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Nightly Variation in Sleep Influences Self-efficacy for Adhering to a Healthy Lifestyle: A Prospective Study

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Abstract

Background: Self-efficacy, or the perceived capability to engage in a behavior, has been shown to play an important role in adhering to weight loss treatment. Given that adherence is extremely important for successful weight loss outcomes and that sleep and self-efficacy are modifiable factors in this relationship, we examined the association between sleep and self-efficacy for adhering to the daily plan. Investigators examined whether various dimensions of sleep were associated with self-efficacy for adhering to the daily recommended lifestyle plan among participants (N=150) in a 12-month weight loss study.

Methods: This study was a secondary analysis of data from a 12-month prospective observational study that included a standard behavioral weight loss intervention. Daily assessments at the beginning of day (BOD) of self-efficacy and the previous night's sleep were collected in real-time using ecological momentary assessment.

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Informed consent: Informed consent was obtained from all individual participants included in the study prior to any data collection.

Ethical approval: All procedures performed in this study, which involved human participants, were in accordance with the ethical standards of the University of Pittsburgh and the National Institutes of Health and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Results: The analysis included 44,613 BOD assessments. On average, participants reported sleeping for 6.93±1.28 hours, reported 1.56±3.54 awakenings, and gave low ratings for trouble sleeping (3.11±2.58;0: no trouble; 10: a lot of trouble) and mid-high ratings for sleep quality (6.45±2.09;0: poor; 10: excellent). Participants woke up feeling tired 41.7% of the time. Using linear mixed effects modeling, a better rating in each sleep dimension was associated with higher self-efficacy the following day (all p values <.001).

Conclusions: The findings supported the hypothesis that better sleep would be associated with higher levels of reported self-efficacy for adhering to the healthy lifestyle plan.

Keywords

self-efficacy; sleep; weight loss; ecological momentary assessment (EMA)

Introduction

Obesity is a chronic condition characterized by a pattern of cyclical weight loss and regain.[1] It is also a well-established risk factor for an array of disorders, most significantly cardiovascular disease and diabetes.[2,3] Since 1999-2000, the prevalence of obesity among men has increased from 27.5% to 43.0% and among women obesity has increased from 33.4% to 41.9%.[4]

The rise in the global prevalence of overweight and obesity has been paralleled with the decrease in sleep duration[5]. The number of adults who do not obtain the recommended minimum 7 hours of sleep has steadily risen over the past few decades.[6] Two large cohort studies have observed that short sleepers (<5 hours of sleep per night) had a 40% greater chance of developing obesity compared to those who obtained 7-8 hours per night[7] and, similarly, that women who slept ≤5 hours were 32% more likely to gain excess weight compared to those who slept for 7 hours per night.[8] Studies also report an association between trouble sleeping and body mass index (BMI);[9] individuals with overweight or obesity had poorer sleep quality than those with normal weight.[10] Potential behavioral mechanisms that can explain these relationships are in the early phases of study.

A potential behavioral mechanism in which sleep affects weight outcomes is self-efficacy, which in this context is one's perceived capability for adhering to the daily lifestyle habits that support weight loss.[11,12] Self-efficacy has been widely studied as a predictor or correlate of changes in weight and weight-related behaviors.[13] An important goal of behavioral weight loss treatment is improving one's self-efficacy for maintaining a healthy lifestyle plan that will support long-term weight loss maintenance. Warziski et al. found that improvement in self-efficacy was associated with greater weight loss,[14] while lower self-efficacy has been associated with a reduced likelihood of practicing weight management behaviors (i.e., physical activity, dietary modification), which could lead to weight regain.[15] Weight management self-efficacy or confidence in one's ability to resist eating in various situations has been found to be a significant predictor of weight loss.[16,17] More recently, Nezami et al.[13] used a temporally-based model to elucidate that the behavior-specific measures of self-efficacy (e.g., eating self-efficacy, physical activity self-efficacy) prior to and during an intervention can have an effect on dietary intake and physical activity.

Hager delineated how sleep and sleep quality are encompassed in a process model of self-control in health behavior and defined pathways by which self-control predicts health behavior and its associated outcomes. He suggested that sleep quality is a direct predictor of state self-control resources, indicating that sleep quality is operational in restoring self-control resources. Barber and colleagues identified two components of sleep quality that are prominent in determining self-regulatory capacity in the context of health: sleep sufficiency and sleep consistency.[18,19]

The majority of individuals who lose weight regain it within a few years. Indeed, individuals may begin to regain weight while still in active treatment.[20] There are many factors that may influence success in weight loss; sleep and self-efficacy for adhering to a healthy lifestyle are among the modifiable factors that can improve weight loss and maintenance.

Therefore, the purpose of the investigation was to examine whether various dimensions of sleep were associated with self-efficacy for adhering to the daily healthy lifestyle plan recommended for adults participating in a 12-month weight loss intervention. Investigators hypothesized that longer, less fragmented sleep would be associated with higher levels of reported self-efficacy for adhering to the healthy lifestyle plan.

Methods

Study design

This study was a secondary analysis of data from a 12-month, prospective observational study of participants receiving a behavioral weight loss intervention to provide the context for observing the lapse/relapse process for weight regain following intentional weight loss.[21] For 12 months, all participants received behavioral treatment for weight loss, which included group sessions, setting daily dietary and weekly physical activity goals as well as self-monitoring of dietary intake, physical activity, and weight. Daily measures of self-efficacy for adhering to the daily lifestyle plan (e.g., meeting daily goals for calorie/fat intake and weekly goals for physical activity) and assessment of the previous night's sleep were collected throughout the 12-month period using ecological momentary assessment (EMA), a method that permits assessment of individuals' emotions and behaviors in real-time in their natural setting.[22] This allowed the researchers to examine if daily changes in sleep duration and quality were associated with daily changes in self-efficacy. The study was conducted from 2010 to 2015 at the University of Pittsburgh. This study was approved by the Institutional Review Board of the University of Pittsburgh. All participants provided written informed consent.

Participants

Eligible individuals in the study were ≥ 18 years of age, had a body mass index (BMI) between 27 and 44 kg/m^2, and had not participated in another weight loss program in the previous 3 months. Individuals were excluded if they had any current conditions that may confound study findings (e.g., diabetes, pregnancy, post-bariatric surgery); planned to become pregnant in the next 12 months; planned frequent travel, extended vacations, or relocation in the next 12 months; were receiving current treatment for a serious mental illness (e.g., schizophrenia); reported alcohol intake ≥ 4 drinks/day; or were unable or unwilling to use the smartphone for EMA data collection.

Measurements: Ecological Momentary Assessments (EMA)

Self-efficacy for adhering to the daily lifestyle plan and several sleep dimensions were assessed daily using EMA. The EMA smartphone application prompted study participants by sending a signal to their smartphone to answer a brief questionnaire at random times throughout the waking hours, targeting a mean of 4 assessments per day as well as beginning-of-day (BOD) and end-of-day (EOD) assessments. For the purpose of this paper, the focus is on BOD assessments of the previous night's sleep and perceived self-efficacy for adhering to that day's lifestyle plan. See Figure 1 for sample screen shots of questions regarding sleep and self-efficacy, respectively.

Several measures of the previous night's sleep were collected at the BOD assessment via the EMA application. Participants were asked to rate on a scale of 0-10 their trouble sleeping (0: no trouble; 10: a lot of trouble) and their sleep quality (0: poor; 10: excellent). They also indicated the duration of their sleep (in hours and minutes) and the number of awakenings (Figure 1). Finally, participants were asked to indicate if they were tired upon awakening (yes/no). The BOD EMA survey also included one item measuring self-efficacy: "How confident are you that you will be able to stick to your healthy lifestyle plan today?" Response options were on a 1-10 scale (1: lowest level of confidence; 10: highest level of confidence).

Data Analysis

Data were analyzed using SAS™ software (v. 9.4; Cary, NC) and the significance level was set at 0.05. Participants were weighed at the 24 intervention sessions scheduled over the 12-month standard behavioral intervention. To obtain a measure of weight change over the year that accounts for adherence with session attendance, rate of weekly weight gain in lbs/week was computed to be equal to $7 \times (wt_{last} - wt_{first}) / (t_{last} - t_{first})$, where t_{first} and wt_{first} respectively are the times and weights in the first clinic visit, and t_{last} and wt_{last} are the times and weights in the last clinic visit. Descriptive statistics were computed for demographic variables, weight gain rate, and other baseline variables deemed to be predictive of sleep and self-efficacy including the number of times participants had intentionally lost 10-19 lbs, and the total score for the Barriers to Healthy Eating scale (BHE).[23] Frequencies and percentages were calculated for categorical variables and means and standard deviations (SDs) were calculated for continuous variables across all BOD assessments. Pearson correlations were computed among person-means of the sleep variables and with self-efficacy. Corresponding within-subject correlations were computed based on residual differences between each variable and the corresponding participant mean. In addition, correlations were computed between the person-means of these BOD survey variables and mean rate of weight change, and baseline variables thought to be predictive of sleep and self-efficacy.

Both separate and multivariable linear mixed effects models were used to predict within-person self-efficacy as a function of daily variation in sleep variables (trouble falling asleep, sleep quality, hours slept, number of awakenings, and whether the participant was tired) using the mixed procedure of SAS (Figure 2). Since our objective is to describe the impact of person-level measures of sleep quality, group-mean centering was applied when fitting all mixed effects models under which all sleep variables with the exception of the dichotomous variable tired were centered on participant means. [24] Owing to missing data, observations are not available at regularly spaced points in time, so we treat the self-efficacy $Y_j(t)$ for each participant j as a continuous function of time t in days since initiation of EMA. For a single sleep variable, the Level 1 model is

$$Y_j(t) = \beta_{0j} + \beta_{1j}t + \beta_{2j}x_j(t) + \varepsilon_i(t),$$

where β_{0j} is the intercept for participant i, β_{1j} and β_{2j} are regression coefficients for participant j, $x_i(t)$ is the (centered) sleep variable for participant i at time t, and $\varepsilon_i(t)$ is the Level 1 error. The Level 1 errors $\varepsilon_i(t)$ are assumed to be sampled from zero-mean normal distributions with variance σ_ε^2. Borrowing from geostatistics,[25] the dependence among repeated measures at times $t \neq t'$ within a given participant is described by the exponential covariance function $cov\{\varepsilon_i(t), \varepsilon_i(t')\} = \sigma_1^2 exp\{-3 \mid t - t' \mid / \alpha\}$, where α is the range of temporal correlation, and $\sigma_1^2 \leq \sigma_\varepsilon^2$ and α is the range of temporal dependence. Under this model, the covariance as a function of lag time between observations converges to a value $\sigma_1^2 \leq \sigma_\varepsilon^2$ as $\mid t - t' \mid \to 0$. The difference $\sigma_0^2 = \sigma_\varepsilon^2 - \sigma_1^2$ describes micro-scale variation and measurement error; latter defined as spatial dependence measured at a scale smaller than that separating adjacent observations. [25] For discrete-time data, the exponential covariance function is equivalent to the AR(1) model with autoregressive parameter $\rho = e^{-3/\alpha}$. The Level 2 models for the random intercept and slopes are

$$\beta_{ij} = \mu_i + \delta_{ij},$$

where μ_0, μ_1, and μ_2 are the mean intercept, mean slope for time, and mean slope for sleep respectively. The errors δ_{ij} are independently sampled from zero mean normal distributions with variances $var(\delta_{ij}) = \tau_j^2$. Restricted maximum likelihood estimation was used to estimate model parameters.[26] Since σ_0^2 is an upper bound on the measurement error, $1 - \sigma_0^2 / (\sigma_0^2 + \sigma_1^2 + \tau_0^2)$ may be regarded as a lower bound for the reliability of the single-item measure of self-efficacy. To assess the relative fit of the mixed-effects models, we report BIC values for each of the fitted models; smaller values are better. We report estimated means and standard deviations of regression coefficients for each sleep variable. The investigators had considered controlling for demographic covariates (i.e., gender, age, socioeconomic status, and education), but these covariates had negligible impact on the results of the analyses, and so were not included in the reported models, see the Supplemental Materials.

Fitting mixed effects modules from the marginal distribution of the observed data may yield biased estimates of model parameters if the data are not missing completely at random (MCAR). Logistic regression models were fit using Generalized Estimating Equations (GEEs) and an autoregressive working correlation matrix to determine what variables are related to the missing value indicator for self-efficacy. Of the variables thought to be predictive of the missing data indicator for self-efficacy (BMI, Intentional Weight

Loss, BHE and time), only BHE and time were found to be significantly predictive. The participants were prompted by a signal to answer 50,458 BOD questionnaires during the 12-month weight loss intervention. Of these, 5,818 (11.5%) prompts were missed entirely, and 280 (0.5%) EMA surveys were abandoned before completion, leaving 44,360 (87.9%) completed questionnaires. Abandonment results in a monotone missing data pattern, under which the number of completed questions is ordered as trouble sleeping (*n*=44,660) > hours slept (*n*=44,593) > #awakenings (*n*=44,554) > sleep quality (*n*=44,519) > tired (*n*=44,501) > self-efficacy (*n*=44,360). Single imputation was carried out predicting missing values of each successive variable as a function of time and observed and imputed values of previous variables in the above order. Mixed effects models similar to those described above including random effects for time and fixed effects for BHEAT as well the previous variables were used for continuous variables. GEEs were used with the autoregressive working correlation function to impute missing values for tired. The imputed data were then used to fit the mixed effects models described in the previous paragraph.

Results

Baseline Characteristics of Study Participants

Baseline data were obtained for the 151 participants who enrolled in the study, one of whom withdrew on the first day of the study without completing any EMA, leaving 150 for analysis. An additional 12 participants withdrew from the study prior to completion: 5 for medical reasons, 4 for personal reasons, and 3 became pregnant so they were no longer eligible. Available data for these 12 participants were included in the analyses. Table 1 summarizes the baseline characteristics of the study participants. The mean age of the participants was 51.1 years. The sample was predominantly female, white, employed and well educated with a mean of 16 years of formal education. Participants reported that they previously had intentionally lost 10-19 lbs a mean of 2.5 times. The mean baseline score for the Barriers to Healthy Eating survey was 57.9, of a possible range of 22 - 110 which is consistent with BHE scores we have observed in other weight loss studies and suggests perception of moderate level of barriers to following a specific dietary plan.[23] Participants regained a mean of 1.3 kg, and averaged gaining 0.06 kg/week between the time of the 6-month and 12-month assessments, This regain represents a small portion of the mean total weight change of 7.86 kg over the 12-month intervention .

Characteristics of BOD Survey Variables

The participants were prompted by a signal to answer 50,458 BOD questionnaires during the 12-month weight loss intervention. Of these, 5,818 (11.5%) prompts were missed, and 280 (0.5%) EMA surveys were abandoned before completion, leaving 44,360 (87.9%) completed questionnaires. All of the following analyses were based on the completed questionnaires.

Participants reported a mean of 6.93±1.28 hours of sleep and 1.56±3.54 awakenings during the previous night and being tired at the beginning of day 41.7% of the time. Mean levels for trouble sleeping and sleep quality (on a 0-10 scale) were 3.11±2.58 and 6.45±2.09, respectively, indicating minimal trouble sleeping and fairly good sleep quality. The mean level of self-efficacy (1-10 scale) was 7.19± 1.92, suggesting that at the beginning of the day participants were generally positive about their abilities to stick to their healthy lifestyle plan for that day.

Correlations among person-means and corresponding within-subject correlations among sleep variables and with self-efficacy are presented in Table 2. Correlations between person-means tend to be stronger than the corresponding within-person correlations. Not waking up tired was negatively correlated with mean number of awakenings (r- −0.33) and trouble sleeping ($r = -0.39$) and positively correlated with hours slept (r = −0.33, sleep quality ($r = 0.51$), hours slept ($r = 0.33$) and self-efficacy ($r = 0.28$). Among the remaining variables, the strongest correlations between person-means were a positive correlation between self-efficacy and sleep quality ($r = 0.59$), a negative correlation between sleep quality and number of awakenings (r = −0.33) and trouble sleeping ($r = -0.58$) and a positive correlation between sleep quality and hours slept ($r = 0.38$). With the exception of a positive correlation with sleep quality ($r = 0.34$), within-person correlations between the sleep variables and self-efficacy were not strong. Participants gained a mean of 1.37 kg from 6 to 12 months. The rate of weight gain was not significantly correlated with mean self-efficacy ($r = 0.01$) nor with any of the sleep dimensions. With a couple of exceptions, the baseline variables were not significantly correlated with mean levels of the sleep variables and self-efficacy. However, Barriers to Healthy Eating, a scale that measures various situations or conditions related to following a prescribed diet such as social and emotional support, was negatively correlated with mean self-efficacy, so Barriers to Health Eating was added as a covariate in the mixed-effects models. In addition, age was positively correlated with the mean number of awakenings ($r = 0.19$).

Predictors of Self-Efficacy

For the null model, the between- and within-subjects variance components were $\hat{\tau}_0^2 = 1.81$ and $\hat{\sigma}_\varepsilon^2 = 1.74$, respectively, yielding an intraclass correlation of 51% (Table 3). Moreover, the variances due to microscale variation and measurement error is estimated to be $\hat{\sigma}_0^2 = 0.0.81$, and hence $1 - \hat{\sigma}_0^2 \,/\, (\hat{\tau}_0^2 + \hat{\sigma}_\varepsilon^2) = 0.77$ may be regarded as a lower bound for the reliability of the single-item measure of self-efficacy.

Variance components and model fit statistics are presented in Table 3, and unadjusted and adjusted estimates of mean effect of sleep variables from the mixed effects models predicting self-efficacy from sleep are summarized in Table 4. With p-values all less than 0.001, all sleep dimensions were significantly associated with self-efficacy. When sleep variables were considered individually in univariate models, sleep quality was the strongest predictor of self-efficacy (BIC=140,145), followed by feeling tired (BIC=141,783), hours slept (BIC=141,999), trouble sleeping (BIC=142,273), and number of awakenings (BIC=142,317). When not adjusted for the remaining sleep dimensions, self-efficacy was predicted to increase by a mean of 0.067 (95% confidence interval, 0.046, 0.087) units for each additional hour of sleep and to be a mean of 0.099 (95% confidence interval, 0.084, 0.114) units higher for each one-unit higher rating of sleep quality. Conversely, self-efficacy was predicted to be a mean of 0.026 (95% confidence interval, 0.017, 0.035) units lower for every one-unit higher rating of trouble sleeping, and a mean of 0.054 (95% confidence interval, 0.037, 0.070) lower for each awakening. On average, participants' self-efficacy was a mean of 0.23 (95% confidence interval, 0.19, 0.28) units lower when they reported being tired. However, estimated standard deviations of regression slopes were often larger than the corresponding means of the slopes suggesting that there is considerable variation among participants in how they respond to the predictors, with many showing an opposite trend to that which is predicted on average. For example, on average self-efficacy is estimated to increase by a mean of $\hat{\mu} = 0.099$ for each unit change in sleep quality. However, with an estimated standard deviation of that slope equal to $\hat{\sigma} = 0.084$, the self-efficacy of approximately 12.1% is estimated to decrease with increasing sleep quality.

The adjusted estimates are from a full (multivariate) model including all sleep variables together (Table 4). After adjusting for the remaining sleep dimensions, hours slept and the number of awakenings were no longer significant predictors of self-efficacy. Sleep quality and not feeling tired remained significant positive predictors of self-efficacy, with self-efficacy predicted to increase by a mean of 0.095 (95% confidence interval, 0.080, 0.110) for each unit increase in sleep quality and to be a mean of 0.10 (95% confidence interval, 0.06, 0.14) units lower when reporting being tired. Paradoxically, self-efficacy was predicted to increase by a mean of 0.0070 (95% confidence interval, 0.0002, 0.0132) units for each unit increase in trouble sleeping when adjusting for the remaining sleep dimensions, but this could be attributed to multicollinearity among sleep variables. For the multivariate model, self-efficacy decreased by a mean of 0.0025 units per day (95% confidence interval, 0.0019, 0.0032; $\hat{\sigma} = 0.0035$); rates only differed in the fifth decimal in the univariate analyses.

DISCUSSION

The researchers examined the relationship between multiple dimensions of day-to-day sleep and daily self-efficacy for adhering to a daily healthy lifestyle plan in a sample of adults participating in a behavioral weight loss intervention. Using an EMA application on a smartphone, they conducted daily assessments of 150 participants' sleep and self-efficacy over the course of the 12-month intervention. To their knowledge, this is the first study to conduct a detailed, longitudinal assessment of this association using EMA. They found that each dimension of sleep was associated with self-efficacy. Among the sleep dimensions, *sleep quality* had the greatest positive impact on one's perceived self-efficacy at the beginning of the day for adhering to the healthy lifestyle plan that day. While longer sleep duration was also associated with higher self-efficacy for adhering to a daily healthy lifestyle plan, feeling tired, greater trouble sleeping and more awakenings were associated with lower self-efficacy.

The investigators also examined the mean amount of weight regained during the second half of the intervention (months 7 to 12), which wase relatively small, Neither weight regain or the rate of weight regain was significantly correlated with mean self-efficacy or any of the measured sleep dimensions. Barriers to Healthy Eating scores were significantly negatively correlated with self-efficacy indicating that as a person perceives more barriers to following the recommended diet plan, their self-efficacy for adhering to the diet is lower. Strong associations between self-regulatory skills measured in this scale and self-efficacy have been reported.[23,27,28]

Research has focused on the model of self-control where self-control is viewed as the capacity to resist impulses or temptations and alter behavior through conscious means; however, self-control resources are finite.[29-31] Subsequent research has suggested that sleep can play a role in restoring the depleted self-control resources.[24] A study by Diestel and colleagues used daily diaries to examine the associations between emotional labor, one's perception of the discrepancy between experienced emotions and those required by a job role, and sleep quality on daily self-control capacity.[32] The study found that day-specific emotional dissonance was strongly associated with ego depletion later in the day when sleep quality for the previous night was low; when the previous night's sleep quality was high, the emotional dissonance was weaker. This study's findings on self-efficacy and sleep are similar to Diestel et al.'s findings. Previous research suggests that sleep quality buffers the negative daily effects of emotional dissonance on one's health since sleep can replenish limited regulatory resources and thus improves one's capacity to exert self-control the following day.[19] Similarly, this study found that sleep quality and longer sleep duration were related to individuals reporting greater perceived confidence in their ability to adhere to the lifestyle goals for that day. The lower reported self-efficacy on mornings when the individual had experienced poor sleep (i.e., lower sleep quality, greater trouble sleeping, more awakenings, or feeling tired) suggest that the sleep had not provided the restorative effect to their limited self-control and thus they did not believe that they had the ability to refuse temptation, expressed as lower self-efficacy.

Additional analyses by Diestel et al.[32] revealed significant inter-individual differences in the day-specific associations of emotional dissonance and sleep quality to reports of well-being, suggesting that the moderating effect of sleep quality may be dependent on person-related variables, which may influence the extent individuals profit from a night of good quality sleep when they have to cope with daily emotional dissonance. This study found that most of the variance in self-efficacy was between persons, which begs the question: Are the same people who sleep poorly the ones who have low self-efficacy rather than people's self-efficacy being low when they have had poor sleep? There are potentially many factors that may be influencing this association, e.g., self-control resources, self-regulatory skills, overweight/obesity status, social context, which warrant further exploration.

Various mechanisms have been proposed to explain how sleep can affect self-efficacy. Fillo et al. explored the mediational role of emotional dysregulation to help explain the relationship between sleep and self-efficacy in quitting smoking.[33] They found that emotional dysregulation, which they defined as difficulty regulating affective states and controlling affect-driven behaviors, mediated the relationship between sleep and smoking relapse situation self-efficacy.[33] Another potential mechanism is daily vitality, or the perceived degree to which people feel energized and activated.[34] Sleep quality has been found to positively predict daily vitality, which in turn was positively related to self-efficacy among otherwise healthy adults.[34]

In examining the relationship between various sleep variables and self-efficacy for adhering to the healthy lifestyle among participants in weight loss program, this study found statistically significant correlations. With the exception of sleep quality and self-efficacy, which was moderately correlated, these associations were small and may not be clinically significant. While the study had excellent completion rates for the daily survey conducted over 12 months, it is possible that the weaker correlations may be due to measurement error as it is plausible that participants did not give sufficient thought to answering the questions every day.

There are limitations worth noting when considering the significance of this study. The study sample was predominantly female, white, well-educated, and currently employed, which limits the generalizability of the findings. Second, the study used self-report to measure the different dimensions of sleep. While commonly used in health research, self-reported data are subject to recall bias.[35] However, the use of EMA is one of the strengths of this study as it reduces the risk for recall bias by assessing the participants in real-time and in their natural setting.[22] In addition, the BOD surveys had a high completion rate (87.9%) despite being conducted over a period of 12 months. Nevertheless, self-reports of sleep dimension are subject to measurement error,[36] which can result in substantial shrinkage of estimates of regression coefficients towards zero and may explain the weak associations found in the analyses.[37] Lauderdale et al. found self-reports of habitual sleep moderately correlated with actigraphy measured sleep but were biased by systematic over-reporting.[36] Matthews and colleagues revealed estimates of sleep duration measured by actigraphy and diary were highly correlated but that sleep duration mean values differed across four different measures.[38] Finally, we did not consider the presence of sleep disordered breathing in the analysis, a potentially confounding variable considering the literature that addresses reduced adherence to weight loss supporting behaviors among those with this condition.[39,40]

There are strengths to the study, primarily the high retention of participants in an intensive 12-month intervention that included daily EMA assessments, and the high level of EMA survey completion.

CONCLUSION

In summary, less trouble sleeping, fewer awakenings, longer sleep duration, better sleep quality, and waking up not feeling tired were each found to be associated with higher self-efficacy for adhering to the daily healthy lifestyle plan. However, the findings from this study showed relatively small associations between sleep and self-efficacy for daily lifestyle adherence. The model of self-control and its limited resources that lead to depletion of self-control capacity until it can be restored seems to be a plausible explanatory pathway to explore in gaining a better understanding of adherence to a lifestyle that supports weight loss and weight loss maintenance. Given the role of sleep in restoring depleted self-control, future research also needs to develop strategies to test if improving sleep quality increases self-control capacity in resisting temptations related to eating and sustaining a healthy lifestyle, including how social and structural contexts may influence sleep and self-control.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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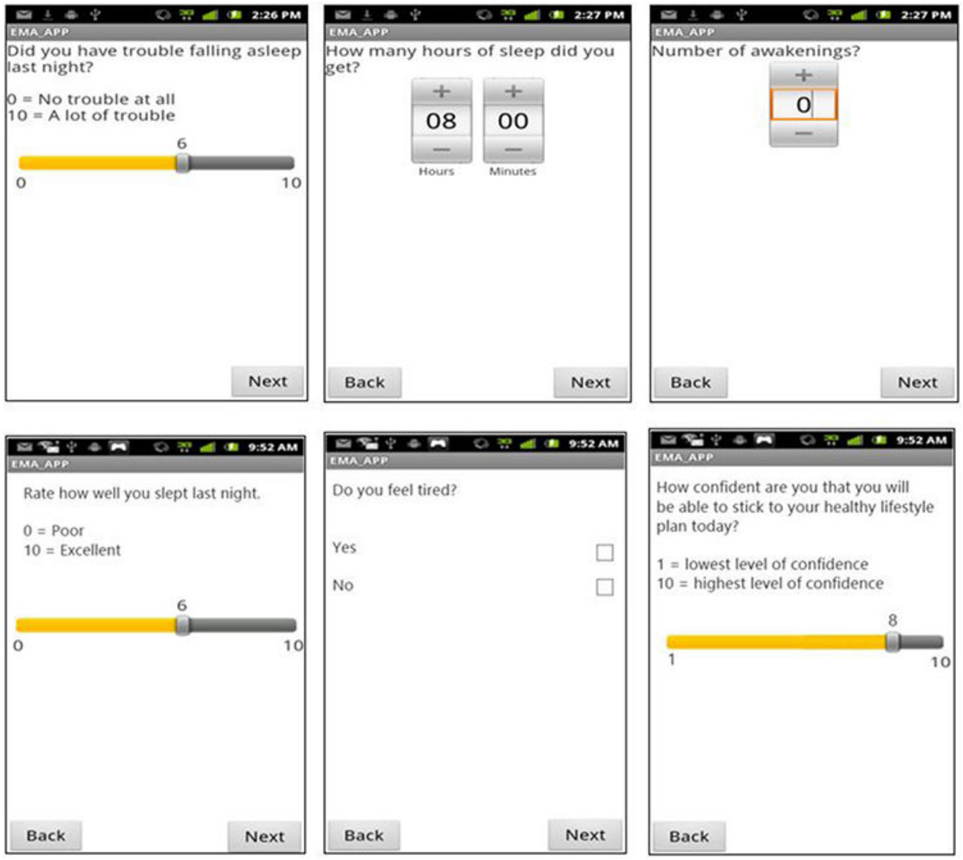

Figure 1.
Screenshots of the Sleep and Self-efficacy Questions

```
proc mixed;
  class participant;
  model self-efficacy=sleep time / solution;
  random participant participant*sleep
participant*time;
  repeated / subject=participant local type=sp(exp)
(time);
  run;
```

Figure 2.

SAS code for mixed model procedure predicting self-efficacy as a function of a single sleep variable

Table 1.

Characteristics of study participants (N =150)

Variable	Statistic*
Age (years)	51.1 ± 10.2
Female – no. (%)	136 (90.7)
White – no. (%)	121 (80.7)
Married – no. (%)	84 (56.4)
Employed Full Time – no. (%)	124 (82.7)
Formal Education (years)	16.4 ± 2.8
Level of Education – no. (%)	
High School	14 (9.3)
Some College or Technical School	28 (18.7)
College Graduate	58 (38.7)
Graduate School	50 (33.3)
BMI (kg/m^2)	34.0 ± 4.6
History of Intentionally Lost 10-19 lbs	2.5 ± 1.3
Barriers to Healthy Eating (BHE)	57.9 ± 13.4
Weight Regain (kg)	1.37 ± 1.74
Rate of Weight Change (kg/week)	0. 060 ± 0.076

*Mean ± standard deviation or frequency (%)

Table 2.

Pearson correlations among person-means for sleep variables and with self-efficacy (lower triangle) and corresponding within-subject correlations among sleep variables (upper triangle).

	Hours Slept	Awakenings	Trouble Sleeping	Sleep Quality	Self-Efficacy
Hours Slept	–	−0.011	−0.241	0.386	0.074
Awakenings	0.023	–	0.100	−0.164	−0.031
Trouble Sleeping	−0.244 **	0.299 ***	–	−0.455	−0.119
Sleep Quality	0.381 ***	−0.327 ***	−0.582 ***	–	0.335
Self-Efficacy	0.145 *	−0.096	−0.263	0.590 ***	–
Not Feeling Tired	0.330 ***	−0.332 ***	−0.386 ***	0.506 ***	0.276 ***
BMI	−0.044	−0.039	−0.136	0.009	−0.011
Weight Regain Rate	−0.038	−0.076	0.088	−0.099	−0.013
Weight Regain	−0.020	−0.086	0.093	−0.085	−0.002
Age	0.050	0.191 *	0.022	0.073	0.110
BHE	−0.006	−0.087	0.038	−0.074	−0.268 ***

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

Table 3.

Variance Components, intraclass correlation, reliability and model fit for the null model, univariate models each including a single sleep variable as predictors of self-efficacy and the multivariate model all sleep variables as predictors.

	Variance Components					
Model	**Between Subjects (τ_0^2)**	**Within Subjects (σ_ε^2)**	**Measurement Error (σ_0^2)**	**ICC**	**Reliability**	**BIC**
Null Model	1.813	1.739	0.813	51.0%	77.1%	142,672
Univariate Models						
Trouble Sleeping	1.856	1.259	0.784	59.6%	74.8%	142,273
Hours Slept	1.840	1.256	0.779	59.4%	74.8%	141,999
Number of Awakenings	1.848	1.257	0.785	59.5%	74.7%	142,317
Sleep Quality	1.855	1.209	0.761	60.5%	75.2%	140,745
Not Feeling Tired	1.738	1.274	0.777	57.7%	74.2%	141,783
Multivariate Model	1.793	1.199	0.751	59.9%	74.8%	140,426

Table 4.

Unadjusted and adjusted estimates of means ($\hat{\mu}$), standard errors of means (SE($\hat{\mu}$)) and standard deviations ($\hat{\sigma}$) of regression coefficients from mixed effects models predicting self-efficacy. The p-values are for tests of the null hypothesis that the means of the regression coefficients are equal to zero.

	Unadjusted				Adjusted			
Variable	$\hat{\mu}$	SE($\hat{\mu}$)	$\hat{\sigma}$	p-value	$\hat{\mu}$	SE($\hat{\mu}$)	$\hat{\sigma}$	p-value
Trouble Sleeping (0-10 scale)	−0.0263	0.0042	0.0405	<0.0001	0.0070	0.0035	0.0271	0.0494
Hours Slept	0.0667	0.0104	0.1107	<0.0001	−0.0059	0.0098	0.0974	0.5494
Number of Awakenings	−0.0537	0.0084	0.0829	<0.0001	0.0027	0.0020	0.0047	0.1676
Sleep Quality (0-10 scale)	0.0990	0.0076	0.0845	<0.0001	0.0949	0.0076	0.0800	<0.0001
Not Feeling Tired	0.2327	0.0236	0.2437	<0.0001	0.1020	0.0188	0.1644	<0.0001