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Beyond single sleep measures: A composite measure of sleep health and its associations with psychological and physical well-being in adulthood

Soomi Lee[a,*], Katie M. Lawson[b]

[a] School of Aging Studies, United States of America, University of South Florida, 4202 E Fowler Avenue, MHC 1344, Tampa, FL, USA
[b] Department of Psychological Science, Ball State University, United States of America, 106 North Quad Building, Muncie, IN, 43706, USA

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ABSTRACT

Rationale. Sleep is important for many functions including body and mind restoration. Studies report the association of sleep with stress and physical deterioration, often focusing only on sleep duration; yet, sleep health needs to be understood by multiple dimensions to comprehensively capture its impact on well-being.

Objective. This study examined cross-sectional and longitudinal associations of multidimensional sleep health with perceived stress and chronic physical conditions.

Methods. We used a sample of 441 adults (*M* age = 57 years) who participated in the biomarker project of the Midlife in the United States Study. Participants provided self-report and actigraphy sleep data in 2004–2009 (T1). We created a composite score of sleep health (*Range* = 0–6; higher indicating more sleep problems) encompassing: actigraphy-measured regularity, timing, efficiency, duration, and self-reported satisfaction and alertness. Participants responded to the perceived stress scale and chronic physical conditions checklist at T1; chronic physical conditions were reassessed in 2013–2015 (T2).

Results. Cross-sectionally, a composite score of sleep health problems was uniquely associated with higher perceived stress and more chronic conditions, explaining additional variance that each individual sleep variable did not explain. Sleep duration – one of the most commonly researched dimensions of sleep – was not associated with either perceived stress or chronic conditions. Longitudinally, for individuals who had fewer chronic conditions at T1, having more sleep health problems was associated with an increase in chronic conditions at T2. Among the multiple dimensions, sleep satisfaction was most consistently and strongly associated with the outcomes.

Conclusion. Findings suggest the importance of considering multiple sleep dimensions concerning psychological and physical well-being in adulthood.

1. Introduction

Sleep plays a critical role in maintaining optimal functions of mind and body, such as recovering from psychological stress and restoration of physical energy (Haroz et al., 2017; Krueger et al., 2016). Prior literature has shown that insufficient or extended sleep duration and poor sleep quality are associated with a variety of adverse well-being and health outcomes, including perceiving more daily stressors (Lee et al., 2017; Sin et al., 2017), elevated risk of inflammation in those with arthritis (Lee et al., 2019a, 2019b, 2019c), incidence of falls (Chen et al., 2017), and pain (Chen et al., 2019; Finan et al., 2013). However, the literature is limited in that many studies have focused on single dimensions of sleep. According to a sleep health perspective, sleep health is not just the absence of a sleep disorder and needs to be understood by multiple dimensions (Buysse, 2014). We take this perspective to examine unique properties of a composite measure of multidimensional sleep health in relation to perceived stress and chronic physical conditions, two important adult well-being outcomes found to be significantly associated with single sleep variables in prior research.

The sleep health perspective by Buysse (2014) highlights multiple dimensions of sleep and their coordinated changes to optimize overall health and functioning. For example, an individual without a sleep disorder may not be considered as healthy if he/she has an irregular sleep schedule and/or inefficient sleep. The idea is in line with previous models of health, such as the World Health Organization (WHO) model and environmental or adaptive models that emphasize prevention,

* Corresponding author.
E-mail addresses: soomilee@usf.edu (S. Lee), kmlawson4@bsu.edu (K.M. Lawson).

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integrated functioning of body and mind, and adaptation, beyond disease and disability (Julliard et al., 2006; Larson, 1999). The sleep health perspective (Buysse, 2014) suggests six dimensions of sleep critical to psychological and physical well-being: regularity, satisfaction, alertness, timing, efficiency, and duration (RU SATED). Research based on this perspective shows that an aggregate measure of sleep health is associated with prevalent and incident depression symptoms in older women (Furihata et al., 2016), mortality in older men (Wallace et al., 2018a, 2018b) and mental and physical health outcomes in adolescents (Dong et al., 2019). Although specific sleep variables used in these studies differ, they have commonly assessed the six sleep dimensions. In the study by Dong et al. (2019), a composite sleep health score encompassing regularity, satisfaction, alertness, timing, efficiency, and duration is determined based on a 7-day sleep diary and a global survey. They report significant associations of the sleep health composite with multiple health outcomes such that higher sleep health is related to lower depressive and anxiety symptoms, fewer social problems related to friends and family, and lower odds of obesity. Little is known about the effect of composite sleep health on adults, despite that adulthood may involve diverse sleep health issues due to various lifestyle factors and age-related changes. For example, marriage, stress stemming from work and family responsibilities, and natural age-related changes in circadian shift and sleep architecture may cause sleep health issues in adulthood (Buxton et al., 2016; French et al., 2019; Maume et al., 2010; Ohayon et al., 2004).

We focus on perceived stress and the number of chronic physical conditions, two independent outcomes that can broadly assess psychological and physical well-being for an average adult. With regard to sleep—stress relationship, previous studies report univariate associations of single sleep variables with a variety of stress-related outcomes, such as work-family conflict, job strain, and stressful life events. Compared to these measures that are mostly event-specific or subgroup (worker)-specific, perceived stress can capture the degree to which overall situations in one's life are appraised as stressful (Cohen et al., 1983). In relation to physical conditions, most studies have often used specific disease conditions (e.g., diabetes, hypertension, obesity), lacking the assessment of cumulated morbidity associated with sleep issues.

Previous studies show the associations of sleep duration and sleep quality with psychological and physical well-being. Adults with shorter actigraphy-measured sleep duration (Berkman et al., 2015) or self-reported sleep duration (Sekine et al., 2014) report more stress across work and family domains. Poorer self-reported sleep quality in adults is also associated with more stressful life events (Hall et al., 2015) and work-related stressors and job strain (Berset et al., 2011; Karhula et al., 2013; Lee et al., 2019a; Lee et al., 2017). Concerning physical well-being outcomes, self-reported sleep duration has u-shaped relationships with physical and mental health functioning and the risks of diabetes, hypertension, obesity, and cardiovascular disease (Buxton and Marcelli, 2010; Sekine et al., 2014). Studies also report that self-reported sleep deficiency (short sleep duration, sleep insufficiency, and frequent insomnia symptoms) in adults is associated with functional limitations and the risks of angina, arthritis, and depression (Buxton et al., 2012; Koyanagi et al., 2014). Most of these studies are cross-sectional and thus directionality between variables cannot be determined. A systematic review of longitudinal studies, however, shows the effect of short sleep duration on follow-up incidents of diseases such as diabetes mellitus, hypertension, cardiovascular diseases, stroke, coronary heart diseases, obesity, depression, and dyslipidemia (Itani et al., 2017). Across studies, findings are consistent on sleep quality, but not on sleep duration; some studies report a lack of association between the quantity of sleep and adult health outcomes (Sato et al., 2020; Wallace et al., 2018a, 2018b).

Compared to the dimensions of sleep duration and sleep quality, less is known about whether and how regularity, timing, and efficiency of sleep are associated with psychological and physical well-being in adulthood. Limited studies, however, provide some insight. For example, age-appropriate bedtime routines and regularity during childhood are associated with lower body mass index in adolescence (Lee et al., 2019a, 2019b, 2019c). Either too early or too late sleep timing are associated with greater mortality risk in older adults (Wallace et al., 2019; Wallace et al., 2018a, 2018b). Sleep efficiency, which refers to difficulty falling asleep and returning to sleep or lower proportion of sleep in total time in bed, is found to be related to coronary heart disease and early mortality (Dew et al., 2003; Grandner et al., 2012; Nilsson et al., 2001).

The present study had three specific aims. First, we aimed to describe multidimensional sleep health characteristics in U.S. adults. We used six sleep dimensions (RU SATED) critical to overall health and functioning as suggested by the sleep health perspective and previous seminal work (Buysse, 2014; Dong et al., 2019). Sleep dimensions that require subjective evaluation (i.e., satisfaction/quality, alertness/sleepiness) were measured by self-report. Other sleep dimensions that can be objectively assessed (i.e., regularity, timing, and duration) were assessed by actigraphy. Second, we examined cross-sectional associations of a composite measure of sleep health with two important adult well-being outcomes – perceived stress and chronic physical conditions. We hypothesized that more sleep health problems across the six dimensions would be associated with higher perceived stress and more chronic conditions. Lastly, taking advantage of follow-up assessment of chronic physical conditions 9 years later, we examined a longitudinal association between sleep health composite and chronic physical conditions. We tested whether sleep health problems were associated with an increase in the number of chronic conditions over time, independent of age effect. We also explored moderation by baseline chronic conditions, because having more chronic conditions may accelerate the speed of multimorbidity accumulation during aging (Marengoni et al., 2011) and the longitudinal implication of sleep health problems may differ between adults with fewer chronic conditions versus those with multiple comorbid conditions initially.

2. Methods

2.1. Participants

Data for the current study were drawn from the Midlife in the United States Survey (MIDUS). Comprehensive details of the design and sample can be found in previous research (Brim et al., 2004). Fig. 1 shows a consort diagram. Out of 1255 individuals who participated in the biomarker project during MIDUS II, 441 individuals participated in the actigraphy sleep study; thus the final analytic sample of this study (T1 hereafter). About 9 years later, MIDUS III rolled out (2013–2014) and reassessed a sub-set of MIDUS II participants. Of our 441 participants, 391 provided data in MIDUS III (T2 hereafter). Among 391 individuals, 366 provided data on chronic physical conditions at T2, comprising a longitudinal sample of our study. Those who did not provide data at T2 ($n = 50$) were significantly older and less likely to be married/partnered at T1 than those who did ($n = 391$), but did not differ in gender, race, or education. Of those who provided data at T2 ($n = 391$), individuals who did not provide chronic conditions at T2 ($n = 25$) were more likely to be male, white, and not married/partnered at T2, but did not differ from those who did ($n = 366$) in age, education, perceived stress, and number of chronic conditions at T1.

2.2. Procedure

Participants were eligible for the biomarker project if they took part in the original MIDUS I study and were able to travel to the clinical research site. Biomarker data collection was carried out at three General Clinical Research Centers (University of California Los Angeles, University of Wisconsin, and Georgetown University). Participants in the actigraphy sleep study were asked to wear a wrist-worn accelerometer that measures rest/activity cycles, for one week and respond to daily sleep diary questions for the same one-week period. The larger MIDUS

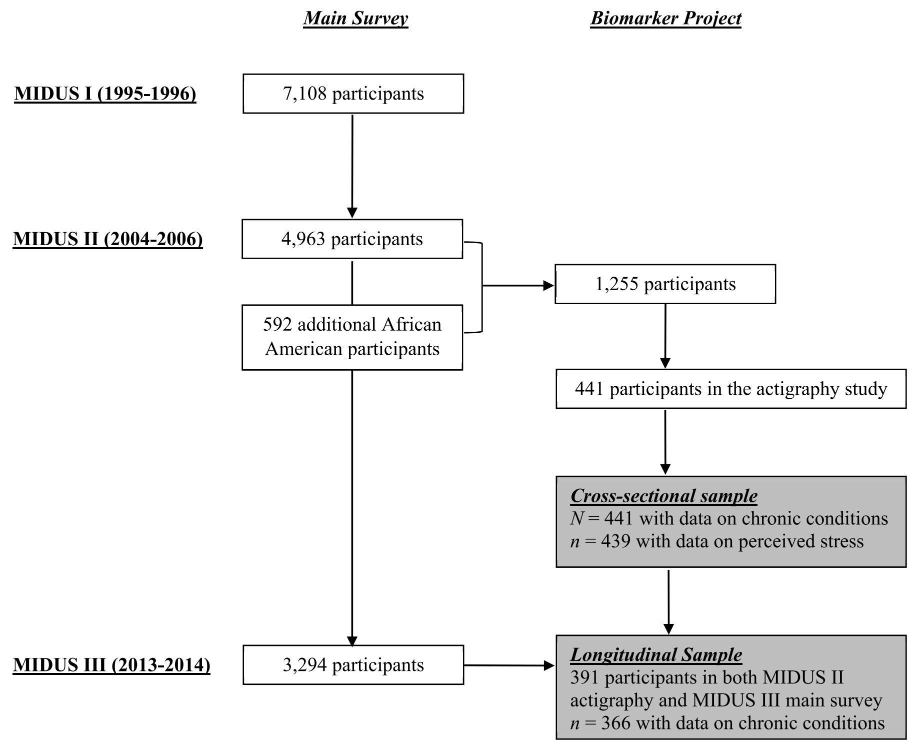

Fig. 1. Flow of participants into study.

study and the Biomarker project were approved by the University of Wisconsin-Madison Institutional Review Board (IRB). The current study was conducted at the University of South Florida and exempt from an IRB review because we used publicly available, de-identifiable data. Written informed consent was received for all MIDUS participants.

3. Measures

3.1. Predictor: composite sleep health

We relied on six indicators (i.e., regularity, satisfaction, alertness, timing, efficiency, and duration) to assess an individual's sleep health. We converted each of these indicators to binary values, where unfavorable conditions were coded as 1 and favorable conditions were coded as 0 (described in more detail below). To create binary variables, we used existing clinical and scientific guidelines to identify values of unfavorable sleep characteristics wherever possible (e.g., Watson et al., 2015). In the absence of such guidelines, we referred to empirically derived cutoff values (Brindle et al., 2019) and used a data-driven approach to identify the most extreme third of the distribution (Wallace et al., 2018a, 2018b). Then, we summed binary values across the six indicators. Thus, the total composite sleep health score ranged from 0 to 6. Higher scores indicated more sleep health problems.

Actigraphy-measured sleep. Four of the sleep health indicators (regularity, timing, efficiency, duration) were measured using the Actiwatch-64 (Philips, Amsterdam, the Netherlands) for seven consecutive days. Detailed descriptions of actigraphy data collection and scoring methods are publicly available (http://www.icpsr.umich.edu), with details relevant to the current analysis provided here. The devices were worn on the non-dominant wrist and the data collection began at 7:00 a.m. on the Tuesday after the day the participant returned home following the clinical visit and ended when they woke up on the following Tuesday. The Actiware 5 software and manufacturer algorithms for detecting sleep based on 30 s epochs were used. We created weekly average for each sleep variable. Previous research that examined the validity of the Actiwatch-64 vs. polysomnography (PSG) reported that sensitivity (actigraphy = sleep when PSG = sleep) and accuracy (total proportion correct) were high, whereas specificity (actigraphy = wake when PSG = wake) was low (Marino et al., 2013). To improve specificity, bed and wake times reported in the sleep diary were additionally used to guide start and end times for the actigraphic records. Previous MIDUS studies showed the validity of actigraphy sleep data in the associations with cardiometabolic morbidity, inflammatory markers, and subjective sleep quality (Brindle et al., 2019; Kim et al., 2016; Lemola et al., 2013).

Sleep regularity was assessed by standard deviation (*SD*) of sleep midpoint across the seven days and dichotomized to irregular (>1*SD*, coded as 1) or regular (≤1*SD*, coded as 0) sleep midpoint. 1*SD* cutoff was chosen, because the third quantile of sleep midpoint was 0.99 (Wallace et al., 2018a, 2018b). *Sleep timing* was assessed by sleep midpoint clock time. We defined early sleep midpoint as ≤2:00 a.m., medium sleep midpoint as 2:01am-4:00am, and late sleep midpoint as >4:00 a.m. (Walch et al., 2016). Extreme sleep midpoint was defined as either early or late sleep midpoint (coded as 1). *Sleep efficiency* was calculated as the ratio of time spent asleep to total time spent in bed, multiplied by 100 (expressed as a percentage). The average sleep efficiency score across the seven nights was dichotomized to reflect lower (<85th percentile; coded as 1) and normal (≥85th percentile; coded as 0) sleep efficiency (Owens et al., 2017). *Sleep duration* was defined as the total amount of minutes scored as main sleep in a given day. The average sleep duration across the seven nights was classified into short (<6 h; coded as 1) or long (>8 h; coded as 1), versus optimal amount (6 h ≤ duration ≤8 h; coded as 0). These criteria were based on the recommended amount of sleep duration for a healthy adult (Watson et al., 2015) and the distribution of sleep duration in the sample (less than 1% had >9 h sleep duration).

Self-reported sleep. The remaining two sleep health indicators (sleep satisfaction and alertness) were measured using a survey and 7-day sleep diary. Sleep satisfaction/quality was measured by the well-validated Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989) completed during the clinic visit, or just prior to the visit while the participant was at home. The PSQI assesses seven domains of sleep using 19 items. As some of the domains overlapped with actigraphy measures, we used one item specifically asked about sleep satisfaction/quality: "During the past month, how would you rate your sleep quality overall?" We dichotomized sleep quality into: poor (which included *fairly bad* or *very bad*; coded as 1) or good (which included *very good* or *fairly good*; coded as 0). Alertness was measured by daily sleep diary that participants completed over the same seven days with the actigraphy data collection period. The question asked, "Did you nap today?" (yes or no). We summed yes responses across the week and dichotomized to: no alertness (≥3 nap frequency; coded as 1) or alertness (<3 nap frequency; coded as 0).

3.2. Well-being outcomes

Perceived stress was measured at T1 by the widely-used and well-validated Perceived Stress Scale (PSS; Cohen and Williamson, 1988). The PSS includes ten items that measure the extent to which respondents perceive their lives as unpredictable, uncontrollable, and overloaded. An example item reads, "(In the past month) how often have you felt that you were unable to control the important things in your life?'' Responses were coded on a 5-point Likert-type scale ranging from 1 (*never*) to 5 (*very often*), with positive items reverse-scored so that higher values reflected greater perceived stress. The index was calculated by summing items (potential range = 10–50). Mean substitution was used in cases with only one missing value. Consistent with previous research (Taylor, 2015), reliability of the overall measure in this sample was high at 0.84.

Chronic physical conditions. Participants reported at both T1 and T2 how many chronic physical conditions they experienced or been treated by a medical doctor in the past 12 months by responding to a checklist of 30 items (e.g., asthma, high blood pressure, and ulcer). We excluded three items not related to chronic physical conditions (Keyes, 2005): (1) anxiety, depression or some other emotional disorder, (2) alcohol or drug problems, and (3) chronic sleeping problems. The number of chronic conditions was totaled for each participant. A higher score indicated having more chronic physical conditions in the past year.

Covariates. We controlled for sociodemographic covariates commonly found to be associated with psychological and physical well-being. Those include age (*0 = older, 1 = middle-aged*: 35 ≤ age < 60), gender (*0 = female, 1 = male*), marital status (*0 = single, 1 = married/cohabiting*), race/ethnicity (*0 = non-White, 1 = White*), and education (*0 = high school graduates or less, 1 = some college, 1 = college graduates or more*). As most of these variables may not vary over time (except marital status), we used sociodemographic data collected from the T1 survey. For marital status, we used both T1 (for cross-sectional) and T2 (for longitudinal) survey data. Additionally, we controlled for the use of sleep medications (*0 = not used, 1 = used*) measured in PSQI (Buysse et al., 1989).

3.3. Analyses

A series of linear regression models (for perceived stress) and Poisson regression models (for number of chronic physical conditions) were conducted in SAS version 9.4. In Step 1, we included covariates only. In Step 2, we added each sleep variable in separate models. In Step 3, we added a composite score of sleep health problems in addition to each sleep variable and covariates. Total variable explained (R^2) and additional variance explained from previous model (changes in R^2) were examined for each model. Because Poisson regression models do not provide R^2, we used deviance that indicates the relative reduction in variance in the outcome due to predictors in the model (Cameron and Windmeijer, 1996; Waldhor, 1998). Changes in pseudo R^2 were calculated as: 1 - [Deviance of the full model/Deviance of the previous model]. For the longitudinal analyses examining whether sleep health at T1 predicts changes in chronic physical conditions 9 years later (T2), T1 chronic physical conditions were used as an additional covariate. A separate model also tested T1 chronic physical conditions as a potential moderator. There were cases with incomplete data due to missingness in covariates (n = 1), perceived stress (n = 2), and individual sleep variables (n = 1 to 5). As the proportion of missingness was very small (<0.02%), the cases with incomplete data were dropped from the analyses.

4. Results

4.1. Descriptive statistics

Sample characteristics and descriptive statistics of main variables can be seen in Table 1. Summing across the six dimensions of sleep health problems, on average, participants had 2.30 sleep health problems (SD = 1.41). Correlations among sleep variables (Appendix Table 1) ranged from 0.03 to 0.49, indicating that individual sleep dimensions were generally related, but not highly overlapped with each other. The highest correlation was observed between sleep efficiency and sleep duration. Except for sleep midpoint, all individual sleep dimensions were correlated with a composite score of sleep health at moderate level (r = .40 to −0.56). Participants reported a low level of perceived stress on average (M = 22.75, SD = 6.51, where the average of 22.75 is between "almost never" and "sometimes"). The mean numbers of chronic physical conditions at T1 and T2 were 2.20 (SD = 2.13) and 2.98 (SD = 2.74), respectively.

Cross-Sectional Associations of Sleep Health with Perceived Stress.

Table 2 shows results from linear regression models predicting perceived stress at T1. In Step 1, covariates explained 12% of the variance in perceived stress. Age, race, and sleep medications were significant covariates, such that middle-aged adults (vs. older; B = 2.06, SE = 0.61, p < .001), minority individuals (vs. participants who identified as white; B = 3.19, SE = 0.70, p < .001), and those who used sleep medications (B = 2.13, SE = 0.70, p < .01) reported higher perceived stress. In Step 2, regularity and satisfaction in sleep (but not alertness, timing, efficiency, duration) explained unique additional variance. Lack of regularity and poor satisfaction in sleep were associated with higher

Table 1
Sample characteristics and descriptive statistics.

	Mean or *n*	*SD or %*
Sociodemographic characteristics		
Age	56.85	(11.44)
Gender, male	175	40%
Race, White	297	67%
Black or African American	133	30%
Some other race	11	3%
Marital status, married/partnered (%)	263	60%
Highest level of education [a]	7.24	(2.57)
Individual sleep variables (% of suboptimal sleep health in each domain)		
Regularity: High variability in actigraphy sleep midpoint (SD > 1)	110	25%
Satisfaction: Poor perceived sleep quality (very bad or bad)	84	19%
Alertness: Excessive napping (frequency ≥ 3 times/week)	139	32%
Timing: Late or early actigraphy sleep midpoint (>4:00 a.m. or ≤ 2:00 a.m.)	224	51%
Efficiency: Low actigraphy sleep efficiency (<85%)	299	68%
Duration: Suboptimal actigraphy sleep duration (<6 h or >8 h/week)	158	36%
Composite of sleep health problems (0–6)	2.30	(1.41)
Perceived stress (10 = never to 50 = very often)	22.75	(6.51)
Number of chronic physical conditions at Time 1	2.20	(2.13)
Number of chronic physical conditions at Time 2 (9 years later)[b]	2.98	(2.74)

Note. n = 441.
[a] Education was ranged from 8th grade/junior high school to PH.D., ED.D., MD, DDS, LLB, LLD, JD, or other professional degrees and the mean level of 7 indicated to 3 or more years of college, but no degree yet.
[b] n = 366 who provided data on chronic physical conditions both at Time 1 and Time 2.

Table 2
Results from linear regression models examining the cross-sectional associations of sleep health with perceived stress.

	B	SE	P	R^2	ΔR^2[c]
Step 1. Covariates only[a]				0.117	
Step 2. Added each sleep variable[b]					
Model 1: Lack of ***Regularity***	1.77	0.71	0.0125	0.130	0.013
Model 2: Poor ***Satisfaction***	4.93	0.75	<.0001	0.200	0.082
Model 3: Low ***Alertness***	0.92	0.65	0.1593	0.114	0.000
Model 4: Late or Early ***Timing***	1.16	0.60	0.0517	0.125	0.008
Model 5: Low ***Efficiency***	1.07	0.69	0.1233	0.122	0.005
Model 6: Suboptimal ***Duration***	−0.01	0.63	0.9827	0.117	0.000
Step 3. Added a composite of sleep health in each model					
Sleep health problems in Model 1	0.97	0.26	0.0002	0.158	0.028
Sleep health problems in Model 2	0.46	0.25	0.0646	0.206	0.006
Sleep health problems in Model 3	1.10	0.26	<.0001	0.150	0.036
Sleep health problems in Model 4	1.05	0.26	<.0001	0.158	0.032
Sleep health problems in Model 5	1.14	0.26	<.0001	0.159	0.037
Sleep health problems in Model 6	1.45	0.27	<.0001	0.174	0.056

Note. $n = 439$.
[a] Covariates were age, gender, race, marital status, education, and sleep medications.
[b] Each sleep variable was examined as a predictor in separate models adjusted for covariates.
[c] Changes in R-square from previous model were calculated.

perceived stress. In Step 3, a composite score of sleep health problems was associated with higher perceived stress, independent of each of the sleep variables. The exception was that the association of sleep health problems with perceived stress became non-significant ($p = .065$) after controlling for the strong association of satisfaction in sleep. The composite sleep health explained 3–6% additional variance that the other five dimensions of sleep did not explain.

Cross-Sectional Associations of Sleep Health with Chronic Physical Conditions.

Table 3 shows results from Poisson regression models predicting chronic physical conditions at T1. In Step 1, sociodemographic covariates explained 14% of the variance in chronic physical perceived stress [1 - (783.41/916.09 = deviance of empty model)]. Older age ($B = -0.22$, $SE = 0.07$, $p < .01$), racial minority ($B = 0.53$, $SE = 0.07$, $p < .001$), and use of sleep medications ($B = 0.47$, $SE = 0.07$, $p < .001$) were significant covariates associated with more chronic physical conditions. In Step 2, lack of regularity, poor satisfaction, low alertness, and low sleep efficiency were associated with more chronic physical conditions after controlling for covariates. There were no significant associations of sleep timing or sleep duration with chronic physical conditions. In Step 3, a composite score of sleep health problems was associated with more chronic physical conditions, independent of each of the six sleep variables. The composite sleep health explained 1–4% additional variance that the individual dimensions of sleep did not explain.

Longitudinal Associations of Sleep Health with Chronic Physical Conditions.

Table 4 shows results from Poisson regression models predicting chronic physical conditions at T2. Results were generally consistent with those in Table 3, although the significance of individual sleep variables predicting chronic physical conditions 9 years later changed. Sleep satisfaction and alertness were consistently significant predictors of T2 chronic conditions, but the associations of regularity and efficiency with T2 chronic conditions did not reach statistical significance. Late or early sleep timing became a significant predictor of T2 chronic conditions. A composite score of sleep health problems at T1 was uniquely associated with more chronic physical conditions at T2, independent of each of the sleep variables at T1. The composite sleep health explained 1–3% additional unique variance in T2 chronic conditions.

We further examined whether sleep health was associated with changes in chronic physical conditions from T1 to T2. There was no main effect of sleep health composite on changes in chronic conditions at T2 after controlling for T1 chronic conditions. However, T1 chronic

Table 3
Results from Poisson regression models examining the cross-sectional associations of sleep health with the number of chronic conditions.

	B	SE	p	*Deviance*[c]	ΔpseudoR^2[d]
Step 1. Covariates only[a]				783.41	
Step 2. Added each sleep variable[b]					
Model 1: Lack of ***Regularity***	0.23	0.07	0.0016	773.66	0.012
Model 2: Poor ***Satisfaction***	0.40	0.08	<.0001	756.48	0.034
Model 3: Low ***Alertness***	0.24	0.07	0.0005	762.25	0.027
Model 4: Late or Early ***Timing***	0.05	0.07	0.4722	782.89	0.001
Model 5: Low ***Efficiency***	0.19	0.08	0.019	777.79	0.007
Model 6: Suboptimal ***Duration***	0.06	0.07	0.3971	782.69	0.001
Step 3. Added a composite of sleep health in each model					
Sleep health problems in Model 1	0.13	0.03	<.0001	754.75	0.024
Sleep health problems in Model 2	0.09	0.03	0.0011	745.77	0.014
Sleep health problems in Model 3	0.12	0.03	<.0001	745.00	0.023
Sleep health problems in Model 4	0.16	0.03	<.0001	751.36	0.040
Sleep health problems in Model 5	0.14	0.03	<.0001	755.13	0.029
Sleep health problems in Model 6	0.17	0.03	<.0001	749.72	0.042

Note. $N = 441$.
[a] Covariates were age, gender, race, marital status, and education, and sleep medications.
[b] Each sleep variable was examined as a predictor in separate models adjusted for covariates.
[c] Deviance indicates the relative reduction in variance in the outcome due to the predictors in the model.
[d] Δpseudo R^2 was calculated as: 1 - [Deviance of the full model/Deviance of the previous model].

conditions moderated the effect of sleep health composite on changes in chronic conditions over 9 years ($B = -0.04$, $SE = 0.01$, $p < .001$). Fig. 2 shows the nature of this interaction. Individuals with more sleep health problems at T1 had an increased rate of chronic conditions at T2 when they had fewer chronic conditions (-1*SD* or 0.08 in number) at T1 (*Slope estimate* $= 0.13$, $SE = 0.03$, $p < .001$). The slope for those with greater chronic conditions (+1*SD* or 4.33 in number) at T1 was not significant (*Slope estimate* $= -0.02$, $SE = 0.03$, $p > .10$). These effects were found after adjusting for covariates.

4.2. Supplemental results

A supplementary analysis was conducted to help determine the relative importance of considering composite sleep health as a predictor of perceived stress, as opposed to individual sleep markers. Covariates and the composite sleep health variable were entered as predictors of perceived stress (i.e., step 2 was removed). In this model, composite sleep health explained 4.00% of the variance in perceived stress. In contrast, for five out of the six models (excluding sleep satisfaction) that included individual sleep variables (i.e., step 2), adding in sleep as a predictor of perceived stress only accounted for explaining between 0 and 1.27% of the variance in perceived stress. In addition, the effect size of sleep health composite was much larger than the effect size of age ($B = -0.07$, $SE = 0.03$, $p < .01$) – a variable that past research has found to be negatively associated with perceived stress. One unit increase in sleep health composite was associated with a 1.02-unit increase in perceived stress, and this effect size was comparable to the effect of approximately 15-year difference in age.

The same supplementary analysis was also conducted with chronic physical conditions as the outcome. Composite sleep health explained 3.60% of the variance in chronic physical conditions, whereas five out of

Table 4
Results from Poisson regression models examining the associations of sleep health with the number of chronic conditions 9 years later.

	B	SE	p	*Deviance*[c]	ΔpseduoR^{2}[d]
Step 1. Covariates only[a]				740.89	
Step 2. Added each sleep variable[b]					
Model 1: Lack of *Regularity*	0.11	0.07	0.1244	738.56	0.003
Model 2: Poor *Satisfaction*	0.27	0.07	0.0002	727.31	0.018
Model 3: Low ***Alertness***	0.13	0.07	0.0435	732.99	0.011
Model 4: Late or Early *Timing*	0.23	0.06	0.0002	727.25	0.018
Model 5: Low ***Efficiency***	0.10	0.08	0.1786	739.07	0.002
Model 6: Suboptimal *Duration*	0.03	0.06	0.688	740.73	0.000
Step 3. Added a composite of sleep health in each model					
Sleep health problems in Model 1	0.11	0.03	<.0001	721.02	0.024
Sleep health problems in Model 2	0.08	0.03	0.0023	718.03	0.013
Sleep health problems in Model 3	0.11	0.03	<.0001	717.29	0.021
Sleep health problems in Model 4	0.08	0.03	0.0021	717.89	0.013
Sleep health problems in Model 5	0.12	0.03	<.0001	720.25	0.025
Sleep health problems in Model 6	0.14	0.03	<.0001	715.68	0.034

Note. $n = 366$ who provided data at both M2 and M3.
[a] Covariates were age, gender, race, marital status, and education, and sleep medications.
[b] Each sleep variable was examined as a predictor in separate models adjusted for covariates.
[c] Deviance indicates the relative reduction in variance in the outcome due to the predictors in the model.
[d] Δpseudo R^2 was calculated as: 1 - [Deviance of the full model/Deviance of the previous model].

the six models with individual sleep variables (excluding sleep satisfaction) explained between 0 and 2.70% of the variance in chronic physical conditions. The effect size of sleep health composite was much larger than the effect size of age ($B = 0.01$, $SE = 0.003$, $p < .001$): one unit increase in sleep health composite was associated with 15% increase in chronic physical conditions, and this effect size was comparable to the effect of an approximately 10-year difference in age.

5. Discussion

Using a sleep health perspective that highlights the importance of multiple sleep characteristics for overall health and functioning (Buysse, 2014), this study examined whether a composite measure of sleep health was associated with psychological and physical well-being in a sample of U.S. adults. We found that more sleep health problems across six dimensions (regularity, satisfaction, alertness, timing, efficiency, and duration) were uniquely associated with higher perceived stress and more chronic physical conditions, explaining additional variance in the well-being outcomes that individual sleep variables did not explain. We also found the benefit of maintaining sleep health in delaying the new onset of chronic physical condition over time. Importantly, in our cross-sectional and longitudinal analyses, sleep duration was not significantly associated with either perceived stress or chronic conditions, suggesting that the quantity of sleep alone may not tell much about adult well-being (Sato et al., 2020; Wallace et al., 2018a, 2018b). Our findings suggest the importance of considering multiple sleep dimensions concerning psychological and physical well-being across adulthood.

This study is one of the first that reports the prevalence of multiple sleep health problems in U.S. adults. By using clinical and empirically derived cutoffs (Brindle et al., 2019; Wallace et al., 2018a, 2018b; Watson et al., 2015), we found that a typical adult in our sample had 2.30 sleep health problems (see Table 1), mostly due to low sleep efficiency (68%) and late or early sleep timing (51%). Sleep efficiency generally decreases with age (Ohayon et al., 2004). Our findings show that the overall prevalence of clinically low sleep efficiency (<85%) is

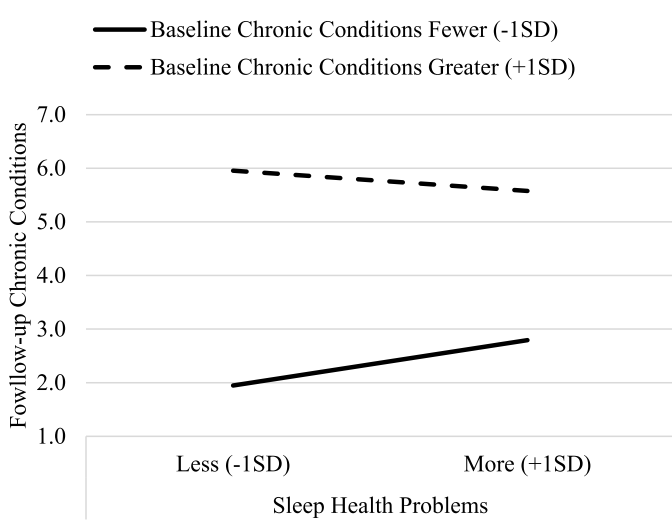

Fig. 2. Longitudinal association of the composite sleep health with changes in chronic physical conditions at Follow-up moderated by Baseline chronic physical conditions.
Note. There was no main effect of sleep health on changes in chronic physical conditions at Time 2 after controlling for Time 1 chronic physical conditions. However, Time 1 chronic conditions moderated (B = −0.04, SE = 0.01, $p < .001$), such that individuals with more sleep health problems had an increased rate of chronic conditions at Time 2 when they had fewer chronic conditions (-1SD or 0.08 in number) at Time 1 (Slope estimate = 0.13, SE = 0.03, $p < .001$). The slope for those with greater chronic conditions (+1SD or 4.33 in number) at Time 1 was not significant (Slope estimate = −0.02, SE = 0.03, $p > .10$).

Note. There was no main effect of sleep health on changes in chronic physical conditions at Time 2 after controlling for Time 1 chronic physical conditions. However, Time 1 chronic conditions moderated (B = -0.04, SE = 0.01, p <.001), such that individuals with more sleep health problems had an increased rate of chronic conditions at Time 2 when they had fewer chronic conditions (-1SD or 0.08 in number) at Time 1 (Slope estimate = 0.13, SE = 0.03, p < .001). The slope for those with greater chronic conditions (+1SD or 4.33 in number) at Time 1 was not significant (Slope estimate = -0.02, SE = 0.03, p > .10).

already high among adults, which raises a concern regarding their cognitive and cardiovascular health (Massar et al., 2017; Waser et al., 2019). Late or early sleep timing is associated with a greater risk of all-cause mortality (Wallace et al., 2018a, 2018b), and this issue could be modified by changing sleep routine behaviors. Our study provides critical information for future sleep interventions targeting adult populations by showing the prevalence of sleep health problems in multiple dimensions.

Findings from this study also show the relative importance of each sleep dimension in the associations with psychological and physical well-being. For concurrent perceived stress, regularity and satisfaction turned to be significant factors. For concurrent chronic physical conditions, regularity, satisfaction, alertness, and efficiency were important factors. For long-term chronic physical conditions, satisfaction, alertness, and timing were important factors. These results show that sleep regularity and satisfaction are closely related to concurrent well-being both psychologically and physically, whereas late or early sleep timing may have long-term health consequences. In the longitudinal model of chronic conditions, the magnitude of the effect of sleep timing was similar to that of sleep satisfaction (see Table 4). Although a small proportion of the variance was explained by each sleep dimension, the results are in line with previous research showing that unsatisfactory sleep and late/early timing are associated with greater mortality risk (Hoffman et al., 2011; Wallace et al., 2018a, 2018b). Compared to sleep dimensions associated with perceived stress, more diverse sleep dimensions were related to chronic physical conditions cross-sectionally and longitudinally, showing the utility of examining multiple sleep dimensions in assessing health risks.

Across the two well-being outcomes, the effect size of sleep satisfaction was the largest, explaining 8 to 3% of additional variance in perceived stress and chronic physical conditions, respectively. The composite measure of sleep health did not seem to add significant incremental value to predict perceived stress and chronic conditions, as compared with sleep satisfaction alone. The strong association of perceived sleep quality (i.e., poor satisfaction) with stress and chronic physical conditions were consistently reported in previous studies (Berset et al., 2011; Hall et al., 2015; Karhula et al., 2013; Koyanagi et al., 2014). In our sample, the prevalence of those with poor satisfaction in sleep (i.e., those who responded "very bad" or "fairly bad" in perceived sleep quality) was about one-fifth. It may be that the self-report of poor sleep quality is sensitive to predict individual well-being. Because this study only used self-reported measures of perceived stress and chronic physical conditions (albeit reported being treated by a medical doctor), future research could replicate our findings with objective markers of well-being.

In contrast, sleep duration was not significantly associated with adult well-being in our study. Previous findings on sleep duration were inconsistent, such that some studies reported short or long sleep duration was associated with adverse health and well-being (Berkman et al., 2015; Buxton and Marcelli, 2010; Itani et al., 2017; Nishiura et al., 2010; Sekine et al., 2014), whereas others reported a lack of association between the quantity of sleep and adult health (Sato et al., 2020; Wallace et al., 2018a, 2018b). The null association of sleep duration may have something to do with our sample characteristics, because the MIDUS sample is known to be healthier and more educated than the U.S. average (Lee et al., 2018). In such samples with potentially more knowledge on sleep hygiene, sleep duration alone may not be sufficient to capture the impact of sleep on well-being. Some research also notes that sleep quality may be more sensitive than sleep duration to capturing health risks (Bin, 2016). Together, our findings show the utility of assessing multiple sleep characteristics, beyond sleep duration.

More importantly, a composite measure of sleep health was uniquely associated with perceived stress and chronic physical conditions, after controlling for each individual sleep variable. The independent effect was also apparent in our longitudinal results showing that having more sleep health problems increased number of chronic conditions at T2 for individuals who had fewer chronic conditions at T1. Except the model that controlled for the strong association of satisfaction in sleep, the composite sleep health explained additional 3–6% variance in perceived stress and 1–4% variance in chronic physical conditions. The effect size of the composite sleep health was comparable to 10–15 years of difference in age, which is not negligible. These findings extend previous studies in that the combination of multiple sleep dimensions explains additional variance in psychological and physical well-being that individual sleep characteristic alone does not explain.

5.1. Limitations

Although this study has many strengths including the use of self-report and actigraphy data that assessed sleep health across multiple dimensions and longitudinal follow-up of adults during their process of aging, it also has limitations that may guide future studies. Our study sample was an actigraphy sub-sample from the larger MIDUS project. Therefore, the study sample may not represent US adults, although the overall MIDUS sample does (Brim et al., 2004). Future research needs to replicate our findings among more diverse samples (including other country samples) and those with fewer resources and capacity. Given social disparities in health (Vineis et al., 2020), the associations of sleep health with psychological and physical well-being may be more apparent in samples with lower socioeconomic status. Furthermore, a one-time measurement of sleep health and perceived stress prevented us from assessing directionality between sleep health and psychological well-being. Although age-related reductions in perceived stress (Carstensen et al., 2003) are likely to blur longitudinal associations with sleep health, it is possible that adults who initially had greater perceived stress may exhibit a slower decline if they had more sleep problems over time. Longitudinal data of chronic physical conditions allowed us to infer that, among those with fewer chronic conditions at T1, having more sleep health problems increased chronic physical conditions at T2. However, the reversed directionally, whether having more chronic physical conditions would increase the number of sleep problems, has not yet been tested. Future studies using longitudinal data could address these remaining questions. Lastly, future research is needed to take into account health behaviors (e.g., diet, exercise, and active lifestyles) as a covariate or as a potential mechanistic pathway linking sleep health and psychological and physical well-being.

5.2. Practical implications

Our findings may have implications for healthcare providers and health practitioners. Given our results that a composite measure of sleep health is associated with psychological and physical well-being, a sleep checklist that asks about habitual sleep patterns across multiple dimensions could be used as a health screening tool. Some studies have suggested the use of questionnaire to detect sleep disorders (Roth et al., 2002). We further suggest using a sleep checklist to identify those who may experience lower psychological and physical well-being in order to intervene on potential issues early on. Our measure of sleep health composite included six sleep dimensions assessed by both self-report and actigraphy. Although this measure can provide a more comprehensive and accurate assessment of sleep health, a simple self-reported checklist may serve its intended purpose of screening those at greater health risk. In particular, self-reported satisfaction/quality of sleep alone had the largest effect size on perceived stress and chronic physical conditions, thus a question about sleep quality should be asked during regular hospital check-ups.

6. Conclusions

This study contributes empirical evidence to the literature on sleep health and well-being, suggesting that a composite measure of sleep health explains additional variance in adult well-being that a single sleep variable does not explain. Among the multiple sleep health dimensions, sleep satisfaction was mostly consistently and strongly associated with adult well-being. The benefit of sleep health observed in this study is found for both psychological and physical well-being domains and independent of sociodemographic characteristics. Findings suggest that sleep health across multiple dimensions is essential to promote psychological and physical well-being across adulthood.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2021.113800.

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