. Four imputations were performed using four iterations. The number of observations in which missing data were imputed were 19 for composite sleep health, 9 for regularity, 8 for satisfaction, 17 for alertness, 9 for timing, 9 for efficiency, 9 for duration, 8 for bed partner, and 46 for AHI. To assess the missing at random assumption, the distributions of the pre-imputation variables were compared with those of the imputed variables. As a sensitivity analysis, the model coefficients were compared between the complete cases for the included predictors and covariates (i.e., sleep health predictors, bed partner, and AHI) and the imputed variables. Since the model estimates for complete cases and imputed covariates were similar, only results from the models with complete cases are reported.

Means and standard deviations were calculated for continuous variables; frequencies and percentages were computed for categorical variables. Linear mixed effects models with random subject effects were fit to examine the percent weight change, percent fat mass change, or percent fat-free mass change in each 6-month interval (0–6 months, 6–12 months) as a function of sleep health at the beginning of that interval. Primary analyses utilized the composite measure of sleep health, a continuous value, as the predictor.

Secondary analyses examined each individual sleep health dimension, categorized as a dichotomous variable (i.e., as used to calculate the composite score) or treated as a continuous variable, as a predictor in separate models. Because both low and high values of sleep midpoint and sleep duration have been associated with health risk, quadratic terms were examined in the models that examined these continuous variables. Since the quadratic terms were not significant for these dimensions in their respective models, they were not included in the final models. Each model adjusted for age (years), sex (male, female), bed partner (from the PSQI: partner in same bed, no partner/partner in another bed), and race (white, black/other). An interaction term was evaluated in each model to investigate whether the association between sleep health and weight change differed according to the interval. Since the interaction term was not statistically significant in any model, it was removed from final models. We considered including menopausal status as a covariate due to the predominantly middle-aged female sample; however, when we added menopausal status as a covariate in exploratory analyses restricted to females, the findings were unchanged and menopausal status was not a significant predictor in any model (each $P > .30$). Therefore, we chose not to include menopausal status as a covariate.

Because OSA is associated with worse sleep⁴³ and we previously reported that OSA is associated with blunted weight loss,²⁵ we also explored whether OSA severity accounted for any associations observed between sleep health and weight change. In the subsample with valid AHI data ($n=117$), AHI at the beginning of each interval was added as a covariate to the models noted above. Finally, because the magnitude of initial weight loss (i.e., from 0–6 months) may influence subsequent weight maintenance (i.e., from 6–12 months),⁴⁴ we explored whether sleep health at 6 months was associated with weight change from 6–12 months after adjusting for weight change from 0–6 months.

RESULTS

Participant Characteristics

Table 2 displays the sample's baseline characteristics. On average, the sample ($N=125$) was middle-aged (50.3 ± 10.6 years), mostly female (91.2%) and mostly white (80.8%). Mean BMI at baseline was 34.1 ± 4.6 kg/m². The mean sleep health score at baseline was 4.5 ± 1.1 . For each sleep health dimension at baseline, >75% of participants met the criteria for 'good' sleep, with the exception of regularity, for which only 42.4% met the 'good' criterion.

Association Between Sleep Health and Weight Change

Mean weight changes from 0–6 months and 6–12 months were $-9.3 \pm 6.1\%$ (-8.5 ± 5.8 kg) and $0.4 \pm 4.8\%$ (0.4 ± 3.9 kg), respectively. Overall sleep health was associated with weight change; better sleep health at the beginning of an interval were associated with greater weight loss over the subsequent 6-month interval ($P = .016$; Table 3). After accounting for AHI, the relationship between overall sleep health and weight change was attenuated to nonsignificance ($P = .102$; Table 3). None of the 6 sleep health dimensions, when evaluated categorically, individually predicted weight change before or after AHI adjustment (Table 3). When evaluated as continuously-measured sleep dimensions, lower sleep regularity (i.e., higher waketime SD), worse sleep satisfaction (i.e., poorer self-reported sleep quality), and

later sleep timing (i.e., later sleep midpoint) were each associated with less weight loss over the subsequent 6-month interval (each P .042); after AHI adjustment, regularity and timing remained associated with weight change (Table 4).

The associations between sleep health at month 6 and weight change from 6–12 months after accounting for weight change from 0–6 months are summarized in Tables 3 and 4 (far-right columns). In each model, greater weight loss from 0–6 months was associated with less weight loss during months 6–12 (each P .005, with regression coefficients from 0.23–0.28) while the magnitude of association between sleep health and weight loss was, in general, unchanged or attenuated.

Association Between Sleep Health and Body Composition Change

Mean fat mass changes from 0–6 months and 6–12 months were $-16.9 \pm 13.5\%$ (-6.7 ± 5.1 kg) and $-0.3 \pm 10.3\%$ (-0.1 ± 3.1 kg), respectively; fat-free mass changes from 0–6 months and 6–12 months were $-3.4 \pm 3.4\%$ (-1.7 ± 1.9 kg) and $0.7 \pm 4.1\%$ (0.4 ± 2.2 kg), respectively. Associations between sleep health and body composition change are summarized in the Supplementary Information. Better overall sleep health was associated with greater fat loss before and after accounting for AHI ($P = .006$ and $P = .040$, respectively; Supplemental Table 1). Regularity, timing, and efficiency were associated with fat loss when evaluated as continuous variables; however, only timing remained associated following AHI adjustment (Supplemental Table 2).

Overall sleep health was not associated with fat-free mass change (Supplemental Table 3). Of the categorical individual sleep dimensions, high alertness (i.e., ESS ≤ 10) was associated with greater fat-free mass loss, which remained after AHI adjustment ($P = .024$ and $P = .034$; Supplemental Table 3). No continuously-measured sleep dimension was associated with fat-free mass change (Supplemental Table 4).

DISCUSSION

This study examined the association between sleep health and weight and body composition change in the context of a behavioral weight loss intervention. Overall, we found that better sleep health was associated with greater subsequent weight and fat loss; however, associations were attenuated once we accounted for OSA severity. Among individual dimensions, greater waketime regularity, higher sleep satisfaction, earlier sleep timing, and greater sleep efficiency were associated with greater weight and/or fat loss, but these associations were only observed when the dimensions were analyzed as continuous variables.

Sleep is a multidimensional behavior, with several dimensions related to obesity risk.^{10–15} However, to our knowledge, this is the first study to examine a multidimensional measure of sleep health—incorporating daytime alertness and sleep regularity, satisfaction, timing, efficiency, and duration—in relation to weight loss. Previous studies have focused on whether individual sleep dimensions were associated with weight change in behavioral interventions, with inconsistent findings. Separate studies have found greater sleep duration variability,²⁰ worse sleep quality,¹⁹ greater sleep fragmentation,¹⁶ and short^{17,19} or long

sleep duration¹⁷ to be related to blunted weight loss in behavioral weight loss interventions. However, similar studies have failed to observe any association between sleep and weight change,^{21–23} and a recent meta-analysis concluded that the association between experimental sleep restriction and weight gain was weak and nonsignificant.⁴⁵ These mixed results may have been due, in part, to their reliance on individual sleep dimensions. The minimal research focused on aggregate sleep health and obesity is also equivocal; while two studies observed no association between sleep health and BMI,^{46,47} another found that better sleep health was associated with lower odds for obesity.⁴⁸

Fewer studies have examined the association between sleep and body composition in weight loss interventions. Our results are in line with existing research. Chaput and colleagues found that poor sleep quality and short sleep duration were associated with less fat loss among adults participating in a dietary weight loss intervention.¹⁸ In addition, two experimental studies demonstrated that 2–8 weeks of sleep restriction (e.g., to <5 h/night) paired with caloric restriction did not impair overall weight loss but led to a greater proportion of fat-free mass loss and lower proportion of fat loss.^{49,50} A primary goal of behavioral weight loss intervention is to preserve fat-free mass and maximize fat loss.⁵¹ We found that better sleep health was associated with greater fat loss but not with fat-free mass loss, which suggests that sleep health may be important for both the quantity and quality of weight loss.

While better overall sleep health was associated with greater weight and fat loss, no individual sleep dimension was related to weight or fat loss when examined as a categorical predictor. These results highlight the utility of a composite measure that incorporates multiple dimensions of sleep. Previous research has similarly found that, compared to individual sleep dimensions, a composite measure of sleep health was more strongly related to a variety of health outcomes including depression,⁵² self-rated health,⁵³ cardiometabolic morbidity,²⁹ and mortality.³⁰ Consideration of multiple sleep dimensions, in isolation and combined, should be encouraged in future studies of sleep and weight loss.

When individual sleep dimensions were evaluated as continuous variables, greater waketime regularity, higher sleep satisfaction, earlier sleep midpoint, and higher sleep efficiency predicted greater weight and/or fat loss. Our findings regarding sleep satisfaction and efficiency are consistent with prior research which reported better sleep quality^{18,19} and lower sleep fragmentation¹⁶ were associated with greater weight or fat loss. In the only other study to examine regularity in the context of a weight loss trial, Papandreou and colleagues found that greater night-to-night sleep duration variability at baseline was associated with blunted weight loss over 12 months.²⁰ These findings are consistent with observational research linking sleep regularity and timing to obesity risk. For example, greater variability in individual sleep dimensions (e.g., bedtime, duration, midpoint, waketime) have been linked to greater adiposity and/or obesity risk in cross-sectional^{54–58} and prospective⁵⁹ studies. Similarly, later sleep timing (e.g., later bedtime, midpoint, or waketime) is associated with obesity across cross-sectional studies.^{13,14,54,55} These findings may imply underlying circadian mechanisms; specifically, high waketime variability could introduce circadian disruption, while excessively late sleep timing may indicate delayed timing of the circadian system.⁶⁰ Garaulet and colleagues previously found that individuals with specific

circadian gene polymorphisms (i.e., CLOCK, SIRT1) had lower weight loss following a diet-induced weight loss program,^{61,62} suggesting that underlying circadian physiology may impact the efficacy of a weight loss program.

The association between the composite measure of sleep health and weight loss was attenuated to nonsignificance after accounting for OSA, while the association with fat loss was weakened but retained significance. Because OSA impairs multiple dimensions of sleep health, including daytime alertness and sleep satisfaction, efficiency, and duration,^{43,63,64} this attenuation was expected. Previous research, including work from the present sample, has found that OSA leads to blunted weight loss.^{25,65} Importantly, these prior studies did not account for indices of sleep quality or sleep health. Because OSA and poor sleep health are common among individuals with overweight and obesity, future research examining the relation of sleep to attempted weight loss should consider both factors.

Poor sleep health may predispose to blunted weight and fat loss through a variety of both behavioral (e.g., increased caloric intake, poorer dietary quality, decreased physical activity) and physiological (e.g., altered substrate utilization) mechanisms.⁶⁶ For example, later sleep timing may predispose to greater post-dinner caloric intake⁶⁷ and lower physical activity.⁶⁸ Although beyond the scope of the current study, future research should attempt to identify the behavioral and/or physiological pathways by which poor sleep health leads to worse weight loss.

Our observational results indicate that better sleep health is associated with greater weight and fat loss among individuals enrolled in a behavioral weight loss intervention, which raises the question of whether optimizing sleep health can facilitate better weight loss.⁶⁹ To our knowledge, only one study has evaluated whether incorporating sleep counseling into a behavioral weight loss intervention impacts weight loss. Compared to those who received a standard 12-week behavioral weight loss program focused on diet and exercise, Logue and colleagues found that those whose weight loss program was supplemented with sleep education had significantly greater weight loss.⁷⁰ Other studies have found that 2–4 weeks of sleep extension improve food choice and macronutrient intake;^{71,72} however, whether increasing sleep duration impacts body weight is unclear.¹¹ Evaluating whether improving sleep health optimizes behaviorally induced weight loss is an important future direction for research.

This study has several strengths. Our examination of multiple dimensions of sleep, independently and combined, is a notable strength. The use of a count-based measure of sleep health facilitates interpretability and replication. In addition, our analyses accounted for OSA and assessed sleep at multiple time points, which addresses key limitations of prior research. However, our study is not without limitations. First, our sample consisted primarily of white females; whether these results generalize to males or other races and ethnicities is unknown. In particular, racial/ethnic minorities experience greater disparities in both obesity and sleep health,⁷³ so it is important to examine whether sleep health contributes to weight loss in these populations. Other limitations related to our operationalization of sleep health. Whenever possible, we assessed individual sleep health dimensions using objective measures and based our thresholds for ‘good’ sleep upon empirically relevant thresholds.

However, other studies have utilized different methods of assessment and thresholds for these dimensions. The count-based approach used in the present study to operationalize sleep health, while commonly utilized,^{28,52} is not the only potential method.⁷⁴ Recent work has derived optimal thresholds using receiver operating curve analyses²⁹ and questionnaire-based assessment;⁵³ these different approaches may yield unique insights to the relationship between sleep health and attempted weight loss. In addition, the dimensions of satisfaction and alertness used in this study were global measures that were evaluated at each time point, while the other dimensions were evaluated by averaging daily values at each time point. Also, there is no consensus on how to operationalize regularity; while our approach has been previously used,³⁰ other studies have used sleep midpoint variability^{28,29,48} or total sleep time variability.⁴⁶ Finally, while the ESS is a well-known measure of daytime sleepiness, it does not directly measure alertness.

In conclusion, we examined the association between sleep health and weight and body composition change in the context of a behavioral weight loss intervention and found that better sleep health was associated with greater weight and fat loss. As expected, this association was attenuated after accounting for OSA severity. Waketime regularity, sleep satisfaction, sleep timing, and sleep efficiency were individual dimensions related to weight and/or fat loss, but this was only when they were evaluated as continuous variables. These results suggest that, when attempting weight loss, poor sleep health could be an important predictor of blunted weight loss. Future studies should examine whether improving sleep health prior to or during attempted weight loss optimizes outcomes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1.

Operationalization of sleep health dimensions.

| Sleep health dimension: | Measurement: | Definition of 'good' sleep: | Rationale: |
|--------------------------------|--|--|---|
| Regularity | SD of actigraphic wake time | < 60 min | Waketime typically corresponds with morning light exposure, which is a potent circadian zeitgeber. A common recommendation is to maintain a regular waketime, ³¹ often prescribed as keeping waketime within a 1-h window regardless of weekday or weekend ³² |
| Satisfaction | PSQI 'sleep quality' item [*] | Response of 'fairly good' or 'very good' | PSQI global score integrates additional sleep dimensions (e.g., duration, latency) ³³ |
| Alertness | ESS total score | 10 | Total score > 10 indicates excessive daytime sleepiness ³⁴ |
| Timing | Mean actigraphic sleep midpoint | 02:00 – 04:00 | The SATED questionnaire indicates the range for the optimal sleep midpoint to be 2–4 am, ²⁶ as both early (< 02:00) and late (> 04:00) sleep midpoints are linked to adverse health outcomes ³⁵ |
| Efficiency | Mean actigraphic sleep efficiency | 85% | Threshold of 85 % typically used to denote acceptable sleep efficiency ³⁶ and differentiate good sleepers from those with insomnia ³⁷ |
| Duration | Mean actigraphic total sleep time | 6–8 h | Consensus sleep duration recommendation is 7–9 hr/night for adults; ³⁸ but this guideline is based on self-report; self-reported TST overestimates actigraphy-assessed TST by approximately 1 h ³⁹ |

Mean and SD data from actigraphy are derived from 7 nights of recording. ESS: Epworth Sleepiness Scale; PSQI: Pittsburgh Sleep Quality Index; SD: standard deviation; TST: total sleep time.

^{*} Specific wording for this item: *During the past month, how would you rate your sleep quality overall?*

Table 2.

Baseline participant characteristics (N = 125).

| Characteristics | Mean ± SD or n (%) |
|---|--------------------|
| Age (years), mean ± SD | 50.3±10.6 |
| Female gender, n (%) | 114(91.2) |
| Bed partner, n (%) | |
| Partner in same bed | 76(60.8) |
| No partner/partner in other bed or room | 49(39.2) |
| Race, n (%) | |
| White | 101(80.8) |
| Other | 24(19.2) |
| Body weight (kg), mean ± SD | 92.0±15.4 |
| Fat mass (kg), mean ± SD | 40.7±10.3 |
| Fat-free mass (kg), mean ± SD | 51.2±7.9 |
| Body mass index (kg/m ²), mean ± SD | 34.1±4.6 |
| Sleep health score [*] , mean ± SD | 4.5±1.1 |
| Sleep health, n (%) meeting 'good' criteria | |
| Regularity | 53(42.4) |
| Satisfaction | 99(79.2) |
| Alertness [*] | 105(85.4) |
| Timing | 95(76.0) |
| Efficiency | 106(84.8) |
| Duration | 95(76.0) |
| AHI (events/h) ^{**} , mean ± SD | 7.0(8.2) |
| OSA (AHI ≥ 5) ^{**} , n (%) | 59(51.3) |

* n = 123 with ESS data and a composite sleep health score at baseline;

** n = 115 with valid AHI data at baseline.

Table 3.

Association of a composite measure of sleep health and its categorical individual dimensions with percent weight change prior to and following adjustment for OSA severity.

| Predictor | Overall Model P | Covariate-adjusted Model | | | | | |
|--------------------------------|-----------------|--------------------------|------|---------------------|------|---------------------|------|
| | | BL to 6M | | 6M to 12M | | 6M to 12M * | |
| | | B (95% CI) | P | B (95% CI) | P | B (95% CI) | P |
| Composite sleep health (0–6) | .016 | −0.96 (−1.95, 0.03) | .056 | −0.58 (−1.36, 0.20) | .141 | −0.48 (−1.30, 0.34) | .249 |
| Regularity | .083 | | .080 | | .544 | | .846 |
| SD of waketime > 1 h | | Ref | | Ref | | Ref | |
| SD of waketime ≤ 1 h | | −1.95 (−4.13, 0.24) | | −0.56 (−2.38, 1.26) | | −0.18 (−2.04, 1.67) | |
| Satisfaction | .064 | | .331 | | .075 | | .088 |
| Fairly/very bad sleep quality | | Ref | | Ref | | Ref | |
| Fairly/very good sleep quality | | −1.29 (−3.92, 1.33) | | −1.96 (−4.11, 0.20) | | −1.87 (−4.02, 0.28) | |
| Alertness | .417 | | .575 | | .415 | | .177 |
| ESS > 10 | | Ref | | Ref | | Ref | |
| ESS ≤ 10 | | 0.89 (−2.24, 4.02) | | 1.18 (−1.67, 4.03) | | 2.08 (−0.95, 5.11) | |
| Timing | .255 | | .201 | | .783 | | .998 |
| Mean midpoint <0200 or >0400 h | | Ref | | Ref | | Ref | |
| Mean midpoint 0200 – 0400 h | | −1.66 (−4.21, 0.89) | | −0.32 (−2.64, 1.99) | | 0.00 (−2.30, 2.31) | |
| Efficiency | .319 | | .885 | | .164 | | .153 |
| Mean SE < 85% | | Ref | | Ref | | Ref | |
| Mean SE ≥ 85% | | −0.22 (−3.20, 2.77) | | −1.78 (−4.30, 0.74) | | −1.91 (−4.54, 0.72) | |
| Duration | .306 | | .326 | | .424 | | .261 |
| Mean TST < 6 or > 8 h | | Ref | | Ref | | Ref | |
| Mean TST 6 – 8 h | | −1.29 (−3.88, 1.30) | | −0.86 (−2.98, 1.26) | | −1.27 (−3.49, 0.96) | |
| Covariate-adjusted model + AHI | | | | | | | |
| Predictor | Overall Model P | BL to 6M | | 6M to 12M | | 6M to 12M * | |
| | | B (95% CI) | P | B (95% CI) | P | B (95% CI) | P |
| Composite sleep health (0–6) | .102 | −0.83 (−1.91, 0.26) | .133 | −0.31 (−1.19, 0.57) | .482 | −0.33 (−1.26, 0.60) | .484 |
| Regularity | .152 | | .135 | | .850 | | .897 |
| SD of waketime > 1 h | | Ref | | Ref | | Ref | |
| SD of waketime ≤ 1 h | | −1.79 (−4.14, 0.56) | | −0.19 (−2.23, 1.84) | | 0.13 (−1.92, 2.19) | |
| Satisfaction | .154 | | .451 | | .224 | | .139 |
| Fairly/very bad sleep quality | | Ref | | Ref | | Ref | |
| Fairly/very good sleep quality | | −1.04 (−3.78, 1.69) | | −1.54 (−4.04, 0.96) | | −1.89 (−4.41, 0.63) | |

| | | | | | | | |
|--------------------------------|------|------------------------|------|------------------------|------|------------------------|------|
| Alertness | .228 | | .441 | | .195 | | .125 |
| ESS > 10 | | Ref | | Ref | | Ref | |
| ESS 10 | | 1.28 (-2.00, 4.56) | | 2.16 (-1.13, 5.46) | | 2.73 (-0.78, 6.23) | |
| Timing | .329 | | .247 | | .980 | | .938 |
| Mean midpoint <0200 or >0400 h | | Ref | | Ref | | Ref | |
| Mean midpoint 0200 – 0400 h | | -1.63 (-4.41, 1.44) | | -0.03 (-2.63, 2.56) | | 0.10 (-2.50, 2.70) | |
| Efficiency | .867 | | .904 | | .667 | | .471 |
| Mean SE < 85% | | Ref | | Ref | | Ref | |
| Mean SE 85% | | 0.21 (-3.27, 3.69) | | -0.64 (-3.60, 2.32) | | -1.17 (-4.38, 2.04) | |
| Duration | .327 | | .348 | | .331 | | .309 |
| Mean TST < 6 or > 8 h | | Ref | | Ref | | Ref | |
| Mean TST 6 – 8 h | | -1.40 (-4.36, 1.55) | | -1.12 (-3.40, 1.16) | | -1.24 (-3.65, 1.17) | |

* These estimates of % weight change from 6M to 12M also account for % weight change from BL to 6M in addition to the standard covariates in each model. 6M: 6-month; 12M: 12-month; AHI: apnea-hypopnea index; BL: baseline; CI: confidence interval; ESS: Epworth Sleepiness Scale; SD: standard deviation; SE: sleep efficiency; TST: total sleep time. The 'Covariate-adjusted model' included the following covariates: age, sex, bed partner, and race. The 'covariate-adjusted model + AHI' included age, sex, bed partner, race, and AHI as covariates.

Table 4.

Association of continuously-measured individual sleep health dimensions with percent weight change prior to and following adjustment for OSA severity.

| Predictor | Covariate-adjusted Model | | | | | | |
|-------------------------------|--------------------------------|---------------------|------|---------------------|------|---------------------|------|
| | Overall Model P | BL to 6M | | 6M to 12M | | 6M to 12M * | |
| | | B (95% CI) | P | B (95% CI) | P | B (95% CI) | P |
| Regularity | | | | | | | |
| SD of waketime (hours) | .005 | 2.25 (0.36, 4.15) | .020 | 1.59 (−0.17, 3.35) | .077 | 1.15 (−0.77, 3.06) | .238 |
| Satisfaction | | | | | | | |
| PSQI sleep quality (4 levels) | .042 | 1.16 (−0.40, 2.71) | .145 | 0.75 (−0.42, 1.93) | .207 | 0.61 (−0.56, 1.78) | .301 |
| Alertness | | | | | | | |
| ESS total score (0–24) | .834 | 0.02 (−0.31, 0.35) | .916 | −0.03 (−0.29, 0.22) | .810 | −0.05 (−0.32, 0.23) | .747 |
| Timing | | | | | | | |
| Mean sleep midpoint (hours) | .015 | 1.27 (0.15, 2.39) | .027 | 0.57 (−0.43, 1.58) | .260 | 0.30 (−0.72, 1.31) | .563 |
| Efficiency | | | | | | | |
| Mean SE (%) | .192 | −0.03 (−0.26, 0.20) | .793 | −0.19 (−0.39, 0.01) | .066 | −0.18 (−0.38, 0.02) | .075 |
| Duration | | | | | | | |
| Mean TST (hours) | .848 | −0.13 (−1.51, 1.25) | .849 | −0.12 (−1.18, 0.95) | .828 | −0.36 (−1.44, 0.71) | .505 |
| Predictor | Covariate-adjusted Model + AHI | | | | | | |
| | Overall Model P | BL to 6M | | 6M to 12M | | 6M to 12M * | |
| | | B (95% CI) | P | B (95% CI) | P | B (95% CI) | P |
| Regularity | | | | | | | |
| SD of waketime (hours) | .024 | 2.04 (0.07, 4.01) | .043 | 1.01 (−0.94, 2.95) | .306 | 0.79 (−1.33, 2.91) | .461 |
| Satisfaction | | | | | | | |
| PSQI sleep quality (4 levels) | .129 | 0.95 (−0.70, 2.60) | .257 | 0.53 (−0.85, 1.92) | .444 | 0.74 (−0.64, 2.12) | .288 |
| Alertness | | | | | | | |
| ESS total score (0–24) | .518 | 0.01 (−0.34, 0.35) | .977 | −0.11 (−0.39, 0.18) | .460 | −0.09 (−0.40, 0.22) | .566 |
| Timing | | | | | | | |
| Mean sleep midpoint (hours) | .011 | 1.13 (−0.08, 2.34) | .068 | 1.04 (−0.06, 2.13) | .063 | 0.78 (−0.35, 1.92) | .172 |
| Efficiency | | | | | | | |
| Mean SE (%) | .656 | 0.04 (−0.26, 0.34) | .806 | −0.13 (−0.38, 0.11) | .286 | −0.16 (−0.41, 0.09) | .200 |
| Duration | | | | | | | |
| Mean TST (hours) | .968 | 0.03 (−1.52, 1.46) | .970 | −0.11 (−1.26, 1.04) | .848 | −0.40 (−1.59, 0.78) | .500 |

* These estimates of % weight change from 6M to 12M also account for % weight change from BL to 6M in addition to the standard covariates in each model. 6M: 6-month; 12M: 12-month; AHI: apnea-hypopnea index; BL: baseline; CI: confidence interval; ESS: Epworth Sleepiness Scale; SD: standard deviation; SE: sleep efficiency; TST: total sleep time. The 'Covariate-adjusted model' included the following covariates: age, sex, bed partner, and race. The 'covariate-adjusted model + AHI' included age, sex, bed partner, race, and AHI as covariates.