Poor sleep quality and physical performance in older adults

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Abstract

Objectives: This study aimed to examine the association between sleep quality and physical performance among a group of UK community-dwelling older adults, according to sex. Methods: Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI). Physical performance was assessed using a short physical performance battery (SPPB), a timed up-and-go, and a hand-grip strength test. Results: Of 591 eligible study members, 401 completed the PSQI. In regression analyses, men who reported poor sleep quality were significantly more likely to have a poor SPPB score, even after adjustment for confounding factors (OR=2.54, 95% CI 1.10-5.89, p=0.03). The direction of the relationship was reversed among women, where those who reported poor sleep were less likely to have a low SPPB score (OR=0.36, 95% CI 0.15-0.85, p=0.02). Poor sleep quality was associated with poorer hand-grip strength among women (regression coefficient=-0.34 z-score, 95% CI -0.64, -0.04, p=0.03), but this relationship was not observed among men (regression coefficient=0.28 z-score, 95% CI -0.01, 0.57, p=0.06). Conclusion: We found evidence of an association between poor sleep quality and poorer physical performance in older adults, though there appear to be important sex differences.

Key words: Sleep, Physical Performance, Grip strength, Sarcopenia, Muscle, Ageing

Introduction

Physical function declines with advancing age which can fundamentally affect health and well-being. When physical function becomes poor, it can increase the risk of falls and fractures,[1] and reduce an individual's ability to carry out everyday activities.[2] This, in turn, leads to a loss of autonomy and independence, and increases the costs of care and caregiver burden.[3] Physical performance measures such as hand-grip strength and balance are primary indicators of overall physical function, and are independently predictive of future morbidity and mortality.[4-6]

Sleep quality is also known to decline in later life.[7] In the UK, around a third of older adults report disturbed sleep.[8] However, poor sleep quality among older people is not necessarily due to ageing alone. Multiple factors that are associated with the ageing process can affect sleep quality, for example changes in physical or mental health, or changes in social engagement, lifestyle, and environment.[9] Sleep quality is a multidimensional construct including sleep latency, wake after sleep onset, number and frequency of night awakenings, as well as subjective reports of feeling well-rested and refreshed upon awakening. Poor sleep quality in older people is associated with poorer quality of life,[10] increased morbidity,[11] and increased mortality.[12]

As both physical performance and sleep quality decline with age, an association between them is plausible. Sleep may interact with muscle mass and strength through metabolic, hormonal, and immunological factors,[13] which may in turn have an effect on physical performance. For example, sleep deficit down-regulates the hormones insulin-like growth factor 1 (IGF-1) and testosterone which play central roles in protein synthesis pathways and thus maintenance of muscle mass.[13,14] Several studies have demonstrated an association between poor physical performance and poor sleep, though most have been conducted in younger adults,[15] athletes,[16] or in clinical populations of older adults, such as those with osteoarthritis or cancer.[17,18] Others have focussed on the association between physical performance and sleep duration or specific sleep disorders such as sleep-disordered breathing, rather than sleep quality.[19,20] Two particularly noteworthy studies are those by

Goldman *et al.*[21] and Dam *et al*.[22] which both involved around 2,800 participants in the United States; the first was among women only and the second among men only. These studies used objective measures of sleep (wrist actigraphy and polysomnography) and included physical performance measures such as walking speed, chair stands, and hand-grip strength. Both studies concluded that poorer sleep measures were associated with worse physical performance.

Few studies have explored sex differences in relation to sleep quality and physical performance outcomes,[13,23,24] thus there is a limited understanding. To our knowledge, no studies that have assessed sex differences in the association have been conducted among UK populations. In fact, much of the research into the association of sleep and physical performance has been completed in the United States, China and Japan with fewer studies based on European populations. One study of sleep duration and physical performance has been conducted in the UK, and this was among older adults.[25] It showed that long sleep duration (>9 hours) was associated with poorer hand-grip strength and very slow walking speed at baseline, however differences between men and women were not explored. If interventions to improve physical performance or sleep are to be designed and targeted appropriately, it should not be assumed that the relationship will be identical across countries and/or ethnicities, or sex. We therefore sought to examine the potential association between sleep quality and physical performance characteristics in a large UK cohort of older adults and to assess differences in the association according to sex.

Methods

Study design and participants

Participants were recruited from the established Hertfordshire Cohort Study (HCS).[26] The HCS is a prospective, longitudinal, population-based study of the lifecourse origins of disease among people born in Hertfordshire, UK, between 1931-1939. In 2011-2012, participants were contacted to ask if they would be interested in taking part in a follow-up study. Those that agreed were visited at home by a trained research nurse, who administered a questionnaire and conducted a clinical examination. The participants were then given a second questionnaire which included a sleep assessment tool to complete in their own time and return to the study team in a pre-paid envelope. The majority (73%) of the participants completed the second questionnaire on the same day as the nurse-assessment. The median (IQR) time in days between the nurse-assessment and completing the second questionnaire was 0 (0 - 1), and the range was 0 - 40 days.

Sleep Assessment

Sleep quality was assessed using the validated and reliable Pittsburgh Sleep Quality Index (PSQI).[27] The PSQI is comprised of seven sub-components: 1) subjective sleep quality; 2) sleep latency (time taken to initiate sleep); 3) sleep duration; 4) sleep efficiency (the ratio of total sleep time to time in bed); 5) sleep disturbance; 6) use of sleep-promoting medication (prescribed or over-the-counter); and 7) daytime dysfunction. Participants provide subjective sleep estimates based on the previous month. The answers were used to generate scores for each of the seven sub-components, which ranged 0-3. A global PSQI score was generated by summing the scores of the sub-components ranging 0-21 with higher scores indicating poorer sleep quality. A score of more than 5 is indicative of poor sleep.[27] This cut-off has been shown to have high specificity and sensitivity for distinguishing poor sleepers and healthy controls.[27]

Physical Performance Assessment

Physical performance was assessed using the short physical performance battery (SPPB),[28] a timed up-and-go (TUG) test and a hand-grip strength test. The SPPB is made up of a walking speed test, a chair rise test, and a standing balance test. To test walking speed, participants were asked to walk 8 feet (ft) at their customary pace whilst being timed using a stopwatch. The chair rise test involved participants moving from a sitting position (in a straight-backed chair) to a fully upright standing position five times as quickly as possible with their arms crossed across their chest while being timed. The standing balance test involved a semi-tandem stand where participants placed one foot in front of the other such that the big toe of one foot was touching the side of the heel of the other. If participants could not hold the semi-tandem stand for 10 seconds, they did a side-by-side stand (standing with the feet side-by-side). If they could hold the semi-tandem stand for 10 seconds, they also attempted a full tandem stand where participants placed one foot in front of the other (touching heel-to-toe) and held this position for as long as they could up to 10 seconds. A binary variable with a cut-off of 5 seconds was calculated for the full tandem stand, as it could not be analysed continuously due to being censored at 10 seconds. Those who did not perform the full tandem stand because they could not hold the semi-tandem stand were recorded as 0 seconds and included in the tandem stand <5 seconds group for analysis. Performance on these tests was measured and reported individually, and also used to calculate a SPPB score.

The SPPB score was calculated as follows. For the walking speed and chair rise tests, those who could not complete the test were given a score of 0. The rest of the participants' times were divided into quartiles and given a score of 1-4, slowest to fastest quartile. For the balance test, if the participant maintained balance in the full tandem stand for 10 seconds, they were given a score of 4; if they obtained a time ≥3 and <10 seconds, they scored 3; if they obtained a time of <3 seconds but were able to maintain a semi-tandem stand, they scored 2; if they could not do the semi-tandem stand but could do the side-by-side stand, they scored 1; and if they could not do either the semi-tandem or the side-by-side stand, they scored 0. The scores were summed for the three measures, with a maximum of 12 and a minimum of 0. In keeping with previous work, those with a score equal to or lower than 9 were designated as having low physical performance.[29,30]

Two other physical performance measures were used: a timed up-and-go (TUG) test and a hand-grip strength test. For the TUG test, participants began seated in a chair with arms and were asked to stand, walk at their customary pace to a marked line at 3 metres, then turn and walk back to sit in the chair while being timed.[31] Hand-grip strength was measured using a Jamar hand-held isokinetic dynamometer while the participant sat in a chair with their wrist just over the end of the arm of the chair in a neutral position.[32] The participants were given three attempts on each hand and the highest value measured in kilograms (kg) was used in analyses.

Covariates

Weight was measured to the nearest 0.1 kg using a calibrated scale, and height was measured to the nearest 0.001 m using a portable stadiometer. Body mass index (BMI) was calculated using the equation kg/m^2. The nurse-administered questionnaire included items about demographics, general health, activity time (frequency and duration spent walking outside, cycling, gardening, doing sports and carrying out household tasks in the last two weeks, converted into average minutes per day for analysis), and lifestyle (smoking and alcohol consumption). Alcohol consumption in units per week was calculated by converting the usual amount consumed of different alcoholic drinks (beer, wine, spirits/liqueurs) into units and multiplying this by the frequency of consumption of each type of alcoholic drink. As per previous research among this cohort,[26] social class was coded on the basis of current or most recent full-time occupation for men and never-married women, and on the basis of the husband's occupation for ever-married women, and categorised into two groups: classes I-IIINM (non-manual) and IIIM-V (manual) of the Standard Occupational Classification 1990 (SOC90) classification of social class. Participants were asked if they had any of the following comorbidities at the time of interview, and the total number was summed: high blood pressure, diabetes, respiratory disease, rheumatoid arthritis, multiple sclerosis, thyroid disease, vitiligo, depression, Parkinson's disease, heart disease, peripheral arterial disease, stroke, osteoporosis, and cancer. Participants were also asked if they regularly took any medications, and the number of these was summed.

Statistical Analysis

Demographic, physical performance and sleep characteristics of study participants were described using frequencies and percentages for dichotomous or categorical variables, and means and standard deviations (SD) or medians and interquartile ranges (IQR) as appropriate for continuous variables.

The association of poor sleep quality (PSQI >5) with physical performance was assessed using logistic regression for dichotomous outcome variables (SPPB score and tandem stand), and linear regression for continuous outcome variables (8ft walk, chair rises, TUG and hand-grip strength). Chair rise time, TUG time, 8ft walk and hand-grip strength were transformed to Fisher Yates (FY) z-scores using the Fisher-Yates rank-based inverse normal transformation to normalise the data. We conducted all analyses for men and women separately due to significant interactions of two PP measures with gender (low overall physical performance (p=0.005) and hand-grip strength (p=0.007)), and our stated aim of exploring gender differences. Two models of adjustment were used. The first model adjusted for age, smoker status, alcohol consumption, social class, BMI and activity time, as these were all significantly associated with at least one of the physical performance outcomes. The second model also adjusted for the number of comorbidities and the number of medications to assess whether these variables had any influence on the relationship between sleep quality and physical performance. These covariates, aside from social class and number of medications, have typically been included in models in similar studies.[13,24] The analyses were repeated for each of the seven sub-components of the PSQI. A sensitivity analysis was conducted excluding participants who were taking any medications which may affect their sleep (including statins, calcium-channel blockers, beta-blockers, and codeine containing drugs). Cases were omitted from analyses where data was missing for variables included in the model (available case analysis).

The analyses were conducted with Stata version 14, and a p-value of <0.05 was considered statistically significant.

Ethical approval and consent

Ethical approval was granted by the Hertfordshire Research Ethics Committee, reference number 10/H0311/59, and all participants provided written, informed consent.

Results

A total of 591 HCS participants were eligible to participate, of whom 443 (75%) provided written informed consent to participate in the study. Of these, 406 (91%) returned the self-completed questionnaire. The PSQI was completed at least in part by 401 participants. A global PSQI score was calculated for those who had completed all of the PSQI sub-components (n=373). Where data were missing for one or more sub-components (N=28), a global PSQI score was not generated and the individual was excluded from analyses relating to global scores. However, these individuals were included in the analyses of sub-components for the sections they had completed. Participant characteristics were compared between those with all the PSQI data, those with just some of the PSQI data and those with none of the PSQI data. There were no significant differences except that those with no PSQI data were more likely to be a current smoker and more likely to have poor tandem stand times (data not shown).

Table 1 shows the demographic characteristics of the 401 participants included in analyses. The mean age of men was 75.5 years and the mean age of women was 75.8 years. The mean BMI for men was 27.7 kg/m2 and for women was 28.6 kg/m2. There were no statistically significant differences between men and women with respect to age, BMI, social class, the number of medications or the number of comorbidities. Men had a higher alcohol consumption (median (IQR) 6.5 (1.0-14.0) units per week) compared to women (median (IQR) 0.5 (0.0-4.0) units per week), $p<0.01$. Men were also more likely to have smoked than women (64.5% of women had never smoked compared to 40.3% of men), $p<0.01$.

The physical performance and sleep characteristics of the study participants are shown in Table 2. The median SPPB score calculated from three of the tests (8 ft walk, chair rises, and tandem stands) was nine for men, and eight for women. With regards to sleep assessment, the median PSQI score was four for men and five for women, with 37% of men and 45% of women scoring more than five, which is indicative of poor sleep.[27]

The association of poor sleep quality (PSQI >5) with physical performance is reported in Table 3. Among men, poor sleep was associated with having a low overall SPPB score after adjustment for age, smoking, alcohol, social class, BMI and activity time (OR=2.60, 95% CI 1.15-5.89, p=0.02). This association remained after additional adjustment for the number of comorbidities and the number of medications (OR=2.54, 95% CI 1.10-5.89, p=0.03). Sub-component analyses indicated that in particular, more sleep disturbance was associated with a higher likelihood of a poor SPPB score for men (Table A, appendix 1). The direction of the relationship was reversed among women, where poor sleep was associated with a lower likelihood of a poor SPPB score, though this association was only statistically significant when the number of comorbidities and medications were included in the adjustments (OR=0.36, 95% CI 0.15-0.85, p=0.02). Contrary to men, sub-component analyses indicated that sleep duration and habitual sleep efficiency were associated with SPPB among women, where shorter duration and worse sleep efficiency were associated with better SPPB (Table A, appendix 1). Overall poor sleep quality (PSQI >5) was not associated with 8 ft walk time, chair rise test, TUG time or tandem stand performance among men or women. Among women, poor sleep was associated with a lower maximum hand-grip strength (regression coefficient=-0.37 z-score, 95% CI -0.66, -0.09, p=0.01); this remained significant after additional adjustment for the number of comorbidities and medications (regression coefficient=-0.34 z-score, 95% CI -0.64, -0.04, p=0.03). The PSQI sub-components subjective sleep quality and daytime dysfunction were associated with hand-grip strength after adjustment for all covariates (Table F, appendix 1). No associations between hand-grip strength and poor overall sleep quality (PSQI >5) or any PSQI sub-components were observed in men.

A sensitivity analysis was performed to exclude people who were on any medication which may affect their sleep. The pattern of the associations between poor sleep and physical performance was generally the same amongst this subgroup (data not shown). However, as the majority of people (70%) were taking medications that may affect their sleep, the sample size of people not taking sleep-affecting medication was very small (51 men and 69 women) meaning the analyses were under-powered to detect statistical significance or produce meaningful results.

Discussion

This study found evidence of a cross-sectional association between poor sleep quality and physical performance in men, where men who reported poor sleep were significantly more likely to have a low overall SPPB score. This association was reversed for women, where women who reported poor sleep were less likely to have a low overall SPPB score. Interestingly, poor sleep quality was associated with poorer hand-grip strength among women, but this relationship was not observed among men.

It is interesting that the individual components of the SPPB (walking speed, chair rises, and standing balance) were not statistically significantly associated with sleep quality in either men or women, but that the composite SPPB score was. This finding suggests that overall physical functioning is related to sleep quality, rather than individual skills such as balance.

These results are similar to those from a cross-sectional study of older adults in Japan[24] where men who had poor sleep quality (measured by PSQI) had poorer physical performance than men with good sleep quality, but the same was not found among women. Conversely, Koh et al.[23] found that sleep quality (measured by PSQI) was associated with physical performance (SPPB score) among women and not men in their study of Korean older adults. Our finding that poor sleep quality was associated with poorer hand-grip strength in women but not men is similar to findings of a study of older people in Germany,[13] where women with poor sleep had reduced hand-grip strength but no association was seen among men.

While these previous studies have found associations between sleep and PP in one sex but not the other, our study is the first to find a difference in directionality between the sexes for the association between sleep and overall SPPB score. There are a number of possible explanations for these findings. The difference could be due to the men and women in the study subjectively assessing their sleep differently so that the pattern of association with PP appears to be different.[33] Changes in sex hormones with age which affect sleep and physiology may also have an impact on the differences observed between men and women. Alternatively, this result could be a spurious association due to the number of statistical tests conducted. Further research is needed to determine whether this is a robust finding or due to chance.

That women with poor sleep quality were less likely to have a low overall SPPB score but more likely to have a poor hand-grip strength score appears discrepant. One hypothesis is that this inconsistency may be related to the physiological areas involved in these tasks (the SPPB primarily assesses lower extremity functioning whereas the grip-strength test is focussed on the upper extremity of the body) if the mechanism by which sleep and physical performance are associated acts differently on different parts of the body. The authors are not aware of any studies investigating the physiological mechanisms behind the association between sleep quality and physical performance.

To our knowledge, this is the first study to examine the association between sleep quality and physical performance among community-dwelling older adults in the UK. Previous research has predominantly been conducted in the United States, China and Japan. One of the strengths of this study is the sampled population. The individuals recruited were a non-selective community-dwelling population who were born in Hertfordshire, UK. HCS characteristic and mortality patterns have previously been demonstrated to be similar to those of the nationally representative Health Survey for England .[26] However, it should be noted that the sample included in this analysis does not represent the whole of the HCS cohort. Additionally, the cohort is predominantly White so results may not be generalisable to other ethnic groups. As with all cohort studies there is also the possibility of healthy responder bias, where the more unwell members of the population contacted are less likely to participate due to their ill-health.

A limitation of this study is that it does not include a measure of sleep-disordered breathing. Sleep-disordered breathing causes hypoxia which in turn may lead to muscle wasting and weakness.[34] The average BMI of both the men and women in this group was in the overweight range, so it is possible that obstructive sleep apnea (OSA) (the most common form of sleep-disordered breathing) was contributing to poor sleep quality and physical decline. To address this, models were adjusted for BMI in our analyses.

The sleep quality data in the current study were self-reported, and therefore may have been affected by biases including social desirability or selective recall bias. This may be especially relevant for the sub-components, which are based on single items. While multi-night laboratory polysomnography is the most accurate method of measuring sleep, it is extremely resource intensive for a large sample. Self-reported sleep data are commonly used for large studies, and the PSQI is a well utilised tool for assessment of sleep quality. While the PSQI cannot be used to screen for polysomnographic sleep abnormalities,[35] it has been shown to be a useful, valid and reliable tool for the assessment of habitual sleep quality and is often independently associated with health outcomes.[36-38]

A further limitation of this study is that, in the analysis of the association between sleep and PP, some of the participants had missing data for PP measures or adjustment variables. To maximise power, we used available case analysis where each individual model included all participants who had complete data for that model (sample sizes presented in table 3). This means that the samples differ across analyses, which could have led to some bias in results and reduces generalisability.

While we have shown that physical performance and sleep could be related among older men and women, the cross-sectional nature of the study prevents the assessment of whether this is a causal relationship or of the longitudinal nature of the relationship. However, a few studies have assessed the relationship between sleep and physical performance longitudinally.[39,40] A prospective study of older women reported that objectively measured poorer sleep quality predicts substantial decline in hand-grip strength over five years, but not decline in gait speed.[39] Similar findings were reported for the association between baseline sleep quality and activities of daily living functioning at 6-month follow-up among residents of assisted living facilities.[40] While there have been several randomised controlled studies measuring the effects of sleep on physical performance among younger adults and athletes,[15,41] the authors are not aware of any such intervention studies amongst older adults.

In conclusion, we found evidence of an association between poor sleep quality and physical performance in UK community-dwelling older adults, as has been reported by studies in other countries. These results also demonstrate important sex differences in the relationship between sleep quality and physical performance. Further prospective longitudinal studies among community dwelling older adults to confirm these cross-sectional findings are warranted.

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Table 1. Demographic characteristics of the study participants

Characteristic	Men		Women		p-value[1]
	Total *n*	Value	Total *n*	Value	
Age (years), mean (SD)	201	75.5 (2.5)	200	75.8 (2.6)	0.29
BMI (kg/m^2), mean (SD)	200	27.7 (3.7)	197	28.6 (5.1)	0.05
Social Class, *n* (%)	191		200		0.68
I-IIINM		82 (42.9)		90 (45.0)	
IIIM-V		109 (57.1)		110 (55.0)	
Activity time in last 2 weeks (min/day), median (IQR)[2]	187	181 (105-270)	191	200 (135-284)	0.10
Alcohol consumption (units per week), median (IQR)	201	6.5 (1.0-14.0)	200	0.5 (0.0-4.0)	<0.01*
Smoker status, *n* (%)	201		200		<0.01*
Never		81 (40.3)		129 (64.5)	
Ex		112 (55.7)		67 (33.5)	
Current		8 (4.0)		4 (2.0)	
Number of medications, median (IQR)	201	5 (2-6)	200	4 (2-7)	0.90
Number of co-morbidities, *n* (%)[3]	201		200		0.15
0		38 (18.9)		49 (24.5)	
1		74 (36.8)		56 (28.0)	
2		55 (27.4)		48 (24.0)	
3		19 (9.5)		23 (11.5)	
4 or more		15 (7.5)		24 (12.0)	

* Significant at the 5% level

[1] p-value for difference between men and women

[2] Activity time based on average minutes per day spent on walking outside, cycling, gardening, sports and household tasks in the last two weeks

[3] Number of co-morbidities out of high blood pressure, diabetes, lung disease, rheumatoid arthritis, multiple sclerosis, thyroid disease, vitiligo, depression, Parkinson's disease, heart disease, peripheral arterial disease, stroke, osteoporosis, and cancer

BMI = body mass index

SD = standard deviation

IQR = interquartile range

n = number

Table 2. Physical performance and sleep characteristics of the study participants

Characteristic	Men		Women		p-value[1]
	Total *n*	Value	Total *n*	Value	
SPPB score, median (IQR)	187	9 (7-11)	180	8 (7-10)	0.01*
8 feet walk test (seconds), median (IQR)	191	3.0 (2.75-3.60)	190	3.2 (2.91-4.00)	<0.01*
Chair rises (seconds), median (IQR)	178	15.7 (13.6-18.7)	171	16.7 (13.7-19.8)	0.13
Tandem stand <5 seconds, *n* (%)	195	21 (10.8)	192	28 (14.6)	0.26
Timed up and go (TUG) test (seconds), median (IQR)	188	11.3 (10.0-13.0)	187	11.9 (10.0-14.0)	0.16
Maximum hand-grip strength (kg), median (IQR)	200	36.5 (32.0-41.0)	200	21.0 (18.0-26.0)	<0.01*
PSQI score, median (IQR)	187	4 (2-7)	186	5 (3-9)	0.02*
PSQI score >5, *n (%)*	187	69 (36.9)	186	84 (45.2)	0.11

* Significant at the 5% level

[1] p-value for difference between men and women

SPPB = Short Physical Performance Battery

IQR = interquartile range

n = number

PSQI = Pittsburgh Sleep Quality Index

Table 3. The association of poor sleep quality (PSQI >5) with physical performance

	Men							Women						
	Adjusted [1]				Adjusted [2]			Adjusted [1]				Adjusted [2]		
	n	Odds ratio (95% CI)	p value		n	Odds ratio (95% CI)	p value	n	Odds ratio (95% CI)	p value		n	Odds ratio (95% CI)	p value
Low SPPB score (≤9)	153	2.60 (1.15, 5.89)	0.02*		153	2.54 (1.10, 5.89)	0.03*	157	0.50 (0.23, 1.09)	0.08		157	0.36 (0.15, 0.85)	0.02*
Poor tandem stand time (<5 seconds)	162	0.82 (0.28, 2.38)	0.71		162	0.82 (0.27, 2.52)	0.73	165	1.10 (0.42, 2.92)	0.84		165	1.04 (0.37, 2.89)	0.94
	n	Regression coefficient (95% CI)	p value		n	Regression coefficient (95% CI)	p value	n	Regression coefficient (95% CI)	p value		n	Regression coefficient (95% CI)	p value
8 feet walk time$^{\alpha}$	155	0.11 (-0.21, 0.42)	0.50		155	0.07 (-0.25, 0.39)	0.66	165	-0.02 (-0.28, 0.25)	0.91		165	-0.15 (-0.41, 0.12)	0.28
Chair rise time$^{\alpha}$	147	0.27 (-0.04, 0.59)	0.08		147	0.28 (-0.03, 0.58)	0.08	148	-0.19 (-0.49, 0.11)	0.22		148	-0.30 (-0.60, 0.01)	0.06
Timed up-and-go (TUG) time$^{\alpha}$	153	0.23 (-0.05, 0.51)	0.11		153	0.18 (-0.10, 0.47)	0.21	162	-0.04 (-0.31, 0.23)	0.78		162	-0.13 (-0.41, 0.14)	0.34
Max hand-grip strength$^{\alpha}$	163	0.24 (-0.04, 0.52)	0.09		163	0.28 (-0.01, 0.57)	0.06	174	-0.37 (-0.66, -0.09)	0.01*		174	-0.34 (-0.64, -0.04)	0.03*

$^{\alpha}$ Fisher Yates z score

* Significant at the 5% level

[1] Adjusted for age, smoking, alcohol, social class, BMI and activity time

[2] Adjusted for age, smoking, alcohol, social class, BMI, activity time, number of comorbidities and number of medications

SPPB = Short Physical Performance Battery

Appendix 1. PSQI sub-component analysis results

Table A. Associations of PSQI domains with low physical performance score (≤9)

	Men								Women							
	Adjusted[1]				Adjusted[2]				Adjusted[1]				Adjusted[2]			
	N	Odds Ratio	95% CI	p-value	N	Odds Ratio	95% CI	p-value	N	Odds Ratio	95% CI	p-value	N	Odds Ratio	95% CI	p-value
Sleep quality	165	1.11	(0.63, 1.93)	0.72	165	1.11	(0.62, 1.98)	0.73	168	0.97	(0.56, 1.67)	0.90	168	0.80	(0.44, 1.45)	0.47
Sleep latency	163	1.46	(0.89, 2.38)	0.13	163	1.39	(0.84, 2.31)	0.20	161	1.33	(0.86, 2.06)	0.21	161	1.27	(0.81, 1.99)	0.29
Sleep duration	164	1.56	(0.96, 2.54)	0.07	164	1.57	(0.95, 2.58)	0.08	167	0.69	(0.44, 1.07)	0.10	167	0.56	(0.34, 0.91)	0.02*
Habitual sleep efficiency	159	1.32	(0.92, 1.89)	0.14	159	1.26	(0.87, 1.83)	0.23	166	0.76	(0.55, 1.07)	0.11	166	0.69	(0.48, 0.98)	0.04*
Sleep disturbances	166	2.65	(1.26, 5.57)	0.01*	166	2.49	(1.17, 5.27)	0.02*	169	0.74	(0.34, 1.58)	0.43	169	0.62	(0.28, 1.38)	0.24
Use of sleep medication	165	1.69	(0.88, 3.25)	0.12	165	1.72	(0.87, 3.37)	0.12	167	1.30	(0.82, 2.05)	0.26	167	1.11	(0.67, 1.82)	0.69
Daytime dysfunction	163	1.71	(0.91, 3.22)	0.10	163	1.59	(0.82, 3.12)	0.17	165	0.92	(0.49, 1.72)	0.80	165	0.87	(0.45, 1.67)	0.67

* Significant at the 5% level

[1] Adjusted for age, smoking, alcohol, social class, BMI and activity time

[2] Adjusted for age, smoking, alcohol, social class, BMI, activity time, number of comorbidities and number of medications

Table B. Associations of PSQI domains with poor tandem stand time (<5 sec)

	Men								Women							
	Adjusted[1]				Adjusted[2]				Adjusted[1]				Adjusted[2]			
	N	Odds Ratio	95% CI	p-value	N	Odds Ratio	95% CI	p-value	N	Odds Ratio	95% CI	p-value	N	Odds Ratio	95% CI	p-value
Sleep quality	174	1.01	(0.49, 2.08)	0.97	174	1.04	(0.50, 2.14)	0.92	175	1.14	(0.56, 2.32)	0.72	175	1.12	(0.53, 2.37)	0.77
Sleep latency	172	1.18	(0.65, 2.16)	0.58	172	1.11	(0.61, 2.03)	0.73	169	1.06	(0.65, 1.72)	0.83	169	1.05	(0.63, 1.74)	0.85
Sleep duration	173	0.87	(0.45, 1.67)	0.68	173	0.87	(0.45, 1.67)	0.67	174	1.11	(0.67, 1.86)	0.68	174	1.10	(0.65, 1.84)	0.73
Habitual sleep efficiency	168	0.77	(0.47, 1.26)	0.30	168	0.79	(0.48, 1.29)	0.34	173	0.86	(0.55, 1.34)	0.51	173	0.84	(0.54, 1.33)	0.47
Sleep disturbances	175	1.66	(0.64, 4.32)	0.30	175	1.69	(0.62, 4.64)	0.31	176	0.71	(0.27, 1.86)	0.48	176	0.66	(0.24, 1.82)	0.43
Use of sleep medication	174	0.91	(0.45, 1.86)	0.80	174	0.89	(0.42, 1.87)	0.75	174	1.20	(0.76, 1.89)	0.44	174	1.20	(0.73, 1.98)	0.47
Daytime dysfunction	172	1.00	(0.45, 2.21)	1.00	172	0.97	(0.43, 2.21)	0.94	172	2.03	(1.07, 3.86)	0.03*	172	2.04	(1.04, 3.99)	0.04*

* Significant at the 5% level

[1] Adjusted for age, smoking, alcohol, social class, BMI and activity time

[2] Adjusted for age, smoking, alcohol, social class, BMI, activity time, number of comorbidities and number of medications

Table C. Associations of PSQI domains with 8 feet walk time (as a sex-specific Fisher Yates z-score)

	Men								Women							
	Adjusted[1]				Adjusted[2]				Adjusted[1]				Adjusted[2]			
	N	Regression coefficient	95% CI	p-value	N	Regression coefficient	95% CI	p-value	N	Regression coefficient	95% CI	p-value	N	Regression coefficient	95% CI	p-value
Sleep quality	167	0.04	(-0.18, 0.27)	0.71	167	0.01	(-0.22, 0.23)	0.94	177	0.03	(-0.17, 0.22)	0.79	177	-0.08	(-0.28, 0.12)	0.42
Sleep latency	165	-0.03	(-0.22, 0.16)	0.77	165	-0.02	(-0.22, 0.17)	0.80	169	0.16	(0.02, 0.29)	0.02*	169	0.12	(-0.02, 0.25)	0.09
Sleep duration	166	0.08	(-0.11, 0.27)	0.42	166	0.06	(-0.13, 0.25)	0.52	176	-0.08	(-0.23, 0.08)	0.33	176	-0.11	(-0.26, 0.04)	0.16
Habitual sleep efficiency	161	0.05	(-0.09, 0.19)	0.48	161	0.04	(-0.10, 0.18)	0.57	175	-0.03	(-0.15, 0.08)	0.58	175	-0.08	(-0.19, 0.04)	0.20
Sleep disturbances	168	0.39	(0.12, 0.67)	0.01*	168	0.38	(0.09, 0.66)	0.01*	178	-0.09	(-0.36, 0.17)	0.49	178	-0.19	(-0.45, 0.08)	0.16
Use of sleep medication	167	0.16	(-0.05, 0.37)	0.14	167	0.13	(-0.08, 0.35)	0.23	176	0.16	(0.03, 0.30)	0.02*	176	0.08	(-0.07, 0.22)	0.28
Daytime dysfunction	165	0.15	(-0.08, 0.38)	0.20	165	0.12	(-0.12, 0.36)	0.34	174	0.19	(-0.01, 0.40)	0.06	174	0.15	(-0.05, 0.35)	0.15

* Significant at the 5% level

[1] Adjusted for age, smoking, alcohol, social class, BMI and activity time

[2] Adjusted for age, smoking, alcohol, social class, BMI, activity time, number of comorbidities and number of medications

Table D. Associations of PSQI domains with chair rise time (as a sex-specific Fisher Yates z-score)

	Men								Women							
	Adjusted[1]				Adjusted[2]				Adjusted[1]				Adjusted[2]			
	N	Regression coefficient	95% CI	p-value	N	Regression coefficient	95% CI	p-value	N	Regression coefficient	95% CI	p-value	N	Regression coefficient	95% CI	p-value
Sleep quality	157	-0.03	(-0.26, 0.20)	0.79	157	-0.03	(-0.25, 0.20)	0.82	160	-0.06	(-0.29, 0.16)	0.59	160	-0.11	(-0.33, 0.11)	0.34
Sleep latency	156	0.11	(-0.09, 0.31)	0.27	156	0.08	(-0.11, 0.27)	0.42	152	-0.07	(-0.24, 0.09)	0.36	152	-0.10	(-0.26, 0.06)	0.22
Sleep duration	156	0.28	(0.10, 0.46)	<0.01*	156	0.27	(0.09, 0.44)	<0.01*	159	-0.09	(-0.28, 0.09)	0.32	159	-0.14	(-0.32, 0.04)	0.12
Habitual sleep efficiency	152	0.13	(-0.02, 0.27)	0.08	152	0.10	(-0.04, 0.25)	0.15	158	-0.08	(-0.21, 0.06)	0.28	158	-0.11	(-0.24, 0.02)	0.11
Sleep disturbances	158	0.08	(-0.22, 0.37)	0.61	158	0.03	(-0.26, 0.32)	0.83	161	-0.02	(-0.32, 0.27)	0.88	161	-0.07	(-0.36, 0.22)	0.64
Use of sleep medication	157	0.24	(0.02, 0.45)	0.03*	157	0.24	(0.03, 0.45)	0.03*	159	0.06	(-0.10, 0.22)	0.46	159	0.00	(-0.16, 0.16)	1.00
Daytime dysfunction	155	0.08	(-0.17, 0.33)	0.53	155	0.05	(-0.20, 0.30)	0.70	157	-0.06	(-0.30, 0.18)	0.63	157	-0.15	(-0.37, 0.08)	0.21

* Significant at the 5% level

[1] Adjusted for age, smoking, alcohol, social class, BMI and activity time

[2] Adjusted for age, smoking, alcohol, social class, BMI, activity time, number of comorbidities and number of medications

Table E. Associations of PSQI domains with timed up-and-go (TUG) time (as a sex-specific Fisher Yates z-score)

	Men										Women								
	Adjusted[1]					Adjusted[2]					Adjusted[1]					Adjusted[2]			
	N	Regression coefficient	95% CI	p-value		N	Regression coefficient	95% CI	p-value		N	Regression coefficient	95% CI	p-value		N	Regression coefficient	95% CI	p-value
Sleep quality	165	0.04	(-0.16, 0.24)	0.71		165	0.02	(-0.18, 0.22)	0.85		174	-0.03	(-0.22, 0.17)	0.80		174	-0.09	(-0.29, 0.10)	0.35
Sleep latency	163	0.08	(-0.09, 0.26)	0.34		163	0.05	(-0.12, 0.22)	0.56		166	0.07	(-0.07, 0.21)	0.31		166	0.05	(-0.09, 0.19)	0.47
Sleep duration	164	0.17	(0.00, 0.34)	0.05*		164	0.17	(0.00, 0.34)	0.05*		173	-0.07	(-0.23, 0.10)	0.42		173	-0.09	(-0.25, 0.07)	0.25
Habitual sleep efficiency	159	0.10	(-0.03, 0.23)	0.12		159	0.08	(-0.05, 0.20)	0.23		172	-0.04	(-0.16, 0.08)	0.47		172	-0.08	(-0.20, 0.04)	0.22
Sleep disturbances	166	0.39	(0.15, 0.64)	<0.01*		166	0.35	(0.10, 0.59)	0.01*		175	-0.05	(-0.32, 0.22)	0.72		175	-0.11	(-0.37, 0.16)	0.43
Use of sleep medication	165	0.13	(-0.06, 0.32)	0.18		165	0.11	(-0.08, 0.30)	0.27		173	0.09	(-0.04, 0.23)	0.19		173	0.02	(-0.12, 0.17)	0.76
Daytime dysfunction	163	0.22	(0.02, 0.43)	0.04*		163	0.16	(-0.05, 0.38)	0.13		171	0.25	(0.05, 0.45)	0.02*		171	0.20	(-0.00, 0.40)	0.05

* Significant at the 5% level

[1] Adjusted for age, smoking, alcohol, social class, BMI and activity time

[2] Adjusted for age, smoking, alcohol, social class, BMI, activity time, number of comorbidities and number of medications

Table F. Associations of PSQI domains with maximum hand-grip strength (as a sex-specific FY z-score)

	Men										Women								
	Adjusted[1]					Adjusted[2]					Adjusted[1]					Adjusted[2]			
	N	Regression coefficient	95% CI	p-value		N	Regression coefficient	95% CI	p-value		N	Regression coefficient	95% CI	p-value		N	Regression coefficient	95% CI	p-value
Sleep quality	175	-0.02	(-0.23, 0.18)	0.84		175	-0.01	(-0.22, 0.20)	0.92		187	-0.27	(-0.48, -0.06)	0.01*		187	-0.23	(-0.45, -0.01)	0.04*
Sleep latency	173	0.04	(-0.14, 0.21)	0.68		173	0.05	(-0.13, 0.23)	0.61		178	-0.16	(-0.31, -0.01)	0.04*		178	-0.13	(-0.28, 0.02)	0.09
Sleep duration	174	-0.04	(-0.21, 0.14)	0.66		174	-0.03	(-0.21, 0.14)	0.69		186	-0.09	(-0.26, 0.08)	0.29		186	-0.08	(-0.25, 0.09)	0.35
Habitual sleep efficiency	169	0.07	(-0.06, 0.20)	0.31		169	0.08	(-0.05, 0.21)	0.22		185	-0.10	(-0.23, 0.03)	0.14		185	-0.08	(-0.21, 0.05)	0.24
Sleep disturbances	176	-0.24	(-0.50, 0.02)	0.07		176	-0.22	(-0.49, 0.05)	0.11		188	-0.17	(-0.45, 0.12)	0.25		188	-0.12	(-0.41, 0.17)	0.40
Use of sleep medication	175	0.05	(-0.13, 0.24)	0.56		175	0.07	(-0.12, 0.26)	0.45		185	-0.16	(-0.30, -0.01)	0.04*		185	-0.14	(-0.30, 0.03)	0.10
Daytime dysfunction	173	-0.09	(-0.30, 0.13)	0.42		173	-0.06	(-0.29, 0.17)	0.59		183	-0.26	(-0.47, -0.05)	0.02*		183	-0.26	(-0.47, -0.05)	0.02*

* Significant at the 5% level

[1] Adjusted for age, smoking, alcohol, social class, BMI and activity time

[2] Adjusted for age, smoking, alcohol, social class, BMI, activity time, number of comorbidities and number of medications