SLEEPJ, 2021, 1–12

doi: 10.1093/sleep/zsab059
Advance Access Publication Date: 11 March 2021
Original Article

ORIGINAL ARTICLE

Associations between longitudinal trajectories of insomnia symptoms and sleep duration with objective physical function in postmenopausal women: the Study of Women's Health Across the Nation

Christopher E. Kline[1,*], Alicia B. Colvin[2], Kelley Pettee Gabriel[3], Carrie A. Karvonen-Gutierrez[4], Jane A. Cauley[2], Martica H. Hall[5,6], Karen A. Matthews[5,6], Kristine M. Ruppert[2], Genevieve S. Neal-Perry[7], Elsa S. Strotmeyer[2] and Barbara Sternfeld[8]

[1]Department of Health and Human Development, University of Pittsburgh, Pittsburgh, USA, [2]Department of Epidemiology, University of Pittsburgh, Pittsburgh, PA, USA, [3]Department of Epidemiology, University of Alabama at Birmingham, Birmingham, AL, USA, [4]Department of Epidemiology, University of Michigan, Ann Arbor, MI, USA, [5]Department of Psychiatry, University of Pittsburgh, Pittsburgh, PA, USA, [6]Department of Psychology, University of Pittsburgh, Pittsburgh, PA, USA, [7]Department of Obstetrics and Gynecology, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA and [8]Division of Research, Kaiser Permanente Northern California, Oakland, CA, USA

*Corresponding author: Christopher E. Kline, Department of Health and Human Development, University of Pittsburgh, 32 Oak Hill Court, Room 227, Pittsburgh, PA 15261, USA. Email: chriskline@pitt.edu

Abstract

Study Objectives: Examine the association between trajectories of self-reported insomnia symptoms and sleep duration over 13 years with objective physical function.

Methods: We utilized data from 1,627 Study of Women's Health Across the Nation participants, aged 61.9 ± 2.7 years at the end of the 13-year follow-up. Latent class growth models identified trajectories of insomnia symptoms (trouble falling asleep, frequent night-time awakenings, and/or early morning awakening) and sleep duration over 13 years. Physical function tests were performed at the end of the 13-year period: 40-ft walk, 4-m walk, repeated chair stand, grip strength, and balance. Multivariable regression analyses examined each physical function measure according to the insomnia symptom or sleep duration trajectory group.

Results: Five insomnia symptom trajectories and two sleep duration trajectories were identified. Women with a consistently high likelihood of insomnia symptoms and women with a decreased likelihood of insomnia symptoms (i.e. improving) had slower gait speed (3.5% slower 40-ft walk [consistently high], 3.7% slower 4-m walk [improving]; each $p \leq .05$) than those with a consistently low likelihood of insomnia symptoms. In contrast, women with a steep increase in the likelihood of insomnia symptoms over time and women with persistent insufficient sleep duration had lower odds of having a balance problem (odds ratio [OR] = 0.36 and OR = 0.61, respectively; each $p < .02$) compared to those with a consistently low likelihood of insomnia symptoms and those with persistent sufficient sleep duration, respectively.

Conclusion: These results suggest that women's sleep during midlife has important implications for maintaining physical function during the transition into older adulthood.

Statement of Significance

Poor sleep has been associated with poor physical function, though predominantly among older adults. We identified trajectories of insomnia symptoms and sleep duration over 13 years during midlife in 1,627 women and examined their association with objective measures of physical function assessed at the end of the 13-year period. Trajectories characterized by either a consistently high likelihood or a high but decreasing likelihood of insomnia symptoms were both associated with slower gait speed; counterintuitively, trajectories characterized by either a severe worsening of insomnia symptoms or persistent insufficient sleep duration were both associated with lower odds of balance problems. These results highlight the potential importance of sleep during midlife as a contributor to physical function in the transition to older adulthood.

Key words: sleep duration; insomnia; postmenopausal women; midlife; physical function; gait speed; balance

Submitted: 28 August, 2020; **Revised:** 17 February, 2021

Introduction

Physical function is an important predictor of health and wellbeing, with poor physical performance linked with increased risk of disability and mortality among older adults [1, 2]. Poor physical function is not restricted to older adults, though, as declines in physical function begin during midlife [3]. This may be especially true for women, as increases in fat mass and decreases in physical activity during midlife may predispose women to a more rapid decline in physical function [4–6].

Poor sleep may be an additional risk factor for poor physical function in midlife women [7]. Sleep problems are common among midlife and postmenopausal women [8], the causes of which are likely multifactorial (e.g. physiologic changes, altered behaviors/environments, emergent mental, or physical health problems) [9]. These sleep problems often persist or increase with aging [10]. Among older adults, poor or insufficient sleep has been associated with earlier and/or more severe decline in physical function [11, 12]. However, research involving the association between sleep and objective physical function has, to date, been largely limited to older adults (i.e. ≥65 years) despite a high prevalence of both sleep problems and poor physical function during midlife. Further, while the prevalence of sleep problems increases during midlife, the actual trajectories of midlife sleep problems vary greatly [13, 14]. The impact of different trajectories of sleep during midlife on physical function is unknown.

The purpose of this study was to examine the association between trajectories of self-reported insomnia symptoms and sleep duration over a 13-year span with objective physical function assessed at the end of the midlife period using data from the Study of Women's Health Across the Nation. We hypothesized that persistent or worsening insomnia symptoms over time and insufficient sleep duration would each be associated with worse objective physical function compared to a consistently low likelihood of insomnia symptoms and adequate sleep duration, respectively. A secondary aim was to identify correlates of different trajectories of insomnia symptoms and sleep duration during midlife.

Methods

Study sample

The sample for these analyses was drawn from the Study of Women's Health Across the Nation (SWAN), a longitudinal study of the menopausal transition and its consequences on health and functioning. Details of the sampling and recruiting strategies for SWAN have been previously described [15]. Briefly, 3,302 pre- and early peri-menopausal women ages 42–52 years were recruited for a baseline SWAN examination in 1996–1997. Women were recruited from seven sites across the United States: Boston (MA), Chicago (IL), Detroit area (MI), Los Angeles (CA), Newark (NJ), Oakland (CA), and Pittsburgh (PA). Eligibility criteria for SWAN included reporting a menstrual period and no exogenous hormone use in the three months before recruitment, not currently pregnant or lactating, and identifying one's primary race/ethnicity as Black (Boston, Chicago, Detroit, and Pittsburgh sites), Japanese (Los Angeles site), Hispanic (Newark site), Chinese (Oakland site), or White (all sites). Following the baseline examination in 1996–1997, the cohort continued to be seen for up to 16 exams through 2018. Visit 13 was the first year that physical function was objectively assessed; as a result, these analyses included data up to and including Visit 13. All participants provided written informed consent, and all protocols were approved by the institutional review boards at each of the participating institutions.

Out of the 2,338 participants who completed Visit 13, our analyses focused on postmenopausal women with available sleep and physical function data (n = 1855). Figure 1 summarizes why participants were excluded from analysis; of particular importance, we excluded participants who reported substantial functional limitations at baseline (i.e. SF-36 Physical Component Summary score ≤ 50). Following exclusions, analyses were conducted on 1,627 participants (n = 1,237 for the 40-ft walk). When comparing baseline characteristics between those who were included and excluded from analysis, women who were excluded (n = 228) had a greater body mass index, were less physically active, were less likely to have a college degree or be White race, and were more likely to report significant financial strain, be early perimenopausal, report significant depressive symptoms, endorse multiple medical conditions, and report fair/poor health status.

Sleep assessment

Insomnia symptoms.

At each follow-up visit, participants reported the frequency of three sleep problems over the prior 2 weeks: trouble falling asleep, waking up several times a night, and waking up earlier than planned and unable to fall asleep again. Each of these frequency responses was dichotomized as no/infrequent (≤2 times per week) or yes (≥3 times per week), consistent with nosological criteria for insomnia [16] and prior SWAN publications [13, 14]. Participants whose responses were classified as "yes" for any of these problems (i.e. reporting ≥ 1 sleep problem ≥ 3 times per week) were categorized as having insomnia symptoms at that visit [14, 17].

Sleep duration.

At follow-up visits 3 (occurring between 1999–2001), 4 (2000–2002), 12 (2009–2011), and 13 (2011–2013), participants reported their typical daily sleep duration over the past month. For trajectory analyses, the continuous values of sleep duration were used. Even though both short (<6 h) [11, 18–20] and long (>8 h) [11, 12, 18–23] sleep durations have been linked to poor physical function in older adult samples, separate analyses of short (<6 h) and long (>8 h) sleep duration groups were not performed due to the low prevalence of long sleep duration in the sample (Visit 3: 3.0%, Visit 4: 3.4%, Visit 12: 3.9%, Visit 13: 2.8%).

Physical function assessment

Participants completed five physical function assessments at the Visit 13 exam: 40-ft walk, 4-m walk, repeated chair stands, grip strength, and balance.

40-ft walk

This assessment was performed on a level floor with tape markers indicating a start and stop points located 40 ft apart. Participants were instructed to walk at a comfortable but steady

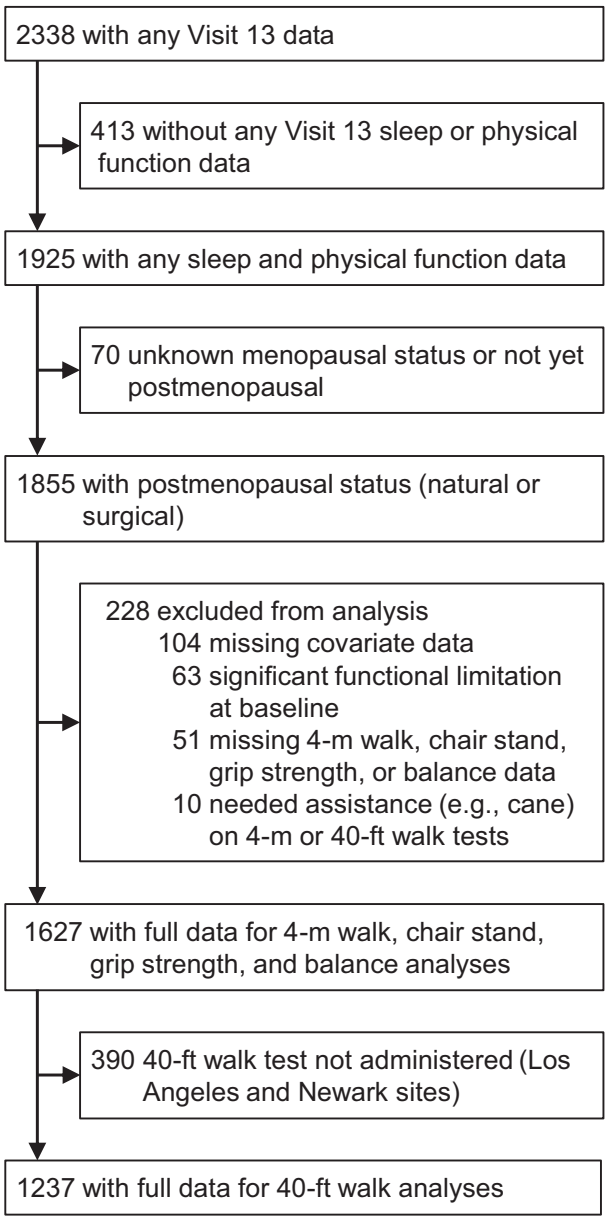

Figure 1. Participant data availability for analysis.

brisk pace until completion; the timing was stopped when both feet crossed the 40-ft mark. The fastest time of two attempts (expressed in metres per second) was used for analysis.

4-m walk

This assessment was performed on a level floor with tape markers indicating start and stop points located 4 m apart. Participants were instructed to walk at their usual speed, and timing was stopped when the first foot completely crossed the 4-m mark. The fastest time of two attempts (expressed in metres per second) was used for analysis.

Repeated chair stands

A chair or bench with its seat height located 18 inches from the ground was placed on a level floor. From a seated position with their arms folded across their chest, participants were asked to rise five consecutive times from the chair. Timing began when the participant visually responded and ended when five sit-stand repetitions were completed. The time (expressed in seconds) to complete the five sit-stand repetitions was used for analysis.

Grip strength

A dynamometer, adjusted for hand size, was used for the dominant hand. Participants were seated with the elbow of the tested arm bent at a 90-degree angle. Participants were instructed to squeeze the handle as hard as they could and then release it. The maximum value (expressed in kilograms) of three attempts was used for analysis.

Balance

Three different balance tasks (side-by-side, semitandem, and tandem stands) were performed in consecutive order. For each task, research staff helped participants into the proper positioning if needed but released their hold before beginning timing. Each task was successfully completed if the position was held for 10 seconds. Successful completion of all three balance tasks (yes/no) was used for analysis.

Covariates

Covariates were chosen for inclusion in statistical analyses due to their established relations with sleep and/or physical function. Other than race/ethnicity and education (both assessed at baseline), all covariates were assessed at Visit 13. Race/ethnicity (Black, Chinese, Hispanic, Japanese, or White), education (categorized into a high school degree or less, some college, or a college degree and higher), age (years), marital status (categorized as single/never married, currently married/living as married, or separated/widowed/divorced), smoking status (categorized as never, prior, or current), difficulty paying for basics (dichotomized into not hard or somewhat/very hard), self-rated health status (categorized as excellent/very good, good, or fair/poor), bodily pain (categorized as none, very mild/mild, moderate, or severe/very severe), depressive symptoms (dichotomized into high [≥16] or low [≤15] based on the Center for Epidemiological Studies Depression scale [24]), menopausal status (natural or surgical), hormone therapy use (dichotomized as current/ever or never [other than the enrollment period, hormone use was allowed]), and the presence (yes/no) of osteoarthritis, osteoporosis, angina/myocardial infarction, stroke, diabetes, and cancer were assessed using standardized questionnaires. Physical activity was assessed using the Kaiser Physical Activity Survey (KPAS) [25], a self-administered questionnaire that assesses activity in three domains (active living, household/caregiving, and sports/exercise) with domain scores that range from 1 (low) to 5 (high); total physical activity scores range from 3 (low) to 15 (high). Insomnia medication use was based upon self-report of at least one medication commonly used to treat insomnia, as indicated by the 2017 American Academy of Sleep Medicine Clinical Practice Guideline [26]. Body mass index (BMI) was calculated in kilograms per meters squared (kg/m^2) based on objective measurements of weight and height. The SWAN clinical site (i.e. Boston, Chicago, Detroit, Los Angeles, Newark, Oakland, and Pittsburgh) was also included as a covariate. Finally, variables specific to each physical function assessment were

included as covariates; these dichotomized variables included foot covering (walking shoes, other) and floor surface (carpet, other) for the 40-ft, 4-m walk, and balance assessments, foot covering (walking shoes, other) and chair surface (carpet, other) for the repeated chair stands, and dynamometer setting (small, nonsmall) and dominant hand (left, right) for grip strength.

Statistical analyses

Latent class growth modeling (PROC TRAJ in SAS) was used to identify subgroups of participants following similar trajectories of insomnia symptoms or sleep duration across time points (i.e. visits 1–13 and visits 3, 4, 12, and 13, respectively), with each sleep variable evaluated in separate models. For each model, participants needed to have sleep data from at least three different time points to be included. The selection of the trajectories' shape and the number of trajectories was determined following previously published methods [27]. Briefly, based on prior analysis of the SWAN sleep data, we anticipated five to six trajectory groups. For estimating the shape of the trajectories, we tested linear, quadratic, and cubic terms. We started with a single trajectory model with the highest polynomial order (cubic) included. The maximum power term with $p < .05$ was selected for each group separately. The number of groups selected was based on Bayesian Information Criteria values, as well as scientific plausibility, in accordance with prior recommendations [28]. We also used average posterior probabilities of group membership (>.70) and reasonable group size (≥5% of the total sample) to further evaluate the selected model [27]. The shapes of the insomnia symptom trajectory groups were as follows: quadratic (*consistently high*, *severe worsening*), cubic (*improving*, *moderate worsening*), and linear (*consistently low*). The shapes of the sleep duration trajectory groups were quadratic (*persistent sufficient*) and linear (*persistent insufficient*). After the trajectory groups were determined, participants were assigned to the trajectory groups that reflected their highest posterior probability [27]. The end of the follow-up period for sleep assessment (i.e. follow-up Visit 1 through Visit 13) overlapped with the physical function assessment at Visit 13. However, since the sleep trajectories represent changes in sleep over the entire follow-up period rather than any particular time point and our intent was to examine associations (and not incident physical function problems), overlap between the sleep trajectory follow-up period and physical function variables at Visit 13 was not a significant concern.

Differences across trajectory groups in covariates and physical function outcomes were examined using analysis of variance for continuous variables and chi-square statistics for categorical variables. When statistically significant between-group differences were observed, individual trajectory groups were compared against the reference trajectories (*consistently low* insomnia symptom trajectory, *persistent sufficient* sleep duration trajectory). Linear regression analyses were used to model each continuous physical function measure (i.e. 40-ft walk, 4-m walk, repeated chair stands, grip strength) as a function of the trajectory group (using the same reference trajectories as noted above), with Dunnett's tests used to adjust for multiple comparisons [29]. Binary logistic regression analyses were used to model successful completion of the balance tasks as a function of the trajectory group, using the same reference trajectories as noted above. For each physical function outcome, two models were examined. In a minimally adjusted model (i.e. Model 1), race/ethnicity, difficulty paying for basics, marital status, smoking status, education, age, BMI, physical activity, clinical site, and outcome-specific variables were included as covariates. In the fully adjusted model (i.e. Model 2), self-rated health status, bodily pain, depressive symptoms, osteoarthritis, osteoporosis, angina/myocardial infarction, stroke, diabetes, cancer, hormone therapy use, menopausal status, and insomnia medication use were included as covariates in addition to those included in Model 1. For the logistic regression models examining the odds of balance task completion, one of the outcome-specific covariates (floor surface) was removed due to significant collinearity with the study site. To aid in interpreting the data for the continuous physical function outcomes, associations were expressed in the text as percent differences and calculated as the adjusted mean value of the trajectory group of interest minus the adjusted mean value of the referent trajectory group (numerator) divided by the adjusted mean of the referent trajectory group (denominator) multiplied by 100. All analyses were conducted in SAS v. 9.4 (SAS Institute, Inc.; Cary, NC).

Results

Characterization and correlates of sleep trajectories

Five trajectories of insomnia symptoms were identified from latent class growth modeling as having an excellent fit and interpretable groups based on the likelihood of reporting insomnia symptoms over time: a *consistently low* likelihood of insomnia symptoms (34.0% of the sample), a decreased likelihood of insomnia symptoms (i.e. *improving*; 15.8%), a gradually increased likelihood of insomnia symptoms (i.e. *moderate worsening*; 23.0%), a steep increase in the likelihood of insomnia symptoms (i.e. *severe worsening*; 12.0%), and a *consistently high* likelihood of insomnia symptoms over time (15.2%) (Figure 2). At Visit 13, women in the *consistently low* insomnia symptom group were less likely to be White, had a lower BMI, were more physically active, were less likely to report poor health status, significant depressive symptoms, bodily pain, or osteoarthritis, and had a faster 4-m walk speed relative to all other insomnia symptom trajectory groups. In addition, women in the *consistently low* group were also less likely to report angina/myocardial infarction, diabetes, hormone use, or insomnia medication use, had less financial strain, were more likely to be married, have never smoked, and report natural postmenopause, had greater grip strength, had faster 40-ft walk and repeated chair stand times, and were less likely to have a balance problem compared to at least one other trajectory group (see Table 1 for specific between-group differences relative to the *consistently low* trajectory group).

Two trajectories of sleep duration were identified from latent class growth modeling, with both demonstrating stability across assessments: one group whose sleep duration was consistently > 7 h over time (i.e. *persistent sufficient* [63.0%]), and another group whose sleep duration was consistently < 6 h over time (i.e. *persistent insufficient* [37.0%]) (Figure 3). Compared to those in the *persistent insufficient* sleep duration trajectory group, women in the *persistent sufficient* group had a lower BMI, greater physical activity, were more likely to be White, have a college degree, and be married, were less likely to report financial strain, poor health status, significant depressive symptoms, bodily pain, diabetes, or hormone use, and had significantly faster times for the 40-ft

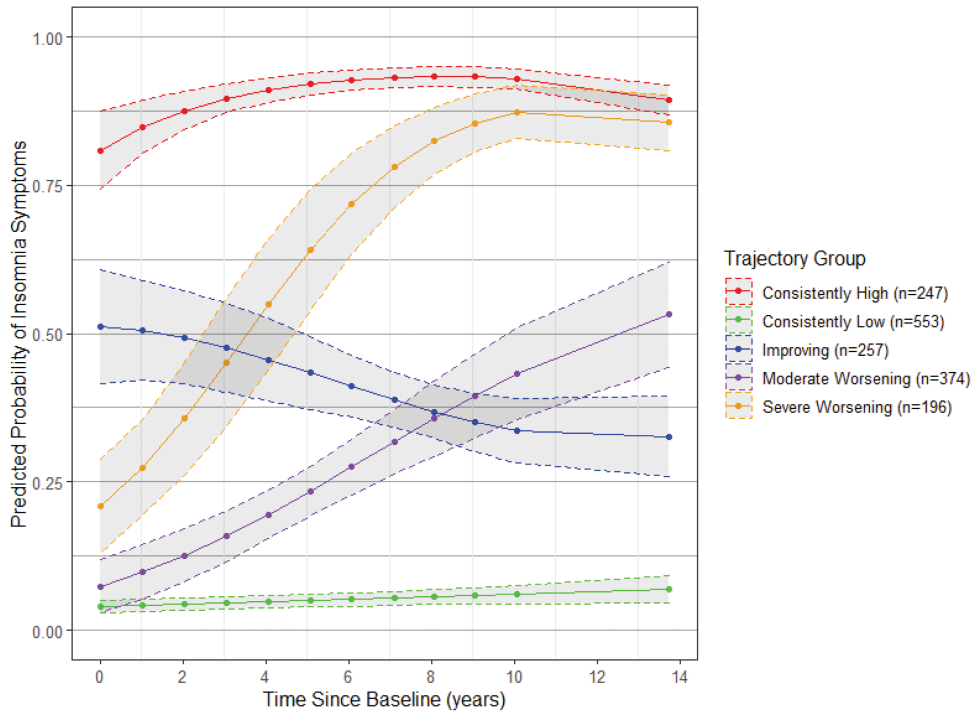

Figure 2. Predicted probability of insomnia symptoms (with 95% confidence intervals) over time for the insomnia symptom trajectory groups. Five groups were identified by latent class growth modeling: (1) *consistently high*: a consistently high likelihood of insomnia symptoms over time; (2) *consistently low*: a consistently low likelihood of insomnia symptoms over time; (3) *improving*: a decreased likelihood of insomnia symptoms over time; (4) *moderate worsening*: a gradually increased likelihood of insomnia symptoms over time; (5) *severe worsening*: a steep increase in the likelihood of insomnia symptoms over time.

walk, 4-m walk, and repeated chair stand tests (Table 2). In addition, women in the *persistent sufficient* group were more likely to be in the *consistently low* insomnia symptom trajectory group and less likely to be in the *severe worsening* or *consistently high* insomnia symptom trajectory groups compared to those in the *persistent insufficient* sleep duration group (Table 2).

Associations between insomnia symptom trajectories and objective physical function

Following basic covariate adjustment (Model 1 of Table 3), the *consistently low* insomnia symptom group had a significantly faster 40-ft walk speed than the *consistently high* insomnia symptom group (4.6% faster; $p = .002$) and a significantly faster 4-m walk speed than the *improving* and *severe worsening* insomnia symptom groups (4.2% [$p = .01$] and 4.1% [$p = .04$] faster, respectively). In the fully adjusted model (Model 2 of Table 3), associations remained similar but smaller in magnitude (i.e. 40-ft walk speed for the *consistently low* group was 3.5% [$p = .04$] faster than the *consistently high* group, 4-m walk speed for the *consistently low* group was 3.7% faster [$p = .04$] than the *improving* group). The only exception was that the 4-m walk speed for the *consistently low* group was no longer significantly faster than the *severe worsening* group following adjustment for multiple comparisons in Model 2 (3.2% faster; $p = .18$).

In Model 1 (Table 3), the *consistently low* insomnia symptom trajectory group had a significantly faster repeated chair stand time compared to the *consistently high* group (5.5% faster; $p = .03$), but that association was no longer significant in Model 2 (3.1% faster; $p = .40$). Grip strength did not differ between the *consistently low* group and any other insomnia symptom trajectory group in minimally or fully adjusted models. Compared to the *consistently low* group, the odds of having a balance problem were 62% lower in the *severe worsening* group (odds ratio [OR] = 0.38; $p = .005$) in Model 1. This association remained similar in the fully adjusted model (OR = 0.36; $p = .004$).

Associations between sleep duration trajectories and objective physical function

Performance in the 40-ft walk, 4-m walk, repeated chair stand, or grip strength assessments did not differ between the *persistent sufficient* and *persistent insufficient* sleep duration trajectory groups in minimally or fully adjusted models (Table 4). Compared to the *persistent sufficient* group, the odds of having a balance problem were 36% lower in the *persistent insufficient* sleep duration group (OR = 0.64; $p = .03$) in Model 1. This association remained similar in the fully adjusted model (OR = 0.61; $p = .02$).

Discussion

This study characterized trajectories of self-reported insomnia symptoms and sleep duration over 13 years in a sample of midlife women and related these trajectories with multiple measures of objective physical function assessed at the end of the 13-year period. Overall, we identified five trajectories of insomnia symptoms and two trajectories of sleep duration. Our examination of the association between these trajectories with objective physical function partially supported our hypotheses. The trajectories were associated with multiple indices of physical function, including gait speed and balance problems,

Table 1. Participant characteristics at visit 13 across insomnia symptom trajectory groups

	Insomnia symptom trajectory group				
Characteristic:	Consistently low	Moderate worsening	Improving	Severe worsening	Consistently high
N (%)	553 (34.0)	374 (23.0)	257 (15.8)	196 (12.0)	247 (15.2)
Age (y), mean ± SD	61.9 ±2.7	61.5 ±2.6**	62.2 ±2.7	62.0 ±2.6	62.2 ± 2.6
Race/ethnicity, n (%)					
Black	136 (24.6)	91 (24.3)	67 (26.1)	47 (24.0)	60 (24.3)
White	227 (41.0)	185 (49.5)*	133 (51.8)**	114 (58.2)***	148 (59.9)***
Chinese	81 (14.6)	45 (12.0)	20 (7.8)**	8 (4.1)***	24 (9.7)
Hispanic	22 (4.0)	19 (5.1)	13 (5.1)	5 (2.6)	4 (1.6)
Japanese	87 (15.7)	34 (9.1)**	24 (9.3)*	22 (11.2)	11 (4.5)***
Education, n (%)					
≤ High school degree	109 (19.7)	67 (17.9)	56 (21.8)	41 (20.9)	35 (14.2)
Some college	166 (30.0)	120 (32.1)	73 (28.4)	68 (34.7)	83 (33.6)
College degree/postcollege	278 (50.3)	187 (50.0)	128 (49.8)	87 (44.4)	129 (52.2)
Marital status, n (%)					
Single/never married	59 (10.7)	48 (12.8)	40 (15.6)*	17 (8.7)	29 (11.7)
Currently married/living as married	359 (64.9)	223 (59.6)	130 (50.6)***	130 (66.3)	150 (60.7)
Separated/widowed/divorced	135 (24.4)	103 (27.5)	87 (33.9)**	49 (25.0)	68 (27.5)
BMI (kg/m^2), mean ± SD	27.7 ±6.4	29.1 ± 6.9**	29.3 ±6.8**	29.4 ±7.3**	30.2 ±7.5***
Physical activity (KPAS total), mean ± SD	7.9 ±1.8	7.6 ± 1.8*	7.5 ±1.9**	7.4 ±1.8**	7.5 ±1.8**
Smoking status, n (%)					
Never	372 (67.3)	235 (62.8)	161 (62.6)	105 (53.6)**	132 (53.4)***
Past only	143 (25.9)	110 (29.4)	79 (30.7)	73 (37.2)	98 (39.7)
Current	38 (6.9)	29 (7.8)	17 (6.6)	18 (9.2)	17 (6.9)
Somewhat/very hard to pay for basics, n (%)	111 (20.1)	95 (25.4)	71 (27.6)*	51 (26.0)	66 (26.7)*
Depression (CESD ≥ 16), n (%)	37 (6.7)	39 (10.4)*	35 (13.6)**	29 (14.8)***	58 (23.5)***
Hormone use (ever), n (%)	208 (37.6)	160 (42.8)	117 (45.5)*	106 (54.1)***	136 (55.1)***
Menopausal status, n (%)					
Natural postmenopause	531 (96.0)	356 (95.2)	238 (92.6)*	180 (91.8)*	222 (89.9)***
Surgical postmenopause	22 (4.0)	18 (4.8)	19 (7.4)	16 (8.2)	25 (10.1)
Self-rated health status, n (%)					
Excellent/very good	344 (62.2)	192 (51.3)**	132 (51.4)**	89 (45.4)***	101 (40.9)***
Good	151 (27.3)	120 (32.1)	91 (35.4)*	78 (39.8)**	105 (42.5)***
Fair/poor	58 (10.5)	62 (16.6)**	34 (13.2)	29 (14.8)	41 (16.6)*
Bodily pain, n (%)					
None	126 (22.8)	51 (13.6)***	34 (13.2)**	24 (12.2)**	21 (8.5)***
Very mild/mild	344 (62.2)	216 (57.8)	155 (60.3)	113 (57.7)	122 (49.4)***
Moderate	65 (11.8)	85 (22.7)***	56 (21.8)***	46 (23.5)***	87 (35.2)***
Severe/very severe	18 (3.3)	22 (5.9)	12 (4.7)	13 (6.6)*	17 (6.9)*
Medical conditions, n (%)					
Osteoarthritis	264 (47.7)	217 (58.0)**	161 (62.6)***	123 (62.8)***	161 (65.2)***
Osteoporosis	93 (16.8)	75 (20.1)	51 (19.8)	44 (22.4)	57 (23.1)
Angina/myocardial infarction	22 (4.0)	16 (4.3)	22 (8.6)**	11 (5.6)	22 (8.9)**
Stroke	9 (1.6)	10 (2.7)	4 (1.6)	6 (3.1)	8 (3.2)
Diabetes	76 (13.7)	72 (19.3)*	40 (15.6)	44 (22.4)**	48 (19.4)*
Cancer	50 (9.0)	32 (8.6)	25 (9.7)	28 (14.3)	28 (11.3)
Insomnia medication use, n (%)	38 (6.9)	39 (10.4)	32 (12.5)**	28 (14.3)**	40 (16.2)***
Sleep duration trajectory group, n (%)					
Persistent insufficient	156 (28.2)	143 (38.2)	96 (37.4)	85 (43.4)	122 (49.4)
Persistent sufficient	397 (71.8)	231 (61.8)**	161 (62.6)**	111 (56.6)***	125 (50.6)***
Objective physical function					
40-ft walk (m/s), mean ± SD	1.53 ± 0.29	1.49 ±0.29	1.45 ±0.29**	1.46 ±0.30**	1.43 ± 0.30***
4-m walk (m/s), mean ± SD	1.10 ± 0.26	1.04 ±0.25***	1.02 ±0.24***	1.04 ±0.23**	1.02 ± 0.27***
Repeated chair stand (s), mean ± SD	10.5 ± 3.2	11.4 ±3.6***	11.5 ±3.7***	10.9 ±3.5	11.6 ± 4.0***
Grip strength (kg), mean ± SD	25.2 ± 5.6	25.5 ±6.0	25.0 ±5.2	26.2 ±5.0*	25.4 ± 5.9
Balance problem, n (%)	47 (8.5)	34 (9.1)	27 (10.5)	9 (4.6)	34 (13.8)*

N = 1,237 for 40-ft walk. *P*-values indicate significant difference relative to the "consistently low" trajectory group: * $p \leq .05$, ** $p < .01$, *** $p < .001$. BMI: body mass index; CESD: Center for Epidemiological Studies Depression scale; KPAS: Kaiser Physical Activity Survey; SD: standard deviation. For the insomnia symptom trajectory groups: *consistently low*: a consistently low likelihood of insomnia symptoms over time; *moderate worsening*: a gradually increased likelihood of insomnia symptoms over time; *improving*: a decreased likelihood of insomnia symptoms over time; *severe worsening*: a steep increase in the likelihood of insomnia symptoms over time; *consistently high*: a consistently high likelihood of insomnia symptoms over time.

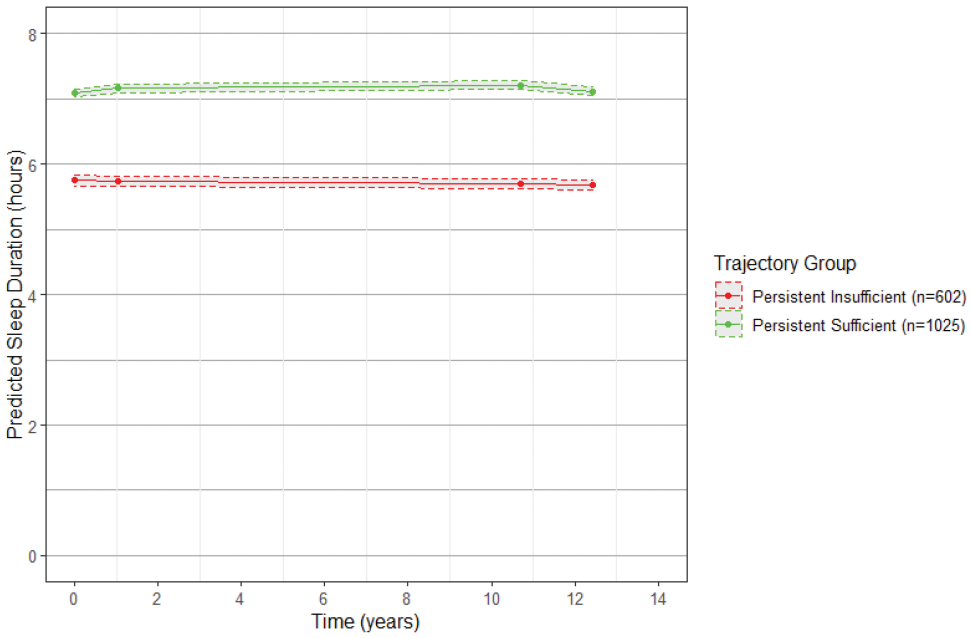

Figure 3. Predicted sleep duration (with 95% confidence intervals) over time for the sleep duration trajectory groups. Two groups were identified by latent class growth modeling: (1) *persistent insufficient*: consistently <6 h of sleep duration over time; (2) *persistent sufficient*: consistently >7 h of sleep duration over time.

independent of important covariates such as bodily pain, health status, BMI, physical activity, and insomnia medication use. However, trajectories of insomnia symptoms or sleep duration did not seem to impact muscle function as measured by chair rises and grip strength. Together, these data highlight the potential significance of sleep for midlife women in maintaining physical function into older adulthood.

Although sleep is generally thought to worsen during midlife among women [30, 31], heterogeneity exists across various dimensions of sleep. Most studies to date have evaluated population average sleep metrics with respect to outcomes, thereby potentially missing information about the importance of differential within-person changes over time. We identified five insomnia symptom trajectories over this 13-year period; in general, these groupings highlighted significant stability in insomnia symptoms for most midlife women but also identified a substantial number of women whose insomnia symptoms improved or worsened during midlife. The most prevalent group had a consistently low likelihood of insomnia symptoms (34.0%), but > 10% of the sample was classified into one of the four other insomnia symptom trajectory groups: initially high probability of insomnia symptoms that decreased (i.e. improved) over time (15.8%), initially low likelihood of insomnia that gradually increased (i.e. worsened) over time (23.0%), initially low likelihood of insomnia that increased substantially over time (12.0%), and a persistent high likelihood of insomnia symptoms (15.2%).

Sleep duration seemed to be more stable than insomnia symptoms in our sample, as we identified only two trajectory groups: one who consistently obtained > 7 h (63.0%), and another who consistently obtained < 6 h (37.0%). Although our analyses utilized a continuous measure of sleep duration to examine trajectories, other studies involving midlife adults have found that ≥67% of the sample remained in the same sleep duration category over follow-up periods of approximately 4–5 years [32, 33]. In contrast, sleep duration may be less stable in older adults; in a study of 2,294 adults older than 65 years of age, less than 50% reported sleep duration in the same category (≤5, 6–7, or ≥8 h) approximately 3 years later [34]. Overall, our findings on insomnia symptom and sleep duration trajectories in midlife women complement those from another recent SWAN publication. Among 300 women who participated in the SWAN Sleep ancillary study, Matthews and colleagues assessed mean changes in actigraphy-assessed sleep duration, timing, and continuity over a 12-year period [35]. They found that sleep duration increased, night-time wakefulness decreased, and sleep timing shifted later over time [35]. Together, these findings suggest that insomnia symptoms and duration are stable throughout midlife for many women, but that significant subgroups may exhibit improvement or deterioration of sleep during this period.

Subjective sleep problems and insufficient sleep duration have previously been associated with worse physical function [11, 12, 18–22, 36–38]. However, most of this research has focused on adults ≥65 years. Minimal research has evaluated the association between sleep and physical function in young adult or midlife cohorts. In a sample of 3,620 adults aged 24–75 years, Friedman and colleagues found that sleep problems predicted a greater likelihood of self-reported physical function limitations 9–10 years later [39]. Notably, this association was moderated by age, with stronger associations between sleep and physical function observed in young and middle-aged adults [39]. Similarly, in a sample of 48 postmenopausal women (mean age: 61 years), Fex and colleagues found that self-reported long sleep duration (≥9 h) was cross-sectionally associated with worse performance across a variety of objective physical function outcomes [23]. Other recent cross-sectional studies have linked poor sleep to physical function in college students [21] and middle-aged adults [40, 41]. We extend this body of research by demonstrating these associations in a sample of late midlife women who, overall, were highly functioning at the time of assessment [42] and for whom longitudinal information about sleep trajectories across midlife was considered.

Table 2. Participant characteristics at Visit 13 across sleep duration trajectory groups

	Sleep duration trajectory group	
Characteristic:	Persistent sufficient	Persistent insufficient
N (%)	1025 (63.0)	602 (37.0)
Age (y), mean ± SD	61.8 ± 2.6	62.0 ± 2.7
Race/ethnicity, n (%)		
Black	190 (18.5)	211 (35.1)***
White	606 (59.1)	201 (33.4)***
Chinese	105 (10.2)	73 (12.1)
Hispanic	28 (2.7)	35 (5.8)**
Japanese	96 (9.4)	82 (13.6)**
Education, n (%)		
≤ High school degree	181 (17.7)	127 (21.1)
Some college	305 (29.8)	205 (34.1)
College degree/postcollege	539 (52.6)	270 (44.9)**
Marital status, n (%)		
Single/never married	117 (11.4)	76 (12.6)
Currently married/living as married	656 (64.0)	336 (55.8)**
Separated/widowed/divorced	252 (24.6)	190 (31.6)**
BMI (kg/m^2), mean ± SD	28.6 ± 6.8	29.3 ± 7.2*
Physical activity (KPAS total), mean ± SD	7.8 ± 1.8	7.5 ± 1.8**
Smoking status, n (%)		
Never	635 (62.0)	370 (61.5)
Past only	322 (31.4)	181 (30.1)
Current	68 (6.6)	51 (8.5)
Somewhat/very hard to pay for basics, n (%)	207 (20.2)	187 (31.1)***
Depression (CESD ≥ 16), n (%)	92 (9.0)	106 (17.6)***
Hormone use (ever), n (%)	485 (47.3)	242 (40.2)**
Menopausal status, n (%)		
Natural postmenopause	958 (93.5)	569 (94.5)
Surgical postmenopause	67 (6.5)	33 (5.5)
Self-rated health status, n (%)		
Excellent/very good	595 (58.1)	263 (43.7)***
Good	314 (30.6)	231 (38.4)**
Fair/poor	116 (11.3)	108 (17.9)***
Bodily pain, n (%)		
None	177 (17.3)	79 (13.1)*
Very mild/mild	611 (59.6)	339 (56.3)
Moderate	196 (19.1)	143 (23.8)*
Severe/very severe	41 (4.0)	41 (6.8)*
Medical conditions, n (%)		
Osteoarthritis	576 (56.2)	350 (58.1)
Osteoporosis	193 (18.8)	127 (21.1)
Angina/myocardial infarction	58 (5.7)	35 (5.8)
Stroke	21 (2.0)	16 (2.7)
Diabetes	155 (15.1)	125 (20.8)**
Cancer	109 (10.6)	54 (9.0)
Insomnia medication use, n (%)	119 (11.6)	58 (9.6)
Insomnia symptom trajectory group, n (%)		
Consistently low	397 (38.7)	156 (25.9)***
Moderate worsening	231 (22.5)	143 (23.8)
Improving	161 (15.7)	96 (15.9)
Severe worsening	111 (10.8)	85 (14.1)*
Consistently high	125 (12.2)	122 (20.3)***
Objective physical function		
40-ft walk (m/s), mean ± SD	1.51 ± 0.29	1.44 ±0.31***
4-m walk (m/s), mean ± SD	1.07 ± 0.25	1.02 ±0.26***
Repeated chair stand (s), mean ± SD	10.9 ± 3.3	11.4 ±4.0**
Grip strength (kg), mean ± SD	25.5 ± 5.5	25.1 ±6.0
Balance problem, n (%)	102 (10.0)	49 (8.1)

N = 1,237 for 40-ft walk. *P*-values indicate significant difference relative to the "persistent sufficient" trajectory group: * $p \leq .05$, ** $p < .01$, *** $p < .001$. BMI: body mass index; CESD: Center for Epidemiological Studies Depression scale; KPAS: Kaiser Physical Activity Survey; SD: standard deviation. For the sleep duration trajectory groups: *persistent sufficient*: consistently > 7 h of sleep duration over time; *persistent insufficient*: consistently < 6 h of sleep duration over time.

Table 3. Associations between insomnia symptom trajectory groups (defined over 13 years) and objective physical function at follow-up visit 13

Insomnia symptom trajectory group	40-ft walk, m/s	4-m walk, m/s	Repeated chair stand, s	Grip strength, kg	Balance problem
	Beta (95% CI)	Beta (95% CI)	Beta (95% CI)	Beta (95% CI)	OR (95% CI)
Model 1					
Consistently low	REF	REF	REF	REF	REF
Moderate worsening	−0.02 (−0.06, 0.01)	−0.03 (−0.05, −0.01)	0.46 (0.08, 0.84)	0.11 (−0.57, 0.79)	0.96 (0.58, 1.57)
Improving	−0.03 (−0.07, 0.01)	−0.04 (−0.07, −0.01)*	0.32 (−0.11, 0.76)	−0.27 (−1.04, 0.50)	1.03 (0.60, 1.76)
Severe worsening	−0.03 (−0.07, 0.01)	−0.04 (−0.07, −0.01)*	−0.11 (−0.59, 0.36)	0.68 (−0.17, 1.53)	0.38 (0.17, 0.82)**
Consistently high	0.07 (−0.11, −0.03)**	−0.03 (−0.06, −0.01)	0.62 (0.17, 1.06)*	0.09 (−0.70, 0.89)	1.39 (0.83, 2.33)
Model 2					
Consistently low	REF	REF	REF	REF	REF
Moderate worsening	−0.01 (−0.04, 0.03)	−0.02 (−0.05, 0.00)	0.32 (−0.06, 0.71)	0.36 (−0.32, 1.04)	0.92 (0.56, 1.54)
Improving	−0.02 (−0.06, 0.02)	−0.04 (−0.06, −0.01)*	0.21 (−0.23, 0.64)	−0.08 (−0.86, 0.69)	1.01 (0.58, 1.75)
Severe worsening	−0.02 (−0.06, 0.02)	−0.03 (−0.06, 0.00)	−0.29 (−0.77, 0.19)	1.01 (0.15, 1.86)	0.36 (0.16, 0.80)**
Consistently high	−0.05 (−0.09, −0.01)*	−0.02 (−0.05, 0.01)	0.35 (−0.11, 0.81)	0.59 (−0.24, 1.41)	1.35 (0.77, 2.37)

N = 1,237 for 40-ft walk. * $p \leq .05$, ** $p < .01$, *** $p < .001$. Beta coefficients represent absolute differences (with 95% confidence interval) relative to the referent group. CI: confidence interval; OR: odds ratio; REF: referent group. Model 1 adjusted for race/ethnicity, difficulty paying for basics, marital status, smoking status, education, age, BMI, physical activity, clinical site, and outcome-specific variables. Model 2 adjusted for Model 1 covariates as well as self-rated health status, bodily pain, depressive symptoms, osteoarthritis, osteoporosis, angina/myocardial infarction, stroke, diabetes, cancer, hormone therapy use, menopausal status, and insomnia medication use.

Table 4. Associations between sleep duration trajectory groups (defined over 13 years) and objective physical function at follow-up visit 13

Sleep duration trajectory group	40-ft walk, m/s	4-m walk, m/s	Repeated chair stand, s	Grip strength, kg	Balance problem
	Beta (95% CI)	Beta (95% CI)	Beta (95% CI)	Beta (95% CI)	OR (95% CI)
Model 1					
Persistent sufficient	REF	REF	REF	REF	REF
Persistent insufficient	−0.02 (−0.04, 0.01)	−0.01 (−0.03, 0.00)	0.11 (−0.19, 0.41)	−0.52 (−1.06, 0.02)	0.64 (0.43, 0.95)*
Model 2					
Persistent sufficient	REF	REF	REF	REF	REF
Persistent insufficient	−0.01 (−0.04, 0.02)	−0.01 (−0.03, 0.01)	0.06 (−0.24, 0.37)	−0.41 (−0.95, 0.13)	0.61 (0.41, 0.92)*

N = 1,237 for 40-ft walk. * $p \leq .05$, ** $p < .01$, *** $p < .001$. Beta coefficients represent absolute differences (with 95% confidence interval) relative to the referent group. CI: confidence interval; OR: odds ratio; REF: referent group. Model 1 adjusted for race/ethnicity, difficulty paying for basics, marital status, smoking status, education, age, BMI, physical activity, clinical site, and outcome-specific variables. Model 2 adjusted for Model 1 covariates as well as self-rated health status, bodily pain, depressive symptoms, osteoarthritis, osteoporosis, angina/myocardial infarction, stroke, diabetes, cancer, hormone therapy use, menopausal status, and insomnia medication use.

We found poor sleep to be consistently associated with slower gait speed, a key predictor of future disability risk [43]. Specifically, the consistently low insomnia symptom group had significantly faster 40-ft and 4-m walk speeds than the consistently high and improving insomnia symptom groups in fully adjusted models, respectively. The magnitude of difference in gait speed between the insomnia symptom groups is of clinical significance based on prior literature (~0.05 m/s) [44]. These results are in line with prior research in older adult samples that linked night-time wakefulness [11, 18, 36], insomnia symptoms [7], and sleep complaints [39] to slower gait speed; however, we did not observe an association between sleep duration and gait speed, as has been shown in prior reports [7, 11, 19, 22].

We also found a *lower* likelihood of a balance problem among women with insomnia symptoms or insufficient sleep duration. Specifically, odds of a balance problem were 64% lower for women in the severe worsening insomnia symptom group compared to the consistently low insomnia symptom group and 39% lower for the persistent insufficient sleep duration group relative to the persistent sufficient sleep duration group. We do not have an explanation for this counterintuitive finding. Other large-scale observational studies in older adults have found balance to be similar [45–49] or worse [18, 22, 23] among those with poor or insufficient sleep; in addition, studies with young adults have reported poorer postural control among poor sleepers [50, 51]. One reason for precaution with these results could be the low prevalence (9%) of balance problems in the sample, with few cases in particular among the severe worsening insomnia symptom and persistent insufficient sleep duration groups (n = 9 and 49, respectively). Because of this small sample size, results should be interpreted with caution. As an alternative (though less likely) explanation, women with poor or insufficient sleep may be less likely to exhibit poor balance because physiologic hyperarousal, a common characteristic among patients with insomnia, confers a protective influence on neuro-cognitive function [52].

The repeated chair stand test, which assesses lower limb strength and balance [53], and grip strength, which serves as a general marker of overall muscular strength [54], are also important tests of muscle function that predict functional decline [55, 56]. In unadjusted models, the consistently low insomnia symptom group performed significantly better on the repeated chair stand test compared to the moderate worsening, improving, and consistently high insomnia symptom groups, while the persistent sufficient sleep duration group had a

faster repeated chair stand time than the persistent insufficient sleep duration group. In unadjusted analyses of grip strength, lower values were observed in the consistently low insomnia symptom group relative to the severe worsening group, while no difference was found between sleep duration groups. However, neither insomnia symptoms nor sleep duration were associated with repeated chair stand performance or grip strength in fully adjusted models. These results may reflect a ceiling effect due to the younger age and preserved muscle strength of this sample. Our findings are similar to those reported by Spira and colleagues; in a sample of 6,050 older adults, associations between insomnia symptoms and objective physical function (including grip strength and repeated chair stand tests) that were present in minimally adjusted models were no longer significant after full covariate adjustment [45]. The overall relationship between sleep and these functional measures remains somewhat equivocal in studies of older adults; studies have found no association [41, 48, 49] or lower grip strength with poor sleep [11, 12, 18, 20–22, 36, 37, 40, 47], while repeated chair stand performance is similar [45, 46] or worse [11, 19, 23] among poor sleepers.

Together, these results indicate that trajectories of self-reported sleep during midlife are related to objective physical function in later midlife and raise the possibility that improving sleep across the midlife period may help preserve physical function. Alternatively, our results could suggest that high levels of physical function in later midlife are restricted to those who do not experience insomnia and maintain sufficient sleep duration throughout midlife. Examining these possibilities would require sleep intervention with long-term follow-up of physical function; to our knowledge, no such study has been conducted.

This study has numerous strengths. One prominent strength is the objective assessment of physical function in a sample of midlife women, as most studies focus on adults ≥65 years of age. Another strength is the characterization of sleep trajectories over a 13-year window of the midlife period. Finally, our analyses accounted for numerous factors that could account for the association between sleep and physical function [39, 42, 57]. Despite these strengths, the study is not without its limitations. One limitation is the reliance on self-reported sleep. Self-reported sleep parameters are only modestly correlated with objective measures of sleep (i.e. actigraphy or polysomnography) [58], and prior research suggests that changes in sleep over the midlife period in women differ between self-reported and polysomnography-assessed sleep [59]. In particular, despite the "past month" recall period for the sleep duration assessment, responses may reflect sleep duration over a shorter time frame than the entire month and provide a less precise measure of self-reported sleep than daily diaries [60]. Trajectories of sleep assessed with actigraphy [11, 12] or polysomnography [18] may have yielded different associations with physical function. This study also did not assess sleep-disordered breathing, despite its high prevalence among midlife women [61] and strong association with poor physical function in older adults [18]. Moreover, sleep duration was assessed only four times during the follow-up period, including a significant gap between visits 4 and 12; this likely led to a less detailed characterization of sleep duration trajectories during midlife. In addition, our analyses are limited by their focus on insomnia symptoms and sleep duration; other dimensions of sleep, such as timing and variability, have been linked with a variety of health outcomes [62] but remain understudied for their association with physical function [16]. Another limitation is the absence of objective physical function measures at baseline. Although we excluded women who reported substantial functional limitations at baseline, the lack of baseline objective physical function assessment precluded our ability to examine whether physical function and sleep evolved independently or synergistically over time. Additionally, lower-extremity muscle strength or power was not assessed; these represent future directions of this work. While our analyses adjusted for a variety of potential confounders, including multiple health indicators and insomnia medication use, we did not account for all possible confounders (e.g. antidepressant medications); as a result, residual confounding may remain, and the results may be due to unaccounted factors (e.g. alcohol consumption, underlying health conditions) that impact both sleep and physical function. In addition, although smoking is related to pulmonary function and, as a result, physical function, we could only evaluate the current smoking status and not the duration of smoking. Our analyses only included those with adequate follow-up data; as such, differential loss to follow-up may have impacted our results. Finally, whether these results generalize to men is unclear. Some studies have found relationships between sleep and physical function differ by sex [7, 22, 37].

Overall, we observed distinct trajectories of insomnia symptoms and sleep duration over a 13-year period in a sample of midlife women that were related to objective indices of physical function. Specifically, women with a consistently high likelihood of insomnia symptoms or an initially high probability of insomnia symptoms that improved over time had slower gait speed than women with a consistently low likelihood of insomnia symptoms, but insomnia symptoms and insufficient sleep duration were also related to lower odds of having a balance problem. These results suggest that women's sleep during the midlife period has important implications for maintaining physical function independence as they transition into older adulthood. Future research should examine whether optimizing sleep in midlife women leads to better functional outcomes in older adulthood.

Funding

The Study of Women's Health Across the Nation (SWAN) has grant support from the National Institutes of Health (NIH), DHHS, through the National Institute on Aging (NIA), the National Institute of Nursing Research (NINR), and the NIH Office of Research on Women's Health (ORWH) (Grants U01NR004061; U01AG012505, U01AG012535, U01AG012531, U01AG012539, U01AG012546, U01AG012553, U01AG012554, U01AG012495). Additional NIH grant support for CEK was provided by K23HL118318. The content of this manuscript is solely the responsibility of the authors and does not necessarily represent the official views of the NIA, NINR, ORWH, or the NIH.

Clinical Centers: University of Michigan, Ann Arbor – Siobán Harlow, PI 2011 – present, MaryFran Sowers, PI 1994–2011; Massachusetts General Hospital, Boston, MA – Joel Finkelstein, PI 1999 – present; Robert Neer, PI 1994 – 1999; Rush University, Rush University Medical Center, Chicago, IL – Howard Kravitz, PI 2009 – present; Lynda Powell, PI 1994 – 2009; University of California, Davis/Kaiser – Ellen Gold, PI; University of California, Los Angeles – Gail Greendale, PI; Albert Einstein College of Medicine, Bronx, NY – Carol Derby, PI 2011 – present, Rachel Wildman,

PI 2010 – 2011; Nanette Santoro, PI 2004 – 2010; University of Medicine and Dentistry – New Jersey Medical School, Newark – Gerson Weiss, PI 1994 – 2004; and the University of Pittsburgh, Pittsburgh, PA – Karen Matthews, PI.

NIH Program Office: National Institute on Aging, Bethesda, MD – Chhanda Dutta 2016- present; Winifred Rossi 2012–2016; Sherry Sherman 1994 – 2012; Marcia Ory 1994 – 2001; National Institute of Nursing Research, Bethesda, MD – Program Officers.

Central Laboratory: University of Michigan, Ann Arbor – Daniel McConnell (Central Ligand Assay Satellite Services).

Coordinating Center: University of Pittsburgh, Pittsburgh, PA – Maria Mori Brooks, PI 2012 - present; Kim Sutton-Tyrrell, PI 2001 – 2012; New England Research Institutes, Watertown, MA - Sonja McKinlay, PI 1995 – 2001.

Steering Committee: Susan Johnson, Current Chair; Chris Gallagher, Former Chair.

We thank the study staff at each site and all the women who participated in SWAN.

Institution where work was performed: University of Pittsburgh

Disclosure Statements

Financial Disclosure: None.

Non-financial Disclosure: None.

Data Availability

SWAN provides access to public use datasets that include data from SWAN screening, the baseline visit, and follow-up visits (https://agingresearchbiobank.nia.nih.gov/). To preserve participant confidentiality, some, but not all, of the data used for this manuscript are contained in the public-use datasets. A link to the public use datasets is also located on the SWAN website: http://www.swanstudy.org/swan-research/data-access/. Investigators who require assistance accessing the public use dataset may contact the SWAN Coordinating Center at the following email address: swanaccess@edc.pitt.edu.

References

1. Blain H, *et al*. Balance and walking speed predict subsequent 8-year mortality independently of current and intermediate events in well-functioning women aged 75 years and older. *J Nutr Health Aging*. 2010;**14**(7):595–600.
2. Rantanen T, *et al*. Coimpairments: strength and balance as predictors of severe walking disability. *J Gerontol A Biol Sci Med Sci*. 1999;**54**(4):M172–M176.
3. Fried LP, *et al*.; WHAS II Collaborative Research Group. Self-reported preclinical disability identifies older women with early declines in performance and early disease. *J Clin Epidemiol*. 2001;**54**(9):889–901.
4. Lebrun CE, *et al*. Fat mass rather than muscle strength is the major determinant of physical function and disability in postmenopausal women younger than 75 years of age. *Menopause*. 2006;**13**(3):474–481.
5. Fragala MS, *et al*. Gender differences in anthropometric predictors of physical performance in older adults. *Gend Med*. 2012;**9**(6):445–456.
6. Riebe D, *et al*. The relationship between obesity, physical activity, and physical function in older adults. *J Aging Health*. 2009;**21**(8):1159–1178.
7. Stenholm S, *et al*. Sleep-related factors and mobility in older men and women. *J Gerontol A Biol Sci Med Sci*. 2010;**65**(6):649–657.
8. Kravitz HM, *et al*. Sleep difficulty in women at midlife: a community survey of sleep and the menopausal transition. *Menopause*. 2003;**10**(1):19–28.
9. Baker FC, *et al*. Sleep problems during the menopausal transition: prevalence, impact, and management challenges. *Nat Sci Sleep*. 2018;**10**:73–95.
10. Stranges S, *et al*. Sleep problems: an emerging global epidemic? Findings from the INDEPTH WHO-SAGE study among more than 40,000 older adults from 8 countries across Africa and Asia. *Sleep*. 2012;**35**(8):1173–1181.
11. Goldman SE, *et al*. Poor sleep is associated with poorer physical performance and greater functional limitations in older women. *Sleep*. 2007;**30**(10):1317–1324.
12. Spira AP, *et al*. Poor sleep quality and functional decline in older women. *J Am Geriatr Soc*. 2012;**60**(6):1092–1098.
13. Kravitz HM, *et al*. Sleep trajectories before and after the final menstrual period in the Study of Women's Health Across the Nation (SWAN). *Curr Sleep Med Rep*. 2017;**3**(3):235–250.
14. Ciano C, *et al*. Longitudinal study of insomnia symptoms among women during perimenopause. *J Obstet Gynecol Neonatal Nurs*. 2017;**46**(6):804–813.
15. Sowers MF, *et al*. SWAN: A multi-center, multi-ethnic, community-based cohort study of women and the menopausal transition. In: Lobo RA, Kelsey J, Marcus R, eds. *Menopause: Biology and Pathobiology*. San Diego: Academic Press; 2000:175–188.
16. American Psychiatric Association. *Diagnostic and statistical manual of mental disorders* (5th ed). Arlington, VA: American Psychiatric Association; 2013.
17. Dam TT, *et al*.; Osteoporotic Fractures in Men Research Group. Association between sleep and physical function in older men: the osteoporotic fractures in men sleep study. *J Am Geriatr Soc*. 2008;**56**(9):1665–1673.
18. Stenholm S, *et al*. Self-reported sleep duration and time in bed as predictors of physical function decline: results from the InCHIANTI study. *Sleep*. 2011;**34**(11):1583–1593.
19. Wang TY, *et al*. A prospective study on the association of sleep duration with grip strength among middle-aged and older Chinese. *Exp Gerontol*. 2018;**103**:88–93.
20. Chen HC, Hsu NW, Chou P. The association between sleep duration and hand grip strength in community-dwelling older adults: the Yilan Study, Taiwan. *Sleep*. 2017;**40**(4). doi:10.1093/sleep/zsx021.
21. Fu L, *et al*. The association between sleep duration and physical performance in Chinese community-dwelling elderly. *PLoS One*. 2017;**12**(3):e0174832.
22. Fex A, *et al*. Relationship between long sleep duration and functional capacities in postmenopausal women. *J Clin Sleep Med*. 2012;**8**(3):309–313.
23. Radloff LS. The CES-D scale: a self-report depression scale for research in the general population. *Appl Psychol Meas*. 1977;**1**(3):385–401.
24. Ainsworth BE, *et al*. Evaluation of the kaiser physical activity survey in women. *Med Sci Sports Exerc*. 2000;**32**(7):1327–1338.
25. Sateia MJ, *et al*. Clinical practice guideline for the pharmacologic treatment of chronic insomnia in adults: an american

academy of sleep medicine clinical practice guideline. *J Clin Sleep Med*. 2017;**13**(2):307–349.
26. Andruff H, *et al*. Latent class growth modelling: a tutorial. *Tutor Quant Methods Psychol*. 2009;**5**(1):11–24.
27. Nagin DS. *Group-based modeling of development*. Cambridge, MA: Harvard University Press; 2005.
28. Dunnett CW. A multiple comparison procedure for comparing several treatments with a control. *J Am Stat Assoc*. 1955;**50**(272):1096–1121.
29. Xu Q, *et al*. A systematic review of the longitudinal relationships between subjective sleep disturbance and menopausal stage. *Maturitas*. 2014;**79**(4):401–412.
30. Lampio L, Polo-Kantola P, Himanen SL, *et al*. Sleep during menopausal transition: a 6-year follow-up. *Sleep*. 2017;**40**(7). doi:10.1093/sleep/zsx090.
31. Ferrie JE, *et al*. A prospective study of change in sleep duration: associations with mortality in the Whitehall II cohort. *Sleep*. 2007;**30**(12):1659–1666.
32. Tang NK, *et al*.. Changes in sleep duration, quality, and medication use are prospectively associated with health and well-being: analysis of the UK Household Longitudinal Study. *Sleep*. 2017;**40**(3). doi:10.1093/sleep/zsw079.
33. Chen HC, *et al*. Predictors of change in self-reported sleep duration in community-dwelling older adults: the shih-pai sleep study, Taiwan. *Sci Rep*. 2017;**7**(1):4729.
34. Matthews KA, *et al*. Does mid-life aging impact women's sleep duration, continuity, and timing?: a longitudinal analysis from the Study of Women's Health Across the Nation. *Sleep*. 2020;**43**(4). doi:10.1093/sleep/zsz259.
35. Kim M, *et al*. Association between objectively measured sleep quality and physical function among community-dwelling oldest old Japanese: a cross-sectional study. *Geriatr Gerontol Int*. 2015;**15**(8):1040–1048.
36. Buchmann N, *et al*. Sleep, muscle mass and muscle function in older people. *Dtsch Arztebl Int*. 2016;**113**(15):253–260.
37. Campanini MZ, *et al*. Duration and quality of sleep and risk of physical function impairment and disability in older adults: results from the ENRICA and ELSA cohorts. *Aging Dis*. 2019;**10**(3):557–569.
38. Friedman EM. Self-Reported sleep problems prospectively increase risk of disability: findings from the survey of midlife development in the United States. *J Am Geriatr Soc*. 2016;**64**(11):2235–2241.
39. Lee G, *et al*. Sleep quality and attention may correlate with hand grip strength: FARM study. *Ann Rehabil Med*. 2018;**42**(6):822–832.
40. Suwa M, *et al*. Age-related reduction and independent predictors of toe flexor strength in middle-aged men. *J Foot Ankle Res*. 2017;**10**:15.
41. Sternfeld B, *et al*. The effect of a healthy lifestyle on future physical functioning in midlife women. *Med Sci Sports Exerc*. 2017;**49**(2):274–282.
42. Guralnik JM, *et al*. Lower extremity function and subsequent disability: consistency across studies, predictive models, and value of gait speed alone compared with the short physical performance battery. *J Gerontol A Biol Sci Med Sci*. 2000;**55**(4):M221–M231.
43. Perera S, *et al*. Meaningful change and responsiveness in common physical performance measures in older adults. *J Am Geriatr Soc*. 2006;**54**(5):743–749.
44. Spira AP, *et al*. Association between insomnia symptoms and functional status in U.S. older adults. *J Gerontol B Psychol Sci Soc Sci*. 2014;**69 Suppl 1**:S35–S41.
45. Vaz Fragoso CA, *et al*.; Lifestyle Interventions and Independence in Elder Study Group. Sleep-wake disturbances in sedentary community-dwelling elderly adults with functional limitations. *J Am Geriatr Soc*. 2014;**62**(6):1064–1072.
46. Malinowska KB, *et al*. Self-reported quality of sleep is associated with physical strength among community-dwelling young-old adults. *Geriatr Gerontol Int*. 2017;**17**(11):1808–1813.
47. Fu L, *et al*. The relationship between sleep duration, falls, and muscle mass: a cohort study in an elderly Chinese population. *Rejuvenation Res*. 2019;**22**(5):390–398.
48. Peng X, *et al*. Associations between objectively assessed physical fitness levels and sleep quality in community-dwelling elderly people in South China. *Sleep Breath*. 2019;**23**(2):679–685.
49. Furtado F, *et al*. Chronic low quality sleep impairs postural control in healthy adults. *PLoS One*. 2016;**11**(10):e0163310.
50. Umemura GS, *et al*. Social jetlag impairs balance control. *Sci Rep*. 2018;**8**(1):9406.
51. Orff HJ, *et al*. Discrepancy between subjective symptomatology and objective neuropsychological performance in insomnia. *Sleep*. 2007;**30**(9):1205–1211.
52. Lord SR, *et al*. Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people. *J Gerontol A Biol Sci Med Sci*. 2002;**57**(8):M539–M543.
53. Bohannon RW. Muscle strength: clinical and prognostic value of hand-grip dynamometry. *Curr Opin Clin Nutr Metab Care*. 2015;**18**(5):465–470.
54. Ward RE, *et al*. Functional performance as a predictor of injurious falls in older adults. *J Am Geriatr Soc*. 2015;**63**(2):315–320.
55. Rantanen T, *et al*. Midlife hand grip strength as a predictor of old age disability. *JAMA*. 1999;**281**(6):558–560.
56. Taipale HT, *et al*. Muscle strength and sedative load in community-dwelling people aged 75 years and older: a population-based study. *J Gerontol A Biol Sci Med Sci*. 2011;**66**(12):1384–1392.
57. Matthews KA, *et al*. Similarities and differences in estimates of sleep duration by polysomnography, actigraphy, diary, and self-reported habitual sleep in a community sample. *Sleep Health*. 2018;**4**(1):96–103.
58. Young T, *et al*. Objective and subjective sleep quality in premenopausal, perimenopausal, and postmenopausal women in the Wisconsin Sleep Cohort Study. *Sleep*. 2003;**26**(6):667–672.
59. Mallinson DC, *et al*. Subjective sleep measurement: comparing sleep diary to questionnaire. *Nat Sci Sleep*. 2019;**11**:197–206.
60. Peppard PE, *et al*. Increased prevalence of sleep-disordered breathing in adults. *Am J Epidemiol*. 2013;**177**(9):1006–1014.
61. Buysse DJ. Sleep health: can we define it? Does it matter? *Sleep*. 2014;**37**(1):9–17.
62. Auyeung TW, *et al*. Sleep duration and disturbances were associated with testosterone level, muscle mass, and muscle strength–A cross-sectional study in 1274 older men. *J Am Med Dir Assoc*. 2015;**16**(7):630.e1–630.e6.