**Title:** Associations between cognitive function, actigraphy-based and self-reported sleep in older community-dwelling adults: findings from The Irish Longitudinal Study on Ageing

**Short title:** Cognitive function and sleep in older Irish adults

Siobhan Scarlett[1], Rose Anne Kenny[1,2], Matthew DL O'Connell[1,3], Hugh Nolan[1], Céline De Looze[1]

[1] The Irish Longitudinal Study on Ageing, Trinity College Dublin, University of Dublin, Ireland
[2] Mercer's Institute for Successful Ageing, St James's Hospital, Dublin, Ireland
[3] Department of Population Health Sciences, School of Population Health and Environmental Sciences, Kings College London, London, UK

Corresponding author: Siobhan Scarlett, The Irish Longitudinal Study on Ageing (TILDA), Trinity Central, 152-160 Pearse Street, Dublin 2, Ireland.

Email: sscarlet@tcd.ie

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**Abstract**

**Objective:** Cognitive impairment is prevalent in older ages. Associations with sleep are well established, however ambiguity remains in which sleep characteristics contribute to this impairment. We examined cross-sectional associations between both self-reported and actigraphy-based sleep and cognitive performance across a number of domains in community-dwelling older adults.

**Methods:** 1,520 participants aged 50 and older with self-reported and actigraphy-based total sleep time (TST) (≤5 hours, 6 hours, 7-8 hours, 9 hours ≥10 hours) and self-reported sleep problems, were analysed. Cognitive function was assessed using the Mini-Mental State Examination (MMSE), Montreal Cognitive Assessment (MoCA), verbal fluency, immediate and delayed recall memory, colour trails tests and choice reaction tests (CRT). Associations between sleep and cognition were modelled using linear and negative binomial regression.

**Results:** Negative associations were found between ≥10 hours of self-reported TST and MoCA error rate (Incidence Rate Ratio[IRR]= 1.42, 95% CI=1.18,1.71, $p$<0.001), verbal fluency (Beta[B]=-2.32 words, 95% CI=-4.00,-0.65, $p$<0.01) and delayed recall (B=-0.91 words, 95% CI=-1.58,-0.25, p<0.05) compared to 7-8 hours. Significant associations with actigraphy-based TST were limited to MoCA error rate in ≤5 hours [IRR=1.22; 95%CI=1.02,1.45, p<0.05] compared to 7-8 hours. Higher numbers of sleep problems were associated with slower performance in CRT cognitive response time (IRR=1.02; 95%CI=1.00,104., p<0.05) and total response time (IRR=1.02 95%CI=1.00,1.04, p<0.05).

**Conclusions:** Self-reported long sleep duration was consistently associated with worse cognitive performance across multiple domains. Marginal associations between cognition and

both actigraphy-based sleep and self-reported sleep problems were also apparent. These results further affirm poor sleep as a risk factor for cognitive impairment.

**Keywords:** Sleep; cognitive impairment; actigraphy; older adults; ageing

**Key points:**

- Sleep was associated with cognitive impairment in community-dwelling older adults.
- The strongest associations were between self-reported long sleep duration and global cognition, executive function and verbal memory.
- Self-reported long sleep duration may be a risk factor for cognitive impairment.
- Longitudinal analyses using actigraphy-based and self-reported measurements are warranted to better understand this relationship.

## Introduction

Cognitive function broadly declines with age, leading to a high incidence of cognitive impairment in older adults.[1-4] This creates health challenges as the global ageing demographic shifts[5] emphasising the need to understand contributing factors. Sleep difficulties are increasingly prevalent with advancing age are common in Alzheimer's disease and have been consistently linked with cognitive impairment.[6-12] However, there remains some ambiguity in which attributes of sleep contribute to impairment.[6,7]

Sleep duration is often shown to have a U-shaped relationship with both short and long duration associated with cognitive impairment.[7] Previous work on self-reported sleep has shown complaints such as insomnia, and long sleep duration to be associated with cognitive impairment[13-15], while others found only short sleep duration to be related.[16,17] Studies also showed varying results across demographic strata and cognitive domains. Potvin et al. found that short sleep duration was linked to cognitive impairment in men, while impairment in women was related to long sleep duration.[18] Miyata et. al showed short sleep duration affected working memory, with others showing memory impairment resulting from poor sleep quality or insomnia, but not short sleep duration.[16] Actigraphy-based total sleep time was shown in some studies to have a weak or no relationship to cognitive impairment in older adults[19-21], however recent research found an association with actigraphy-assessed sleep times.[22,23]

Disparity in findings may be a consequence of inconsistent measurement of sleep and cognitive function.[6] Sleep is typically self-reported in household surveys, while laboratory-based studies often use objective measures such as polysomnography (PSG).[24] Laboratory-based studies using PSG can determine a precise picture of sleep architecture but monitoring is invasive, expensive, and generally spans just 24 hours limiting the ability to measure habitual patterns.[24,25] Actigraphy is non-invasive and causes less disruption to sleep

routines.[26,27] Use of actigraphy has become feasible in larger surveys and allows measurement in home environments where natural sleep patterns can be recorded over longer periods.[25,27] It has been shown that self-reported and actigraphy-based sleep do not correlate well, limiting comparability between methods.[28-33] Few studies have assessed cognitive function with both self-reported and objectively measured sleep, and where it has been possible, studies had limited sample sizes, cognitive testing, measurement periods, confounder information or were based in laboratory settings.[19,22,34-37]

Population studies of older adults such as The Irish Longitudinal Study on Ageing (TILDA) have recently included self-reported and actigraphy-based measurement of sleep. The US National Sleep Foundation recommends between 7-9 hours of sleep for adults aged 26-64 years, and 7-8 hours for those aged 65 years and older.[38] Sleep duration may be negatively impacted by sociodemographic factors or health conditions.[39-47] In Irish older adults, 13.9% recorded sleep durations less than recommended, and 16.5% longer than recommended.[39] Associations between sleep and cognitive outcomes in this population are not yet established. Availability of both self-reported and actigraphy-based sleep measurement, coupled with extensive cognitive measurement and confounder information provides opportunity to analyse associations while addressing previously noted limitations in similar studies.[19,34-36]

This study will investigate cross-sectional associations between self-reported and actigraphy-based sleep duration, self-reported disturbances and cognitive performance in a population-derived sample of community-dwelling older adults.

## Methods

This was a cross sectional study from Wave 3 of TILDA. TILDA is a nationally representative population study of community-dwelling older adults in Ireland. The TILDA study design has been described previously.[48,49] Briefly, the population was randomly sampled using the RANSAM procedure.[50] Household addresses were drawn from the Irish National Geodirectory. Participants provided written consent. Ethical approval was granted from the Trinity College Dublin Faculty of Health Sciences Research Ethics Committee.

The first wave of data collection was completed between October 2009 and February 2011 with 8,175 adults aged 50 and over completing an interview. Wave 3 interview data was collected between March 2014 to October 2015 (n=6,902).[51] Participants completed a structured interview which collected information on their social, health and financial situation. Participants who could not complete the interview due to a cognitive or physical impairment were offered a proxy interview. Only participants who completed a self-interview were included in this analysis (n=6,497) (Figure 1). A health assessment including tests of cognitive function, vision, bone health, walking, balance, grip strength was offered to participants after their interview and carried out by trained research nurses. Anthropometric measurements, blood and hair samples were also taken. Wave 3 included an accelerometer sub-study on health assessment participants using GENEActiv™ Original wrist-worn accelerometers (Activinsights, Cambridgeshire, UK).[52] A limited number of devices were available (n=190) which precluded the study from capturing data on all health assessment participants. Participants were randomly selected following their assessment and asked to wear the device for seven consecutive days to facilitate the sub-study. Data was collected for 1,578 participants.

*GENEActiv™ Device*

The GENEActiv™ accelerometer is a lightweight, robust, waterproof, non-invasive device with a measurement range of ±8g. The device has a maximum logging period of seven days at 100Hz and a body temperature sensor to determine non-wear periods. Sleep data from the devices were processed using a fully automated micro-electrical-mechanical systems classification algorithm.[39,53] Automated threshold detection was used to classify the data into sleep and wake cycles.[39,53] The algorithm was verified previously using actigraphy-recordings matched to sleep diary logs, finding a zero-mean difference suggesting close agreement between measurements.[39,53] The devices were programmed to begin measuring at 9pm on the day of the health assessment and record for a full week with a major sleep period classified for each day.

A Spearman-Brown reliability analysis has shown at least four recorded major sleep periods are required to meet the threshold for an acceptable estimate of total sleep time in this cohort.[39] In a number of cases (n=45), devices were returned with less than four recorded major sleep periods. This occurred where a participant did not wear their device everyday (n=3), or where a technical fault occurred in the field (n=42). This analysis included participants with at least four days of accelerometer data and complete data on self-reported sleep duration and quality (n=1,520).

[Figure 1]

**Sleep Measures**

Participants were asked how likely they were to doze off during the day, with responses ranging from 0 to 3 referring to likelihood of dozing. Participants were also asked how often they have trouble falling asleep, and how often they have trouble waking up too early and not being able to fall asleep again with responses ranging 0 to 2 representing frequency of symptoms.[54] A composite sleep score was derived by summing the items (0-7) with higher

scores representing more sleep problems. Self-reported total sleep time (TST) was classified using a single question which although not formally validated, has routinely been used to capture self-reported sleep in large, epidemiological studies and typically shows the expected correlations with health outcomes.[33,55-57] Participants were asked "Approximately how many hours do you sleep on a weeknight?" with answers rounded to the nearest hour.

Actigraphy-based TST was classified as average total sleep time recorded by the GENEActiv™ device. Actigraphy-based and self-reported TST were categorised as ≤5 hours, 6 hours, 7-8 hours, 9 hours and ≥10 hours to reflect sleep period recommendations and for comparability with studies using similar definitions.[19,38,58,59]

**Cognitive Measures**

This analysis focused on four cognitive domains (Supplementary Table 1).

*Global Cognition* was measured using the Mini-Mental State Examination (MMSE)[60], and the Montreal Cognitive Assessment (MoCA) both of which are widely used in clinical settings.[61] Although the MoCA is understood to be more sensitive for assessing people with mild cognitive impairment, we included both to maximise comparability with other studies.[62]

*Verbal memory* was assessed with an immediate and delayed word recall test using a list of 10 words.[63]

*Processing Speed* was assessed using part one of the Colour Trails Test, where participants are asked to draw a line connecting circles numbered 1-25 in consecutive order,[64] and a computer-based cognitive response test (Choice Reaction Test (CRT)).[65] Participants were instructed to press and hold the central key on a specialised keyboard and press a corresponding yes/no key on appearance of a yes/no stimulus on the screen producing three measures. Cognitive response as the time taken to release the button in response to the

stimulus, movement response as the time taken to press the corresponding stimulus button, and total response as the combined cognitive and movement response time.

*Executive Function* was assessed using two tests. The first was a verbal fluency test, where participants were asked to list as many animals as they could name in one minute.[66] The second was part two of the Colour Trails Test where participants must repeat the instructions from part one while alternating between pink and yellow circles.

**Covariates**

Additional measures recognised as risk factors for sleep or cognitive impairment were adjusted for including age, sex, educational attainment (primary or none/secondary/third level or higher); location of residence (urban/rural); marital status (married/never married/separated or divorced/widowed); employment status (employed/retired or not employed); self-reported exercise group as measured by the Short-Form International Physical Activity Questionnaire (low/moderate/high)[67,68] and smoker status (never or past/current). Depressive symptoms were assessed using the eight-item version of the Centre for Epidemiological Depression Scale (CES-D8), a short-form version of the 20-item scale which has been validated in TILDA where the measurement of latent factors of depression while using fewer items was confirmed.[69] The CES-D8 was included from Wave 3 to shorten the length of the assessment and reduce participant burden.[69,70] Depressive symptoms were measured as scoring nine or higher on the scale.[71] Medications were classified using the Anatomical Therapeutic Chemical (ATC) classification codes. Sleep medications included ATC codes N05A (antipsychotics), NO5B (anxiolytics), N05C (hypnotics and sedatives), and R06A (antihistamines). Antihypertensive medication included ATC codes C02 (antiadrenergic agents), C03 (diuretics), C07 (β blockers), C08 (calcium-channel blockers) and C09 (angiotensin-converting enzyme inhibitors). Antidepressant medication included

ATC code N06A. Participants were asked if they had ever been diagnosed with any chronic conditions including lung disease, asthma, arthritis, osteoporosis, cancer, Parkinson disease, stomach ulcer, varicose ulcer, liver disease, thyroid disease, or kidney disease. Participants were categorised as having no chronic conditions or chronic condition ≥1. Participants were also asked if they had any cardiovascular disease including hypertension, stroke, angina, heart attack, heart murmur atrial fibrillation, or other abnormal heart rhythms. Participants were categorised as having no cardiovascular conditions or cardiovascular condition ≥1. Seasonal variation in actigraphy-based TST has been found previously[39] and was also adjusted for.

**Statistical Analysis**

Statistical analyses were performed using Stata 15.1 (StataCorp. 2017. College Station, TX: StataCorp LLC.). Participant characteristics of actigraphy-based and self-reported TST categories, and self-reported sleep problems were presented. Descriptive characteristics were presented as percentages or means and standard deviations (SD). Means and SD of cognitive tests and TST categories, and correlations between cognitive tests and sleep problems were assessed. Regression analyses were fitted to model mutually adjusted associations between actigraphy-based TST, self-reported TST and sleep problems and all cognitive tests. Both actigraphy-based and self-reported TST were treated as categorical predictor variables with 7-8 hours as a reference category. Sleep problems were treated as a continuous predictor. Model assumptions were tested prior to analysis. Following this, linear models were used for verbal fluency, immediate and delayed recall. Colour Trails 1, 2, cognitive response time, movement time and total time were positively skewed approximating a Poisson distribution. The MMSE and MoCA revealed both a ceiling effect and skewed distribution. For analysis, the number of errors made for MMSE and MoCA (30-Score) was calculated and modelled as

a count process. Negative binomial regression was then used to model MMSE errors, MoCA errors, Colour Trails 1, Colour Trails 2, cognitive response time, movement time and total response time. Linear models were used for verbal fluency, immediate and delayed recall. Models were adjusted for all covariates defined previously. Full model outputs are displayed in supplementary tables 5-14. Cases with complete sleep data were analysed. Some missing data was present in cognitive tests (MoCA: n=8; colour trails 1: n=13; colour trails 2: n=33; CRT: n=133). Statistical significance was set at $p<0.05$.

## Results

*Accelerometer sub-study sample*

The accelerometer sample was characteristically similar to the self-interview sample (Supplementary Table 2). The main difference was a higher prevalence of retired/not employed participants in the accelerometer sample (73.4%) compared to the self-interview sample (67.0%).

*Sample Characteristics by Total Sleep Time categories*

Mean age of the sample was 67.6 years (SD=9.1). 53.7% were female, 34.9% had third level or higher education and 55.8% lived in an urban area (Table 1). The majority were married (72.4%) and either retired or not employed (73.4%).

Approximately 60% of participants had 7-8 hours sleep by both actigraphy (62.4%) and self-reported TST (59.7%). Just 3.7% of participants recorded ≤5 hours of actigraphy-based TST and 6.4% ≥10 hours, while 12.4% of participants self-reported ≤5 hours of TST and 3.2% self-reported ≥10 hours. Concordance between measurements was low (Supplementary Table 3). The highest concordance was in those recording 7-8 hours actigraphy-based TST, with 62.9% of participants also self-reporting 7-8 hours TST. Just 9.5% of those with 9 hours of

actigraphy-based TST also self-reported 9 hours, while 13.4% recording ≥10 hours also self-reported ≥10 hours.

Mean age was highest in the shortest and longest actigraphy-based TST categories. This age gradient was only apparent in the longest self-reported TST categories.

Use of medications was highest in ≥10 hours across both actigraphy-based and self-reported TST categories. Those with ≥10 hours of actigraphy-based TST had the highest prevalence of depressive symptoms, however in self-reported TST, depressive symptoms were highest in those with ≤5 hours. Prevalence of ≥1 cardiovascular conditions was highest in ≤5 hours and ≥10 hours in both actigraphy-based and self-reported TST.

[Table 1]

*Sample characteristics by sleep problems*

Table 2 displays mean (standard deviation) sleep problems by sample characteristics (full outputs in supplementary table 4). The overall sample had a mean of 2.2 (SD=1.6) problems. Sleep problems were highest in those who reported primary/none education, taking sleep medications, anti-depressant medication or depressive symptoms.

[Table 2]

*Cognitive tests by total sleep time categories*

MoCA errors were highest in both ≤5 hours actigraphy-based TST (Figure 2). Similarly, in verbal fluency those with ≤5 hours and ≥10 hours recorded the fewest. In verbal memory, those with ≤5 hours recorded the fewest words in immediate recall and delayed recall, as did those with ≥10 hours. Distributions were similar for almost all other tests, with the exception of CRT movement time where longest times were most notable only in ≥10 hours.

In self-reported TST, differences were most apparent in longer TST. Highest numbers of MoCA errors were recorded in those with 9 hours of self-reported TST and ≥10 hours. One of the largest differences was in the colour trails 1 test, where participants with ≥10 hours recorded completion times nearly 10 seconds longer than other self-reported TST times. Similar, though less pronounced, trends were seen for verbal fluency, immediate and delayed recall.

[Figure 2]

*Cognitive tests by sleep problem scores*

Higher numbers of reported sleep problems were associated with significantly worse performance in cognitive tests, but correlations were weak ranging between 0.05 to 0.10

(Table 3). The strongest association was between CRT cognitive response time and sleep problems, followed by total response time.

[Table 3]

*Regression analyses of cognitive outcomes and sleep parameters*

In actigraphy-based TST, an association was only found with global cognition. Recording ≤5 hours was associated with a higher MoCA error rate than those recording 7-8 hours (Figure 3).

Stronger relationships were seen for longer self-reported sleep. In global cognition, self-reported TST of ≥10 hours was associated with a higher MMSE error rate and a higher MoCA error rate compared to 7-8 hours. Correspondingly in executive function, ≥10 hours self-reported TST was associated with lower verbal fluency scores and 9 hours self-reported TST was associated with slower higher colour trails 2 compared to 7-8 hours. In verbal memory, ≥10 hours self-reported TST were negatively associated with immediate recall scores and delayed recall scores compared to 7-8 hours. ≤5 hours self-reported sleep was not clearly associated with poorer cognitive performance.

Higher scores on the sleep problem scale were associated with a slower CRT cognitive response and CRT total response. There were no clear associations with the other tests.

[Figure 3]

*Discussion*

This study assessed cognitive performance and associations with actigraphy-based and self-reported sleep. Long self-reported sleep duration was consistently associated with poorer cognitive performance. ≥10 hours of self-reported TST was associated with 1.39 times and 1.42 times more errors on the MMSE and MoCA respectively compared to 7-8 hours.

Similarly, ≥10 hours recorded two fewer words in verbal fluency, and one fewer word in both immediate and delayed recall. Associations with actigraphy-based sleep were more limited. Participants recording ≤5 hours of sleep recorded 1.22 times more errors on the MoCA than those recording 7-8 hours. Finally, self-reported sleep problems were associated with processing speed, showing that with each additional point on the sleep problems scale, participants recorded slower times in both CRT cognitive and total response time. This is one of the largest studies using actigraphy-based and self-reported sleep to assess cognitive function in a population derived sample of community-dwelling older adults.

In line with previous studies, we found discrepancies between actigraphy-based and self-reported sleep.[30,35] Concordance between those reporting long sleep and recording long sleep duration was below 14%. Discrepancies may result from overestimation by actigraphy devices where wakeful but motionless periods in bed have been registered as sleep, or where a participant has reported long sleep reflecting time spent in bed rather than prolonged sleep.[72,73] Landry et al. suggest these measurements target different aspects of sleep with each providing valuable insights, and recommend where possible both self-reported and objective methods are included when assessing sleep patterns.[35]

Our finding that self-reported long sleep duration is associated with worse cognitive performance is consistent with previous studies and further affirms long sleep as a risk factor for cognitive impairment.[7,10-15,18,74] We identified this association after extensive adjustment for known confounding variables including medication use and depressive symptoms. Long sleep duration is linked with greater sleep fragmentation and wake after sleep onset, while perception of long sleep duration is associated with health outcomes and said to potentially result from longer time spent in bed, rather than extended sleep periods.[7,11,59,72] It was shown that after controlling for wake after sleep onset, the association between self-reported long sleep duration and cognitive impairment was attenuated.[19] These confounding effects on self-

reported sleep duration emphasise the need for objective measurement to capture a more accurate reflection of the relationship between sleep duration and cognitive impairment.

Similar to previous findings, sleep problems were associated with poorer cognitive performance in processing speed.[75] Processing speed is understood to be a strong predictor of age related cognitive decline and shown to have negative implications in everyday life such as slower functional mobility in older adults.[76,77]

The association with cognitive decline and actigraphy-based TST was not as clear as in self-reported measures. Analyses mutually adjusted for sleep parameters but trends were similar in models which did not. Previous studies have shown a weak or no association with actigraphy-based TST and cognitive impairment.[19-21] We extend these findings by showing in a large sample with an extensive battery of cognitive tests, actigraphy-based TST was not strongly associated with cognitive impairment. Longitudinal analyses using objectively measured sleep duration and quality will further our understanding of this relationship.[7,59]

This study was cross-sectional data meaning temporal direction cannot be established. The sample was relatively young (67.6 years) and healthy. The sample was limited to participants who wore an accelerometer, though found to be characteristically similar to the full sample.[39] There were differences in timings of sleep and cognitive measurements. Self-reported sleep duration and problems were collected during self-interviews. Actigraphy-based sleep was recorded directly after health assessments. It has been shown that this time difference did not contribute to disagreement between actigraphy-based and self-reported measurements.[32] Self-reported sleep refers to average sleep on a weeknight, while actigraphy measurement included weekends. As actigraphy-based sleep requires a minimum number of recordings for reliability, this may be unavoidable where devices can only be worn for a limited period of time. This raises the possibility of weekend and weekday differences, although they were

found to be similar in this population of mainly retired men and women.[39] We used the maximum sampling frequency of the GENEActiv devices which allowed for the highest possible precision, but limited measurement to seven days. Longer periods would provide more reliable estimates of routine sleep patterns and reduce susceptibility to short term changes, but this may not be practical in epidemiological studies.

This study also has a number of strengths. We used a large population-derived cohort of community-dwelling older adults. Self-reported and actigraphy-based measured sleep were available coupled with a comprehensive battery of cognitive tests and confounder information. This addressed limitations of previous studies where either sleep measurement or cognitive testing was limited.

*Conclusion*

Our study shows that sleep is associated with cognitive performance in older adults across a number of cognitive domains, with the strongest associations evident in self-reported long sleep duration. These findings may have clinical relevance, potentially identifying groups of community-dwelling adults at risk of cognitive decline. Longitudinal studies of community-dwelling older adults assessing change in self-reported and objective sleep patterns, and their relationship with cognitive decline, are warranted as a means of understanding the temporal direction of this relationship.

## Conflict of interest

The authors declare no conflict of interest.

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## Data Availability Statement

Researchers interested in using the publicly archived TILDA data may access the data for free from the following sites: Irish Social Science Data Archive at University College Dublin (https://www.ucd.ie/issda/data/tilda/wave3/#d.en.379721). Interuniversity Consortium for Political and Social Research at the University of Michigan (http://www.icpsr.umich.edu/icpsrweb/ICPSR/studies/34315). Further details of access to the Researcher Microdata Files can be made to the corresponding author.

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Table 1. Sample characteristics overall and by actigraphy-based total sleep time and self-reported total sleep time categories

| | Overall (n=1,520) | Actigraphy-based total sleep time (hours) | | | | | Self-reported total sleep time (hours) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ≤5 3.7% (n=56) | 6 10.2% (n=155) | 7-8 62.4% (n=948) | 9 17.4% (n=264) | ≥10 6.4% (n=97) | ≤5 12.4%, (n=189) | 6 18.7% (n=284) | 7-8 59.7% (n=907) | 9 6.1% (n=92) | ≥10 3.2% (n=48) |
| **Age, Mean±Standard Deviation** | 67.6±9.1 | 71.8±10.7 | 66.1±9.2 | 67.2±9.0 | 67.8±8.9 | 70.7±9.2 | 67.4±8.7 | 67.6±9.5 | 67.0±8.9 | 70.8±8.8 | 72.3±10.8 |
| **Sex: Male, %** | 46.3 | 53.6 | 48.4 | 46.2 | 43.8 | 47.5 | 42.9 | 38.7 | 48.6 | 57.6 | 39.6 |
| **Education, %** | | | | | | | | | | | |
| Primary/None | 25.5 | 32.1 | 21.9 | 24.7 | 26.0 | 33.3 | 32.8 | 22.2 | 24.2 | 27.2 | 37.5 |
| Secondary | 39.6 | 32.1 | 42.6 | 39.1 | 40.4 | 42.4 | 42.3 | 41.2 | 39.3 | 33.7 | 39.6 |
| Third Level or higher | 34.9 | 35.7 | 35.5 | 36.2 | 35.6 | 24.2 | 24.9 | 36.6 | 36.6 | 39.1 | 22.9 |
| **Location: Urban, %** | 55.8 | 62.5 | 52.3 | 56.9 | 52.7 | 55.7 | 65.1 | 59.9 | 52.9 | 47.8 | 45.8 |
| **Marital Status, %** | | | | | | | | | | | |
| Married | 72.4 | 55.4 | 72.9 | 74.3 | 75.0 | 55.7 | 72.5 | 69.7 | 74.3 | 65.2 | 64.6 |
| Never Married | 7.7 | 16.1 | 7.7 | 7.8 | 6.1 | 6.2 | 7.9 | 7.0 | 7.8 | 10.9 | 2.1 |
| Separated/Divorced | 6.8 | 1.8 | 20.3 | 5.9 | 8.0 | 10.3 | 10.6 | 7.0 | 6.1 | 7.6 | 4.2 |
| Widowed | 13.1 | 26.8 | 9.0 | 12.0 | 11.0 | 27.8 | 9.0 | 16.2 | 11.8 | 16.3 | 29.2 |
| **Retired/Not Employed, %** | 73.4 | 80.0 | 69.0 | 70.1 | 80.2 | 90.7 | 79.4 | 69.0 | 71.9 | 80.2 | 91.5 |
| **Exercise Group, %** | | | | | | | | | | | |
| Low | 36.1 | 51.0 | 36.8 | 33.3 | 39.4 | 44.7 | 38.7 | 38.7 | 33.3 | 38.8 | 57.8 |
| Moderate | 36.4 | 29.4 | 32.6 | 37.1 | 38.2 | 34.0 | 38.7 | 34.6 | 37.9 | 29.4 | 22.2 |
| High | 27.6 | 19.6 | 30.6 | 29.6 | 22.5 | 21.3 | 22.7 | 26.8 | 28.8 | 31.8 | 20.0 |
| **Smoker: Never/Past, %** | 89.3 | 87.5 | 90.3 | 89.7 | 89.4 | 83.8 | 87.3 | 89.4 | 89.5 | 90.2 | 87.5 |
| **Season** | | | | | | | | | | | |
| Winter | 19.3 | 12.5 | 15.5 | 18.9 | 24.2 | 20.2 | 22.2 | 17.3 | 19.0 | 23.9 | 18.8 |
| Spring | 16.6 | 23.2 | 14.8 | 17.5 | 14.7 | 13.1 | 12.7 | 15.1 | 18.0 | 17.4 | 12.5 |
| Summer | 30.2 | 30.4 | 43.9 | 29.7 | 25.3 | 27.3 | 28.6 | 32.8 | 29.7 | 32.6 | 31.3 |
| Autumn | 33.8 | 33.9 | 25.8 | 34.0 | 35.9 | 39.4 | 36.5 | 34.9 | 33.4 | 26.1 | 37.5 |
| **Takes Sleep Medication, %** | 8.4 | 10.7 | 7.1 | 7.5 | 10.9 | 11.1 | 13.2 | 6.0 | 7.6 | 10.9 | 14.6 |
| **Takes Anti-Hypertensive Medication, %** | 46.3 | 55.4 | 40.7 | 45.6 | 45.3 | 58.6 | 49.7 | 43.7 | 44.9 | 51.1 | 66.7 |
| **Takes Anti-depressant Medication, %** | 9.4 | 19.6 | 6.5 | 7.1 | 13.2 | 20.2 | 11.6 | 8.5 | 7.8 | 17.4 | 18.8 |
| **Body Mass Index Category, %** | | | | | | | | | | | |
| Normal Weight | 23.4 | 18.9 | 24.7 | 24.2 | 19.7 | 25.5 | 24.9 | 21.7 | 24.3 | 19.6 | 16.7 |
| Overweight | 44.8 | 37.7 | 41.6 | 45.3 | 48.7 | 38.8 | 39.7 | 48.7 | 44.4 | 47.8 | 45.8 |
| Obese | 31.8 | 43.4 | 33.8 | 30.5 | 31.7 | 35.7 | 35.5 | 29.6 | 31.3 | 32.6 | 37.5 |
| **Depressive Symptoms, %** | 9.2 | 10.7 | 11.0 | 7.4 | 12.5 | 14.1 | 21.8 | 13.8 | 5.6 | 2.2 | 8.3 |
| **Cardiovascular Condition ≥1, %** | 48.0 | 57.1 | 44.5 | 47.3 | 48.9 | 54.6 | 55.6 | 46.5 | 46.3 | 50.0 | 58.3 |
| **Chronic Condition ≥1, %** | 56.1 | 58.9 | 56.8 | 55.1 | 58.3 | 56.7 | 59.8 | 63.4 | 52.8 | 57.6 | 56.3 |

**Table 2. Sample characteristics by sleep problems score**

| | Sleep Problems Mean±Standard Deviation |
|---|---|
| **Overall** | 2.2±1.6 |
| **Sex** | |
| Male | 2.1±1.7 |
| Female | 2.2±1.6 |
| **Education** | |
| Primary/None | 2.5±1.8 |
| Secondary | 2.2±1.7 |
| Third Level or higher | 2.0±1.5 |
| **Location** | |
| Urban | 2.2±1.7 |
| Rural | 2.1±1.6 |
| **Marital Status** | |
| Married | 2.2±1.6 |
| Never Married | 2.1±1.6 |
| Separated/Divorced | 2.3±1.7 |
| Widowed | 2.2±1.6 |
| **Employment Status** | |
| Retired/Not Employed | 2.3±1.6 |
| Employed | 1.9±1.6 |
| **Exercise Group** | |
| Low | 2.3±1.7 |
| Moderate | 2.2±1.7 |
| High | 2.0±1.5 |
| **Smoker Status** | |
| Never/Past | 2.2±1.6 |
| Current | 2.3±1.8 |
| **Season** | |
| Winter | 2.3±1.7 |
| Spring | 2.2±1.6 |
| Summer | 2.1±1.6 |
| Autumn | 2.2±1.6 |
| **Sleep Medication** | |
| No | 2.1±1.6 |
| Yes | 2.8±1.8 |
| **Anti-Hypertensive Medication** | |
| No | 2.0±1.6 |
| Yes | 2.4±1.7 |
| **Anti-depressant Medication** | |
| No | 2.1±1.6 |
| Yes | 2.6±1.8 |
| **Body Mass Index Category** | |
| Normal Weight | 2.3±1.6 |
| Overweight | 2.2±1.6 |
| Obese | 2.2±1.7 |
| **Depressive Symptoms** | |
| No | 2.1±1.6 |
| Yes | 3.3±1.8 |
| **Cardiovascular Condition ≥1** | |
| No | 2.0±1.6 |
| Yes | 2.4±1.7 |
| **Chronic Condition ≥1** | |
| No | 1.9±1.6 |
| Yes | 2.4±1.7 |

**Table 3. Pearson's correlation results for individual cognitive tests by sleep problem score**

| Cognitive Domain | Cognitive Test | r |
|---|---|---|
| Global Cognition | MMSE Errors | 0.05* |
| | MoCA Errors | 0.10*** |
| Executive Function | Verbal Fluency | -0.06* |
| | Colour Trails 2 | 0.10*** |
| Memory | Immediate Recall | -0.06* |
| | Delayed Recall | -0.05* |
| Processing Speed | Colour Trails 1 | 0.05* |
| | Cognitive Response Time | 0.10*** |
| | Movement Time | 0.08** |
| | Total Response Time | 0.10*** |

* p <0.05; **p < 0.01; ***p < 0.001

**Figure Captions:**

**Figure 1.** Sample flowchart.

**Figure 2.** Median and mean results of all cognitive tests by actigraphy-based and self-reported total sleep time categories.

**Figure 3.** Linear and negative binomial regression models of associations between total sleep time, sleep problems, and individual cognitive tests

Reference category: Self-reported Total Sleep Time: 7-8 Hours; Actigraphy-based Total Sleep Time: 7-8 hours.

95% CI = 95% Confidence Interval; IRR = Incident Rate Ratio; B = Beta Coefficient; MMSE = Mini-Mental State Examination; MoCA = Montreal Cognitive Assessment

Models adjusted for age, sex, education status, location, marital status, employment status, smoker status, season of actigraphy recording, sleep mediation, anti-hypertensive medication, body mass index category, exercise group, depressive symptoms, any cardiovascular condition, any chronic condition.

[a]Negative binomial

[b]Linear regression

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

**Supporting Information:**

**Supplementary Table 1:** Cognitive Measures

**Supplementary Table 2:** Characteristics of the Wave 3 self-interview and accelerometer samples

**Supplementary Table 3**: Concordance between actigraphy-based Total Sleep Time categories and self-reported Total Sleep Time categories

**Supplementary Table 4:** Median [interquartile range] and mean [standard deviation] scores for individual cognitive tests by actigraphy-based total sleep time and self-reported total sleep time categories

**Supplementary Table A.5:** Negative binomial model of MMSE errors, actigraphy-based Total Sleep Time categories, self-reported Total Sleep Time categories, and sleep problems score.

**Supplementary Table A.6:** Negative binomial model of MoCA errors, actigraphy-based Total Sleep Time categories, self-reported Total Sleep Time categories, and sleep problems score.

**Supplementary Table A.7:** Linear regression model of Verbal fluency, actigraphy-based Total Sleep Time categories, self-reported Total Sleep Time categories, and sleep problems score.

**Supplementary Table A.8:** Negative binomial model of Colour Trails 2 time, actigraphy-based Total Sleep Time categories, self-reported Total Sleep Time categories, and sleep problems score.

**Supplementary Table A.9:** Linear regression model of immediate recall, actigraphy-based Total Sleep Time categories, self-reported Total Sleep Time categories, and sleep problems score.

**Supplementary Table A.10:** Linear regression model of delayed recall, actigraphy-based Total Sleep Time categories, self-reported Total Sleep Time categories, and sleep problems score.

**Supplementary Table A.11:** Negative binomial model of colour trails 1, actigraphy-based Total Sleep Time categories, self-reported Total Sleep Time categories, and sleep problems score.

**Supplementary Table A.11:** Negative binomial model of choice reaction test cognitive response time, actigraphy-based Total Sleep Time categories, self-reported Total Sleep Time categories, and sleep problems score.

**Supplementary Table A.12:** Negative binomial model of choice reaction test movement time, actigraphy-based Total Sleep Time categories, self-reported Total Sleep Time categories, and sleep problems score

**Supplementary Table A.13:** Negative binomial model of choice reaction test total response time, actigraphy-based Total Sleep Time categories, self-reported Total Sleep Time categories, and sleep problems score