Gerontology & Geriatric Medicine
Volume 7: 1–9

DOI: 10.1177/23337214211016222
journals.sagepub.com/home/ggm
SAGE

Multidimensional Sleep Health and Physical Functioning in Older Adults

Caitlan A. Tighe, PhD[1], Ryan C. Brindle, PhD[2], Sarah T. Stahl, PhD[3], Meredith L. Wallace, PhD[3], Adam D. Bramoweth, PhD[1], Daniel E. Forman, MD[1,3], and Daniel J. Buysse, MD[3]

Abstract

Objective: To examine the association between multidimensional sleep health and objective measures of physical functioning in older adults. **Method:** We conducted a secondary analysis of 158 adults ≥65 years who participated in Midlife in the United States (MIDUS) 2 and MIDUS Refresher studies. Physical functioning was assessed using gait speed during a 50-foot timed walk, lower extremity strength via chair stand test, and grip strength via hand-held dynamometers. Composite multidimensional sleep health scores were derived from 1 week of sleep diaries and wrist actigraphy. **Results:** Multiple linear regression was used to examine the associations between multidimensional sleep health and physical functioning measures. In adjusted regression analyses, multidimensional sleep health was significantly positively associated with gait speed but not lower extremity strength or grip strength. **Discussion:** These findings suggest multidimensional sleep health may contribute to physical functioning in older adults. Longitudinal examinations are needed to determine the value of multidimensional sleep health as a therapeutic target to optimize physical functioning.

Keywords

sleep, sleep health, physical function, older adults

Manuscript received: January 11, 2021; **final revision received:** March 6, 2021; **accepted:** April 1, 2021.

Introduction

Rowe and Kahn's (1997) model defines successful aging as a multidimensional construct that includes low risk of disease and disease-related disability, maintenance of high cognitive and physical functional capacity, and active engagement with life. This model also highlights the importance of modifiable behavioral and environmental factors to successful aging. As one of the essential components of successful aging, physical functioning has been consistently linked to the health and well-being of older adults (e.g., Groessl et al., 2007; Trombetti et al., 2016). However, which specific modifiable behavioral factors contribute to physical functioning capacity are less understood. Sleep health is one such factor that may contribute to physical functioning capacity.

Just as successful aging comprises several elements, sleep can be defined along multiple dimensions and viewed from a health promotion, rather than a disease treatment, framework. Sleep health can be conceptualized as a "multidimensional pattern of sleep-wakefulness. . .that promotes physical and mental well-being" (Buysse, 2014, p. 12). Measurable and well-supported domains of sleep health include regularity in sleep and wake times, perceived sleep quality, alertness during waking, timing of sleep, sleep efficiency, and sleep duration. Approaching sleep from a multidimensional framework describes an individual's experience of sleep-wake behavior more completely than single measures such as sleep duration, which is particularly important in the context of physical functioning (Stenholm et al., 2011). This framework also takes into account that an individual may have a disturbance in one domain of sleep health, while others are maintained; for instance, one may report poor sleep quality despite getting the recommended amount of sleep. The sleep health framework is dimensional, rather than dichotomous, as in the case of a sleep disorders framework. As such, it considers the *degree* to which an individual experiences

[1]VA Pittsburgh Healthcare System, PA, USA
[2]Washington and Lee University, Lexington, VA, USA
[3]University of Pittsburgh, PA, USA

Corresponding Author:
Caitlan A. Tighe, VISN 4 Mental Illness Research, Education and Clinical Center, VA Pittsburgh Healthcare System, University Drive C, Pittsburgh, PA 15206-1297, USA.
Email: caitlan.tighe@va.gov

healthy sleep and, relatedly, encourages examination of the extent to which healthy sleep relates to optimal health and functioning.

Multidimensional sleep health has been linked to physical health outcomes such as cardiometabolic morbidity, all-cause mortality, and cardiovascular mortality (Brindle et al., 2019; Wallace et al., 2019). To date, one study has linked better multidimensional sleep health to better physical functioning in community-dwelling midlife to older adults (DeSantis et al., 2019). A primary limitation of this existing work, however, is the exclusive use of self-report measures to measure physical functioning. Although valuable, self-report measures are susceptible to bias and are weakly to moderately correlated with performance-based measures of physical functioning, suggesting that self-report and performance-based measures assess distinct aspects of physical functioning (Cress et al., 1995; Guralnik et al., 1995; Hoeymans et al., 1996; Louie & Ward, 2010; Reuben & Siu, 1990). Additionally, performance-based measures of physical functioning have added value beyond self-report measures when predicting outcomes such as mortality, particularly among women (Eekhoff et al., 2019).

The present analysis extends the successful aging literature by examining if multidimensional sleep health is associated with objective, performance-based measures of physical functioning in a community-based sample of older adults. More specifically, we examined associations of multidimensional sleep health with measures of gait speed, grip strength, and lower extremity strength in adults 65 years and older who participated in Midlife in the United States (MIDUS) 2 and MIDUS Refresher studies. Prior work has shown that individual sleep parameters are significantly related to performance-based measures of functioning (e.g., Dam et al., 2008; Goldman et al., 2007), and that multidimensional sleep health is associated with self-report measures of physical functioning (DeSantis et al., 2019). Based on observations in published studies, we hypothesized that better multidimensional sleep health would be associated with three performance-based measures of physical functioning: faster gait speed, stronger lower extremity strength, and stronger grip strength.

Methods

Participants and Procedures

We conducted a secondary analysis of publicly available data from the Midlife in the United States (MIDUS) 2 and MIDUS Refresher studies. MIDUS is a national, longitudinal study of health and well-being in US adults. MIDUS 2 is a longitudinal follow-up (2004–2009) of MIDUS 1 (1995–1997). The MIDUS Refresher study (2011–2014) was designed to replenish the original sample of MIDUS 1 participants and parallels prior MIDUS studies in methodology. The MIDUS 2 and MIDUS Refresher Biomarker projects with concurrent actigraphy were conducted only at the University of Wisconsin site. Therefore, we included only participants from the University of Wisconsin site who were 65 years or older ($N = 158$).

The sampling procedures, protocol, and measures for MIDUS Biomarker projects are described in detail elsewhere (Dienberg Love et al., 2010). MIDUS studies were approved by institutional review boards at the participating sites and written informed consent was obtained from all study participants. Participants in the Biomarker projects completed clinic-based protocols over the course of a 24-hour stay at a General Clinical Research Center. Clinic-based protocols included completion of a medical history interview, self-administered questionnaires, and a physical examination. Physical examinations involved assessment of vital signs, waist and hip measurements, and functional assessments including grip strength, 50-foot timed walk, and chair stand tasks. Following completion of the 2-day clinic protocol, interested and consenting participants completed a 7-day actigraphy protocol. For the actigraphy protocol, participants wore a wrist actigraph continuously for 7 days and concurrently maintained paper daily sleep diaries. All diaries were pre-labeled with completion dates and all studies began on a Tuesday at 07.00 hours and ended at the same time the following Tuesday. Materials were returned by mail to the study site at the conclusion of the data collection period.

Study Measures

Multidimensional sleep health. Multidimensional sleep health domains included regularity of sleep timing, sleep quality, daytime alertness, sleep timing, sleep efficiency, and sleep duration. Regularity of sleep timing, sleep timing, sleep efficiency, and sleep duration values were derived from actigraphy. Actiwatches (Models 64 and 2; Philips Corporation, Andover, MA) were set to collect activity data in 30-second epochs. Actiware software (versions 5 or 6) was used for analysis. The rest interval was determined using primarily diary responses. In the event that diary responses were unavailable, event markers, and adjacent data were used to define the rest interval. Actiware software calculated summary statistics using a wake activity threshold of 40. Sleep timing was defined as the mean sleep midpoint across the week, and regularity of sleep timing was defined as the standard deviation of the sleep midpoint. Sleep efficiency (percentage) was defined as total time spent asleep divided by total time in bed, multiplied by 100. Sleep duration was total time spent asleep (minutes). Average sleep quality and alertness scores were derived from daily sleep diaries. Participants completed a morning section in which they reported on the previous night's sleep, and an evening section in which they reported on the day's activities. Sleep quality was assessed in the morning diary with the prompt, "Overall quality of your sleep last night" (1 = *Very good*, 5 = *Very poor*). Alertness was

Table 1. Sleep Health Domain Definitions and Frequencies.

Sleep health domain	Assessment method	Definition[a]	"Good" sleep health, % (*n*)	"Poor" sleep health, % (*n*)
Regularity	Actigraphy	Good: Sleep midpoint standard deviation <65 minutes Poor: Midpoint standard deviation ≥65 minutes	88.0 (139)	12.0 (19)
Quality	Daily sleep diary	Good: Average <2.8 Poor: Average ≥2.8	73.4 (116)	26.6 (42)
Alertness	Daily sleep diary	Good: Average <2.2 Poor: Average ≥2.2	71.5 (113)	28.5 (45)
Timing	Actigraphy	Good: Sleep midpoint average between 2:24 am and 3:30 am Poor: Sleep midpoint average earlier than 2:24 am or later than 3:30 am	46.8 (74)	53.2 (84)
Efficiency	Actigraphy	Good: >83% Poor: ≤83%	48.7 (77)	51.3 (81)
Duration	Actigraphy	Good: 320 minutes to 426 minutes Poor: <320 minutes or >426 minutes	57.0 (90)	43.0 (68)

Note. [a]Definitions reflect empirically-derived cutoffs set forth by Brindle et al. (2019).

assessed in the evening diary with the question, "How alert were you today?" (1 = *Most alert*, 5 = *Not at all alert*). Diary data was blind double entered to verify accuracy.

Brindle et al. (2019) used receiver operating characteristic (ROC) curves to identify empirically-derived cutoffs for "good" and "poor" sleep in each of the six sleep health domains with data from MIDUS 2; these cutoff values were relatively stable across differing outcomes (e.g., total cardiometabolic morbidity, hypertension, diabetes, depression) and are similar to threshold values reported in the published literature. We used these cutoff values to create dichotomous scores (0 = *Poor*, 1 = *Good*) for each sleep health domain (Table 1). We then summed scores across sleep health domains to yield a composite multidimensional sleep health score (range 0–6), with higher scores indicating better sleep health. This increasing scale (higher scores indicative of better sleep health) is consistent with prior work involving calculation of a multidimensional sleep health variable (e.g., Becker et al., 2018; Brindle et al., 2019).

Physical functioning. MIDUS functional assessments were administered as described in Harada et al. (1999) and Reuben and Siu (1990). Gait speed was assessed with a standardized 50-foot timed walk procedure. Participants were instructed to walk at their usual speed to a 25-foot turn around point and back to the starting point. Timing began on the instruction to "go" and concluded once the participant's foot crossed the starting point on their return. Participants completed two trials and completion time (in seconds) was recorded for each trial. We calculated gait speed scores (meters per second) by dividing 15.24 m by the trial time in seconds. We then averaged gait speed scores across the two trials to obtain an average gait speed. Higher scores (speed in meters per second) reflect faster gait.

Lower extremity strength was assessed with a standardized five-repetition chair stand task. Participants were instructed to first assume a seated position with arms crossed over their chest and then stand and sit five times as quickly and safely as possible. Timing began on the instruction to "go" and concluded once the subject became fully erect with a cessation of body movement. Extremity strength was measured as seconds to complete the task. Higher scores (in seconds) reflect worse lower extremity strength.

Grip strength in kilogram (Kg) force was assessed by dynamometer. Three grip strength measurements were taken in each hand and participants indicated their dominant hand. For the current analysis, we averaged scores for those who had three trials in the dominant hand. If no dominant hand was identified, we compared data from the left and right hands and used the data from the hand with stronger average grip strength. Higher scores reflect stronger grip strength.

Covariates. Age, sex, race (white, non-white), body mass index (BMI; Kg/m^2), depressive symptoms, and comorbid symptoms/conditions were included as covariates in statistical models based on prior literature linking these variables to physical functioning (e.g., Riebe 2009; Seeman et al., 1994). Depressive symptoms were assessed with the General Distress-Depressive Symptoms scale of the Mood and Anxiety Symptom Questionnaire (MASQ; Clark & Watson, 1991; Watson, Clark, et al., 1995; Watson, Weber, et al., 1995). The MASQ is a validated measure of symptoms of depression and anxiety in which respondents rate past-week symptoms on a 5-point Likert-type scale (1 = *Not at all*, 5 = *Extremely*). General Distress-Depressive Symptoms scores were calculated by summing scale items, excluding the item "felt sluggish or tired" due to conceptual similarity to the multidimensional sleep health variable. Comorbid symptoms/conditions were assessed using a

Table 2. Participant Demographics and Characteristics ($N=158$).

Variable	n	%
Female sex	82	51.9
Race		
White or non-Hispanic	132	83.5
Non-white	26	16.5
Composite multidimensional sleep health score		
0	2	1.3
1	7	4.4
2	18	11.4
3	27	17.1
4	50	31.6
5	39	24.7
6	15	9.5
Variable	**Sample range**	***M (SD)***
Age	65–85	71.8 (5.4)
Number of symptoms/conditions	0–15	4.9 (3.2)
BMI	20.4–51.6	30.5 (5.8)
Depressive symptoms	11–39	15.3 (4.9)

symptom and condition checklist. Participants indicated yes or no whether they had 23 symptoms and conditions such as heart disease, diabetes, cancer, and arthritis; participants could also identify "other" conditions/symptoms not already specified. Symptoms and conditions were summed to create a symptoms/conditions variable that was treated continuously in statistical models.

Statistical Analysis

Analyses were conducted using SPSS Version 26.0 (IBM Corp, 2019). Descriptive statistics were calculated for covariates, sleep health, and physical functioning variables. In preliminary analyses, we assessed associations of the dichotomous sleep health domains using Phi correlations and the associations of multidimensional sleep health scores and physical functioning variables with Pearson correlations; *p*-values smaller than .05 were considered statistically significant.

For our primary analyses, we examined the association of multidimensional sleep health with gait speed, lower extremity strength, and grip strength using three separate hierarchical regression models; listwise deletion was used for missing data. In step 1 of each model, age, sex, race, BMI, symptoms/conditions, and depressive symptoms were entered, based on known associations with physical functioning and in order to determine the amount of variance (R^2) explained without sleep health. In step 2, multidimensional sleep health was entered. We examined the change in R^2 from step 1 to step 2 (ΔR^2) to determine the amount of unique variance explained by the inclusion of the multidimensional sleep health variable. We also report and compare the adjusted R^2 (R^2_{adj}) and change in adjusted R^2 (ΔR^2_{adj}) for all models. R^2_{adj} includes a penalty for the number of predictors included in the model; thus, it increases only if ΔR^2 is greater than what one would expect from chance alone. In these primary analyses, *p*-values less than .017 were considered significant to account for multiple comparison; this threshold was determined by dividing .05 by the number of regression models (three).

In addition to our primary analyses, we ran exploratory follow-up analyses that parallel analytic approaches taken in existing studies and contribute to our understanding of the value of examining sleep health as a multidimensional construct. Consistent with a prior study examining multidimensional sleep health and self-reported physical functioning (DeSantis et al., 2019) we examined the associations of each sleep health domain with physical functioning variables, while holding the other sleep health variables constant. To do this, we ran three multiple regression models (one for each physical functioning outcome) in which covariates were entered in step 1 and dichotomous sleep health domains were entered simultaneously in step 2. In a second set of follow-up regression analyses, covariates were entered in step 1 and dichotomous sleep health domains were entered individually in step 2. In this approach, individual sleep health domains were assessed without accounting for, or holding constant, other sleep health domains. Because these follow-up analyses were exploratory in nature, we did not adjust for multiple comparisons; *p*-values $<.05$ were considered statistically significant (Cao & Zhang, 2014).

Results

Characteristics and associations of sleep health and physical functioning are presented in Tables 1 and 3, as well as Supplemental Tables 1 and 2. Sociodemographic characteristics are presented in Table 2. The mean age of participants was 71.8 years ($SD=5.4$ years); half (52%) were women and most (84%) were White. Most of the sample (65.8%) had good sleep health on at least four of the six sleep health domains, suggesting a relatively high level of sleep health overall. Sleep domains were at most moderately correlated, suggesting they represent relatively independent aspects of sleep (Supplemental Table 1).

Multidimensional sleep health and physical functioning outcomes. The overall model of covariates and multidimensional sleep health predicting gait speed was significant, $F(7, 140)=20.59$, $p<.001$ (Table 4). Covariates accounted for 47% of variance (R^2) in gait speed. The multidimensional sleep health composite variable entered in step 2 accounted for an additional 4% of variance in gait speed, $\Delta R^2=.04$; R^2_{adj} increased from step 1 to step 2. Higher levels of sleep health were significantly associated with faster gait speed, $B=0.03$, $p=.001$. Specifically, each additional good sleep health domain is associated with a .03 meter per second faster gait speed.

Table 3. Descriptive Statistics and Pearson Correlations among Sleep Health and Physical Functioning Variables.

Variable	Range	*M*	*SD*	1.	2.	3.	4.
1. Sleep health	0–6	3.85	1.35	—	—	—	—
2. Gait speed (m/sec)	0.27–1.45	0.91	0.21	0.25*	—	—	—
3. Grip strength (Kg/force)	9.33–70.00	30.46	10.89	0.03	0.32*	—	—
4. Chair stand time (seconds)	4–27	11.71	4.66	−0.04	−0.54*	−0.10	—

*$p < .001$, one-tailed.

Table 4. Hierarchical Multiple Regression of Gait Speed, Lower Extremity Strength, and Grip Strength on Multidimensional Sleep Health and Covariates ($n = 148$).

Predictor	R^2	ΔR^2	R^2_{adj}	ΔR^2_{adj}	β	*B* [95% CI]	SE *B*	*B p*-value
Gait speed								
Step 1	0.47	0.47**	0.44	0.44				
Step 2	0.51	0.04*	0.48	0.04				
Constant						2.19 [1.78, 2.60]	0.21	<.001
Sleep health					.21	0.03 [0.01, 0.05]	0.01	.001
Lower extremity strength								
Step 1	0.26	0.26**	0.22	0.22				
Step 2	0.26	<0.001	0.21	−0.01				
Constant						−17.3 [−30.1, −4.55]	6.45	.01
Sleep health					−.02	−0.06 [−0.60, 0.48]	0.27	.83
Grip strength								
Step 1	0.53	0.53**	0.51	0.51				
Step 2	0.53	0.001	0.51	−0.002				
Constant						90.0 [68.99, 110.93]	10.6	<.001
Sleep health					.04	0.32 [−0.61, 1.25]	0.47	.50

Note. Results are reported from three separate regression models. In each model, covariates (age, sex, race, symptoms/conditions, depressive symptoms, BMI) were entered in Step 1 and the multidimensional sleep health variable was added in Step 2. ΔR^2 and ΔR^2_{adj} reflect changes from step 1 to step 2. β = standardized regression coefficients; *B* = unstandardized regression coefficients.
*$p < .05$. **$p < .001$.

The overall model of covariates and multidimensional sleep health predicting lower extremity strength was significant, $F(7, 126) = 6.19$, $p \leq .001$. Covariates accounted for 26% of variance (R^2) in lower extremity strength. Multidimensional sleep health did not account for additional explained variance in lower extremity strength beyond covariates, $\Delta R^2 < .001$, $p = .83$, and R^2_{adj} decreased from step 1 to step 2. The association of multidimensional sleep health with lower extremity strength was not significant, $B = -.06$, $p = .83$.

The overall model of covariates and multidimensional sleep health predicting grip strength was significant, $F(7, 144) = 23.34$, $p < .001$. Covariates accounted for 53% of variance (R^2) in grip strength. Multidimensional sleep health did not account for added variance beyond covariates, $\Delta R^2 = .001$, $p = .50$ and R^2_{adj} did not change from step 1 to step 2. The association of multidimensional sleep health with grip strength was not significant, $B = .32$, $p = .50$.

Follow-up analyses of individual sleep health domains and physical functioning outcomes. Model information for follow-up analyses of sleep health domains with physical functioning outcomes is included in Supplemental Tables 3 to 8. For gait speed, the addition of concurrently entered sleep health domains significantly improved the model fit. The R^2_{adj} increased from step 1 to step 2 and the magnitude of change was consistent with that in the model examining the association of multidimensional sleep health with gait speed. Only sleep efficiency was significantly associated with gait speed; having good sleep efficiency (>83%) was associated with faster gait speed. In gait speed models where sleep health domains were entered individually, the addition of sleep efficiency and sleep duration domains improved respective model fit; good sleep efficiency (>83%) and good sleep duration (320–426 minutes) were each significantly associated with faster gait speed. In each model, the R^2_{adj} increased from step 1 to step 2 but the magnitude of change was lower than in models where sleep health was examined as a composite variable and where sleep health domains were entered concurrently. Models assessing associations of sleep health domains (entered concurrently and individually) with lower extremity strength and grip strength were not significant.

Discussion

We examined multidimensional sleep health as it relates to objective measures of physical functioning in community-dwelling older adults. Multidimensional sleep health was significantly associated with gait speed but not with measures of lower extremity strength or grip strength. Follow-up analyses of individual sleep health domains suggested sleep efficiency and sleep duration domains are relevant to gait speed. Gait speed is considered a marker of physiologic reserve and functional capacity (Middleton et al., 2015; Studenski et al., 2011; van Kan et al., 2009). Findings from this study suggest multidimensional sleep health may be a determinant of physical functioning in older adults.

In this sample, much of the variance in gait speed was explained by demographic (e.g., age, sex, race) and clinical (e.g., number of symptoms/conditions, BMI) characteristics. As such, it is noteworthy that multidimensional sleep health accounted for unique variance in gait speed above and beyond these important demographic and clinical characteristics. Our findings further identified that each additional good sleep health domain was associated with a .03 meter per second faster gait speed. Among older adults, estimates of clinically meaningful change in gait speed range from .05 meters per second for small meaningful change to .10 meters per second for substantial change (Perera et al., 2006). Relatedly, a .10 meter per second improvement in gait speed over 1 year has been linked to survival in older adults (Hardy et al., 2007). Thus, for individuals who can improve their sleep health in >1 domain, the magnitude of the multidimensional sleep health–gait speed association may be clinically relevant. Considered together, the significance and magnitude of the association of multidimensional sleep health with gait speed suggest the potential clinical utility of assessing multidimensional sleep health in those experiencing limited physical functioning and, conversely, assessing physical functioning in those with poor sleep multidimensional sleep health.

Follow-up analyses of individual sleep health domains and physical functioning variables identified that, holding other sleep health domains constant, good sleep efficiency (>83%) was significantly associated with faster gait speed; the variance in gait speed explained by sleep efficiency was consistent with that explained by multidimensional sleep health in primary analyses. When each sleep health domain was entered individually, not accounting for other sleep health domains, good sleep efficiency (>83%) and good sleep duration (320–426 minutes) were each associated with faster gait speed; the variance in gait speed explained individually by sleep efficiency and duration was less than that of the models including the multidimensional sleep health variable and all sleep health domains. These findings corroborate work linking sleep efficiency and duration to gait speed in older adults (Dam et al., 2008; Goldman et al., 2007). Importantly, models that accounted in some way for the multidimensionality of sleep (i.e., multidimensional sleep health variable, concurrent analysis of multiple sleep health domains) were more explanatory than those that considered sleep health domains in isolation. Specifically, the addition of the multidimensional sleep health variable and the multiple sleep health domains simultaneously improved the R^2 more than simply adding sleep efficiency or sleep timing. Thus, these findings also reinforce the need to consider multiple aspects of sleep. Other studies have similarly identified the utility of concurrently examining multiple aspects of sleep when examining associations with physical functioning. For instance, in a study of sleep and physical functional decline in older adults, a combined self-report measure of sleep duration *and* time in bed revealed risk for decline in physical functioning and mobility beyond the risk related to sleep duration alone (Stenholm et al., 2011).

The association of multidimensional sleep health with gait speed is likely multifactorial. Multiple organ systems and physiological subsystems contribute to one's ability to walk (Ferrucci et al., 2000; Studenski et al., 2011). Ferrucci et al. (2000) classify factors that influence walking ability into the following physiological subsystems: central nervous system, peripheral nervous system, perceptual system, muscles, bones/joints, and energy production and delivery. As a fundamental biobehavioral process, sleep is relevant to most if not all of these subsystems either directly or indirectly, potentially through psychological (e.g., depression; Alvaro et al., 2013; Demakakos et al., 2013) or behavioral pathways (e.g., physical activity; Fiser et al., 2010; Holfeld & Ruthig, 2014). The association of multidimensional sleep health and gait speed is also likely bidirectional. Gait speed is referred to as a functional vital sign and is conceptualized as a general indicator of one's health status. Poorer health status is a consistent risk factor for sleep difficulties (e.g., Smagula et al., 2016). As such, it is plausible that gait speed is predictive of sleep health.

In this sample of older adults, neither multidimensional sleep health nor individual sleep health domains were significantly associated with lower extremity strength or grip strength. Total sleep time, sleep latency, wake after sleep onset, and sleep efficiency have each been associated with lower extremity strength and/or grip strength in some studies of older adults, but not others (Dam et al., 2008; Goldman et al., 2007). Differences in the analytic approaches, sample sizes, and the operationalization of sleep and physical functioning variables may contribute to differences between the current study and existing literature. Of note, this sample demonstrated rather good sleep health. It is possible that chair stand and grip strength tasks are more resistant to the negative effects of poor sleep and only manifest at poorer levels of sleep health that were not sufficiently represented in the current sample. More generally, the finding that multidimensional sleep health is differentially associated with unique performance-based measures of physical functioning reinforces the notion that these measures reflect different physiologic capacities and aspects of health and functioning.

Findings from this study should be interpreted with consideration of several limitations. First, causal conclusions regarding the associations of sleep health and physical functioning cannot be drawn due to the cross-sectional study design. As previously discussed, the association between sleep health and physical functioning is likely multifactorial and bidirectional. Future experimental and longitudinal studies would provide insight into the causal and temporal associations of these constructs. A second limitation relates to generalizability. The study sample was relatively small and reflects less racial diversity than would be expected in the general population of older adults in the US (Administration on Aging, 2018). Additionally, the sample demonstrated relatively good sleep health overall, potentially limiting our ability to detect significant associations across measures of physical functioning. Associations of multidimensional sleep health and objective measures of functioning should be examined in larger samples, ideally diverse in sociodemographic and clinical characteristics, to determine the extent to which these findings are generalizable. Finally, although validation work for self-report and actigraphy multidimensional sleep health measures is burgeoning (Benítez et al., 2020; Brindle et al., 2019; Wallace et al., 2021), additional measurement development and validation work is needed to further optimize the assessment of multidimensional sleep health.

Conclusion

In sum, better multidimensional sleep health was significantly associated with faster gait speed. Future studies should use both subjective and objective methods that support the assessment of causal and mechanistic links between sleep health and gait speed to better understand how these phenomena relate. Intervention studies could help to determine whether multidimensional sleep health is modifiable, and if so, whether improvements in sleep health enhance gait speed and promote functional capacity and, ultimately, successful aging in older adults.

Acknowledgments

The views expressed in this article are those of the authors and do not necessarily represent the position or policy of the Department of Veterans Affairs or the United States Government.

IRB Information

MIDUS studies were approved by institutional review boards at the participating sites. The secondary analysis of MIDUS data was determined by the VAPHS IRB to be not human subjects research (PRO3221).

Support

This material is the result of work supported with resources and the use of facilities at the Veterans Integrated Service Network 4 Mental Illness Research, Education, and Clinical Center at the VA Pittsburgh Healthcare System, Pittsburgh, Pennsylvania. Dr. Tighe is supported by Career Development/Capacity Building Award Number IK2 RX003393 from the United States (U.S.) Department of Veterans Affairs Rehabilitation R&D (Rehab RD) Service. Dr. Wallace is funded by NIA grant R01 AG056331. Dr. Stahl is supported by NIMH grant R01 MH118270. Dr. Bramoweth is supported by the Department of Veterans Affairs, Health Services Research and Development Service (CDA 13-260/HX001548 and IIR 19-340/HX003096). Dr. Forman is funded by R01AG060499, R01AG058883, U19AG065188, and P30AG024827. Dr. Buysse is funded by UH3 HL125103, R01 AG047139, P50 DA046346.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: (Past 5 years) Dr. Bramoweth and Dr. Wallace have served as paid consultants to Noctem LLC. Dr. Buysse has served as a paid consultant to Bayer, BeHealth Solutions, Cereve/Ebb Therapeutics, Emmi Solutions, National Cancer Institute, Pear Therapeutics, Philips Respironics, Sleep Number, and Weight Watchers International. He has served as a paid consultant for professional educational programs developed by the American Academy of Physician Assistants and CME Institute, and received payment for a professional education program sponsored by Eisai (content developed exclusively by Dr. Buysse). 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.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Publicly available data from the MIDUS study was used for this research. Since 1995 the MIDUS study has been funded by the following: John D. and Catherine T. MacArthur Foundation Research Network, National Institute on Aging (P01-AG020166), National institute on Aging (U19-AG051426). Biomarker data collection was further supported by the NIH National Center for Advancing Translational Sciences (NCATS) Clinical and Translational Science Award

(CTSA) program as follows: UL1TR001409 (Georgetown), UL1TR001881 (UCLA), 1UL1RR025011 (UW).

ORCID iDs

Caitlan A. Tighe https://orcid.org/0000-0003-0592-4213
Sarah T. Stahl https://orcid.org/0000-0001-5712-1266

Supplemental Material

Supplemental material for this article is available online.

References

Administration on Aging. (2018). *2018 Profile of older Americans. Administration on Aging (AoA), Administration for Community Living*. U.S. Department of Health and Human Services.

Alvaro, P. K., Roberts, R. M., & Harris, J. K. (2013). A systematic review assessing bidirectionality between sleep disturbances, anxiety, and depression. *Sleep*, *36*(7), 1059–1068.

Becker, N. B., Martins, R. I. S., de Neves Jesus, S., Chiodelli, R., & Rieber, M. S. (2018). Sleep health assessment: A scale validation. *Psychiatry Research*, *259*, 51–55.

Benítez, I., Roure, N., Pinilla, L., Sapiña-Beltran, E., Buysse, D. J., Barbé, F., & de Batlle, J. (2020). Validation of the satisfaction, alertness, timing, efficiency and Duration (SATED) questionnaire for sleep health measurement. *Annals of the American Thoracic Society*, *17*(3), 338–343.

Brindle, R. C., Yu, L., Buysse, D. J., & Hall, M. H. (2019). Empirical derivation of cutoff values for the sleep health metric and its relationship to cardiometabolic morbidity: Results from the Midlife in the United States (MIDUS) study. *Sleep*, *42*(9), zsz116.

Buysse, D. J. (2014). Sleep health: Can we define it? Does it matter? *Sleep*, *37*(1), 9–17.

Cao, J., & Zhang, S. (2014). Multiple comparison procedures. *JAMA*, *312*(5), 543–544.

Clark, L. A., & Watson, D. (1991). Tripartite model of anxiety and depression: Psychometric evidence and taxonomic implications. *Journal of Abnormal Psychology*, *100*(3), 316.

Cress, M. E., Schechtman, K. B., Mulrow, C. D., Fiatarone, M. A., Gerety, M. B., & Buchner, D. M. (1995). Relationship between physical performance and self-perceived physical function. *Journal of the American Geriatrics Society*, *43*(2), 93–101.

Dam, T. T. L., Ewing, S., Ancoli-Israel, S., Ensrud, K., Redline, S., Stone, K., & Osteoporotic Fractures in Men Research Group. (2008). Association between sleep and physical function in older men: The osteoporotic fractures in men sleep study. *Journal of the American Geriatrics Society*, *56*(9), 1665–1673.

Demakakos, P., Cooper, R., Hamer, M., de Oliveira, C., Hardy, R., & Breeze, E. (2013). The bidirectional association between depressive symptoms and gait speed: Evidence from the English Longitudinal Study of Ageing (ELSA). *PLoS One*, *8*(7), e68632.

DeSantis, A. S., Dubowitz, T., Ghosh-Dastidar, B., Hunter, G. P., Buman, M., Buysse, D. J., Hale, L., & Troxel, W. M. (2019). A preliminary study of a composite sleep health score: Associations with psychological distress, body mass index, and physical functioning in a low-income African American community. *Sleep Health*, *5*(5), 514–520.

Dienberg Love, G., Seeman, T. E., Weinstein, M., & Ryff, C. D. (2010). Bioindicators in the MIDUS national study: Protocol, measures, sample, and comparative context. *Journal of Aging and Health*, *22*(8), 1059–1080.

Eekhoff, E. M., Van Schoor, N. M., Biedermann, J. S., Oosterwerff, M. M., De Jongh, R., Bravenboer, N., van Poppel, M. N. M., & Deeg, D. J. (2019). Relative importance of four functional measures as predictors of 15-year mortality in the older Dutch population. *BMC Geriatrics*, *19*(1), 1-10.

Ferrucci, L., Bandinelli, S., Benvenuti, E., Di Iorio, A., Macchi, C., Harris, T. B., & Guralnik, J. M. (2000). Subsystems contributing to the decline in ability to walk: Bridging the gap between epidemiology and geriatric practice in the InCHIANTI study. *Journal of the American Geriatrics Society*, *48*(12), 1618–1625.

Fiser, W. M., Hays, N. P., Rogers, S. C., Kajkenova, O., Williams, A. E., Evans, C. M., & Evans, W. J. (2010). Energetics of walking in elderly people: Factors related to gait speed. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, *65*(12), 1332–1337.

Goldman, S. E., Stone, K. L., Ancoli-Israel, S., Blackwell, T., Ewing, S. K., Boudreau, R., Cauley, J. A., Hall, M., Matthews, K. A., & Newman, A. B. (2007). Poor sleep is associated with poorer physical performance and greater functional limitations in older women. *Sleep*, *30*(10), 1317–1324.

Groessl, E. J., Kaplan, R. M., Rejeski, W. J., Katula, J. A., King, A. C., Frierson, G., Glynn, N. W., Hsu, F. C., Walkup, M., & Pahor, M. (2007). Health-related quality of life in older adults at risk for disability. *American Journal of Preventive Medicine*, *33*(3), 214–218.

Guralnik, J. M., Ferrucci, L., Simonsick, E. M., Salive, M. E., & Wallace, R. B. (1995). Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. *New England Journal of Medicine*, *332*(9), 556–562.

Harada, N. D., Chiu, V., & Stewart, A. L. (1999). Mobility-related function in older adults: Assessment with a 6-minute walk test. *Archives of Physical Medicine and Rehabilitation*, *80*(7), 837–841.

Hardy, S. E., Perera, S., Roumani, Y. F., Chandler, J. M., & Studenski, S. A. (2007). Improvement in usual gait speed predicts better survival in older adults. *Journal of the American Geriatrics Society*, *55*(11), 1727–1734.

Hoeymans, N., Feskens, E. J., van den Bos, G. A., & Kromhout, D. (1996). Measuring functional status: Cross-sectional and longitudinal associations between performance and self-report (Zutphen Elderly Study 1990–1993). *Journal of Clinical Epidemiology*, *49*(10), 1103–1110.

Holfeld, B., & Ruthig, J. C. (2014). A longitudinal examination of sleep quality and physical activity in older adults. *Journal of Applied Gerontology*, *33*(7), 791–807.

IBM Corp. (2019). *IBM SPSS statistics for windows* (Version 26.0). IBM Corp.

Louie, G. H., & Ward, M. M. (2010). Association of measured physical performance and demographic and health characteristics with self-reported physical function: Implications for the interpretation of self-reported limitations. *Health and Quality of Life Outcomes*, *8*(1), 84.

Middleton, A., Fritz, S. L., & Lusardi, M. (2015). Walking speed: The functional vital sign. *Journal of Aging and Physical Activity*, *23*(2), 314–322.

Perera, S., Mody, S. H., Woodman, R. C., & Studenski, S. A. (2006). Meaningful change and responsiveness in common physical performance measures in older adults. *Journal of the American Geriatrics Society*, *54*(5), 743–749.

Reuben, D. B., & Siu, A. L. (1990). An objective measure of physical function of elderly outpatients: The physical performance test. *Journal of the American Geriatrics Society*, *38*(10), 1105–1112.

Riebe, D., Blissmer, B. J., Greaney, M. L., Ewing Garber, C., Lees, F. D., & Clark, P. G. (2009). The relationship between obesity, physical activity, and physical function in older adults. *Journal of Aging and Health*, *21*(8), 1159–1178.

Rowe, J. W., & Kahn, R. L. (1997). Successful aging. *The Gerontologist*, *37*(4), 433–440.

Seeman, T. E., Charpentier, P. A., Berkman, L. F., Tinetti, M. E., Guralnik, J. M., Albert, M., Blazer, D., & Rowe, J. W. (1994). Predicting changes in physical performance in a high-functioning elderly cohort: MacArthur studies of successful aging. *Journal of Gerontology*, *49*(3), M97–M108.

Smagula, S. F., Stone, K. L., Fabio, A., & Cauley, J. A. (2016). Risk factors for sleep disturbances in older adults: Evidence from prospective studies. *Sleep Medicine Reviews*, *25*, 21–30.

Stenholm, S., Kronholm, E., Bandinelli, S., Guralnik, J. M., & Ferrucci, L. (2011). Self-reported sleep duration and time in bed as predictors of physical function decline: Results from the InCHIANTI study. *Sleep*, *34*(11), 1583–1593.

Studenski, S., Perera, S., Patel, K., Rosano, C., Faulkner, K., Inzitari, M., Brach, J., Chandler, J., Cawthon, P., Connor, E. B., & Nevitt, M. (2011). Gait speed and survival in older adults. *JAMA*, *305*(1), 50–58.

Trombetti, A., Reid, K. F., Hars, M., Herrmann, F. R., Pasha, E., Phillips, E. M., & Fielding, R. A. (2016). Age-associated declines in muscle mass, strength, power, and physical performance: Impact on fear of falling and quality of life. *Osteoporosis International*, *27*(2), 463–471.

van Kan, G. A., Rolland, Y., Andrieu, S., Bauer, J., Beauchet, O., Bonnefoy, M., Cesari, M., Donini, L. M., Gillette Guyonnet, S., Inzitari, M., Nourhashemi, F., Onder, G., Ritz, P., Salva, A., Visser, M., & Vellas, B. (2009). Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people an International Academy on Nutrition and Aging (IANA) Task Force. *The Journal of Nutrition, Health & Aging*, *13*(10), 881–889.

Wallace, M. L., Buysse, D. J., Redline, S., Stone, K. L., Ensrud, K., Leng, Y., Ancoli-Israel, S., & Hall, M. H. (2019). Multidimensional sleep and mortality in older adults: A machine-learning comparison with other risk factors. *The Journals of Gerontology: Series A*, *74*(12), 1903–1909.

Wallace, M. L., Yu, L., Buysse, D. J., Stone, K. L., Redline, S., Smagula, S. F., Stefanick, M. L., Kritz-Silverstein, D., & Hall, M. H. (2021). Multidimensional sleep health domains in older men and women: An actigraphy factor analysis. *Sleep*, *44*(2), 1–11.

Watson, D., Clark, L. A., Weber, K., Assenheimer, J. S., Strauss, M. E., & McCormick, R. A. (1995). Testing a tripartite model: II. Exploring the symptom structure of anxiety and depression in student, adult, and patient samples. *Journal of Abnormal Psychology*, *104*(1), 15.

Watson, D., Weber, K., Assenheimer, J. S., Clark, L. A., Strauss, M. E., & McCormick, R. A. (1995). Testing a tripartite model: I. Evaluating the convergent and discriminant validity of anxiety and depression symptom scales. *Journal of Abnormal Psychology*, *104*(1), 3.