Associations of accelerometer-based sleep duration and self-reported sleep difficulties with cognitive function in late mid-life: The Finnish Retirement and Aging Study

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ABSTRACT

Objectives: Prior evidence suggests that sleep duration and sleep difficulties may associate with cognitive function in old age, but little is known about the sleep-cognition association in late mid-life. Our aim was to examine the associations of accelerometer-based sleep duration as well as subjective sleep difficulties with different domains of cognitive function among aging workers.

Methods: The study population consisted of 289 participants (mean age 62.4 years, SD 1.02; 83% women) from the Finnish Retirement and Aging Study (FIREA). Sleep difficulties were measured using Jenkins Sleep Problem Scale (difficulties falling asleep, difficulties maintaining sleep, waking up too early in the morning, and nonrestorative sleep). Sleep duration was measured with wrist-worn accelerometer and self-report, and participants were divided into short (<7 h/night), mid-range (7-9 h/night) and long (≥9 h/night) sleepers. Participants underwent extensive cognitive testing covering three domains: 1) memory, 2) executive function, and 3) attention and information processing.

Results: Greater difficulties in waking up too early in the morning were associated with poorer executive function measured with Spatial Working Memory (SWM) test (p=0.005). Additionally, nonrestorative sleep was associated with poorer executive function measured with Trail Making Test, B-A, (p=0.036) and borderline significantly with lower SWM (p=0.056). Compared to mid-range sleepers, long sleepers tended to have poorer cognitive function (all memory function tests and SWM), but the associations were not statistically significant due to small number of long sleepers.

Conclusions: Subjective sleep difficulties may be linked to poorer executive function in a relatively healthy population of older workers in their 60s. Thus, promoting good sleep quality may translate into better cognitive health in late mid-life.

Key words: Sleep duration, Sleep quality, Sleep difficulties, Cognitive function, Accelerometer

1. Introduction

With the population aging, prevalence of cognitive deficits is increasing. To suppress this increase, it is important to detect underlying risk factors early enough in the life-course to enable primary prevention of cognitive deficits. Turning the research focus on the time-window before any clinical cognitive deficits are detectable is crucial for the identification of early risk factors determining cognitive function. There is some, albeit inconsistent, evidence suggesting that different sleep characteristics might have roles as potential risk factors for cognitive deficits.[1,2]

Sleep complaints are common both in middle aged and older adults.[3-5] Simultaneously, aging is accompanied with an increase in various sleep complaints, including insomnia and daytime drowsiness.[6] Previous studies have suggested that both short and long sleep duration as well as impaired sleep quality may associate with poorer cognition[1,2,7-12] and increased risk of dementia and Alzheimer's disease[13-15]. However, the research has mainly relied on self-reported sleep measurements while there are only few previous studies that have examined the association between objectively measured sleep and cognition.[13,14,16-19]

The specific cognitive domains related to sleep characteristics are also under dispute. Many of the previous studies have used only a single test or at most a few tests to assess cognition, yet they have interpreted results as reflecting links between sleep and participants' general cognition.[9,11,12,20-27] There are also studies that employed a wide battery of cognitive tests but did not report associations between sleep and cognitive performance on individual tests, but instead used different test results to produce an indicator for global cognitive function status (e.g., mild cognitive impairment, dementia).[7,13-

[15] However, cognition is comprised of many different domains which can be individually affected by various risk factors and they should be separately examined.

The few studies examining associations between sleep and cognitive function with a broader battery of cognitive tests have produced conflicting results about the domains that are mainly affected by sleep characteristics.[28,29] Long sleep duration has been previously linked with poorer verbal short-term memory[30], attention shifting[17] and vigilance[17], while subjective poor sleep quality measured with a variety of questionnaires has been associated with poorer working memory[28], attention shifting[28], abstract problem solving[28], executive funtioning[31], and slower speed of processing[29,32]. However, some studies did not find an association between sleep quality and attention shifting[29], executive functioning[32] or processing speed[28,30]. Furthermore, the cognitive tests used in these studies are traditional paper-and-pencil tests which are not necessarily sensitive to subtle differences in cognitive function in relatively healthy study subjects. Thus, further studies are needed to elucidate the association between sleep characteristics and comprehensively measured cognitive domains.

Furthermore, most of the previous studies on the associations between sleep characteristics and cognitive function have been conducted among older adults[2,12,14,20,27,28,30,33,34] or on middle aged[1,1,35,36,36] populations with relatively wide age-ranges (*i.e.* up to 30 years[27]). A wide age-range makes the study population heterogeneous, especially in terms of health conditions. In the present study, we focused on well-functioning persons in their 60s who are still in the working life, but close to their statutory retirement age. To our knowledge, there is only one previous study focusing on healthy individuals within a comparable age range (*i.e*. in their 50s) with a comprehensive cognitive test battery including computer–based tests.[35] In that study, Waller et al. followed participants' cognitive function from their 20s to their 50s (mean follow-up of 26 years) and

showed that lower quality of sleep was associated with greater decline in general cognitive function among men.[35] However, that study did not find an association between sleep duration and any of the studied cognitive domains.

The aim of this study was to elucidate the associations between both accelerometer-based and self-reported sleep duration as well as self-reported sleep difficulties with cognitive function measured with an extensive battery including sensitive computer–based cognitive tests among relatively healthy aging workers in their 60s.

2. Methods

2.1. Study population

The study population consisted of participants from the Finnish Retirement and Aging Study (FIREA), an ongoing longitudinal cohort study of older public sector workers in Finland established in 2013. Detailed description of the FIREA study design has been reported elsewhere.[37] Briefly, participants were first contacted 18 months prior to their estimated retirement date by sending a questionnaire. After responding to the questionnaire, Finnish-speaking participants with an estimated retirement date between 2017 and 2019, who live in Southwest Finland and were still working, were invited to participate in the clinical sub-study (n=773). Of them, 290 (38%) participated in the sub-study between September 2015 and May 2018. One person was excluded from the current study due to inability to perform cognitive testing; thus, the current study sample consisted of 289 participants. Informed consent was obtained from all participants. The FIREA study was conducted in accordance with the Helsinki declaration and was approved by the Ethics Committee of Hospital District of Southwest Finland.

2.2. Assessment of Sleep

Sleep was measured with a wrist-worn triaxial ActiGraph wActiSleep-BT accelerometer (ActiGraph, Pensacola, Florida, US) and it was initialized to record at 80 Hz. The accelerometer was sent to participants via mail before clinical examination and they were asked to wear it on their non-dominant wrist at all times at least for 7 days and nights including at least two working days and two days off. In an accompanying log, participants were asked to record date, in bed time, out of bed time, and information about working day (working day or day off) for each day that they wore the devices. After the measurement period, the participants returned devices and logs by mail. On average the participants wore the accelerometer for 7.9 nights (SD 1.8, min 1, max 16).

The R package GGIR version 1.7-1 was used to analyze raw acceleration data from the wrist-worn accelerometer in R statistical software, version 3.5.1 (R Foundation for Statistical Computing, Vienna, Austria, https://cran.r-project.org/). Sleep time was detected based on the combination of algorithm of the GGIR-package and daily logs[38] so that sleep was defined as periods of time during which there was no change larger than 5° in the arm angle over at least 5 minutes if that period was within a sleep window defined in the daily log (in bed time and out of bed time). For the current study we used sleep time parameter, which indicates time between the beginning of the first sleep period (initial sleep onset) and the end of the last sleep period (final awakening).[38] We use term accelerometer-based sleep duration and categorize it for the analytical purposes into three groups: short (<7 hours), mid-range (7-9 hours), and long sleepers (≥9 hours) according to National Sleep Foundation's sleep time duration recommendations.[39]

Data on subjective usual sleep duration were also derived from questionnaires. Sleep duration was assessed with the question "How many hours do you usually sleep in 24 hours?" with response categories: 6 hours or less, 6.5 hours, 7 hours, 7.5 hours, 8 hours,

8.5 hours, 9 hours, 9.5 hours, and 10 hours or more. For analyses, the sleep duration was categorized into three groups: short (6.5 hours or less), mid-range (7-8.5 hours), and long sleepers (9 hours or more) according to National Sleep Foundation's sleep time duration recommendations.[39]

Sleep difficulties were evaluated with Jenkins Sleep Problem Scale[40] which is a four-item survey question of the occurrence of sleep-related difficulties. The participants were asked to report the frequency of each of the following difficulties during the previous 4 weeks: (1) difficulties falling asleep (*i.e.* "have trouble falling asleep"), (2) difficulties maintaining sleep during the night (*i.e.* "wake up several times per night"), (3) waking up too early in the morning (*i.e.* "have trouble staying asleep (including too early awakening)") and (4) nonrestorative sleep (*i.e.* "wake up after your usual amount of sleep feeling tired or worn out"). There were six response categories for each difficulty: never, 1-3 nights per month, 1 night per week, 2-4 nights per week, 5-6 nights per week, and nearly every night. To examine any sleep difficulties, a variable was created based on the most frequent symptom the participant reported. The four items of the scale were also analyzed individually. Both any sleep difficulties and the specific sleep difficulties were dichotomized, and the participant was considered to have a sleep difficulty if the frequency was equal or higher than 2-4 nights per week.

2.3. Assessment of cognition

Cognitive function was measured with a computerized neuropsychological test battery including five tests from Cambridge Neuropsychological Test Automated Battery (CANTAB®), and four traditional paper-and-pencil neuropsychological tests that complemented the computerized tests. The tests were conducted by a trained study nurse

during a clinical study visit. The accelerometer measures were obtained around the same time as the clinical measures. Detailed description of the cognitive tests is presented in the supplemental material.

CANTAB® is a standardized computer-based method for assessing cognitive function and it is widely used in clinical trials and research purposes.[35,41-43] It consists of several tests which account for different cognitive domains, including attention and psychomotor speed, executive function, learning and memory as well as social and emotional cognition. The tests are performed on a touch-screen computer system, and a suitable test battery may be selected among all individual tests to cover the cognitive subdomains of interest in each specific study. The tests selected for this study were 1) motor screening task (MOT) for a training / screening tool to indicate difficulties in test execution; 2) paired associates learning test (PAL) for visual memory and new learning; 3) spatial working memory test (SWM) for retention, manipulation of visuospatial information, executive function and strategy use; 4) rapid visual information test (RVP) for sustained attention; and 5) attention switching task (AST) for executive function and cognitive flexibility. Together they account for a wide spectrum of those cognitive subdomains that are usually affected in cognitive disorders. Each CANTAB® test produces several outcome variables. We used *Z* score-based classification to reduce the number of variables and to obtain components that would explain most of the variation within the data set. Specifically, all individual variables in the cognition data were transformed into a scale with a mean of 0 and a standard deviation of 1. The testwise scores were calculated by summing all individual standardized variables within each test and then divided by the number of variables in that particular test. The MOT test component did not discriminate the participants and was therefore removed from the subsequent statistical analyses. Finally, all variables were converted so

that a higher value reflects better cognitive function (*e.g.* higher value in the reaction time component indicates better reaction time performance *i.e.* shorter reaction time).

In addition to the CANTAB® tests, the cognitive testing included Trail Making Test (TMT), B-A[44], measuring cognitive flexibility, and two components from the Consortium to Establish a Registry for Alzheimer´s Disease (CERAD) test battery[45]: immediate and delayed verbal recall[46]. The variables used in the analyses were the number of words remembered correctly at the first try (immediate) and at the delayed trial, and the percentage of the learned words (at the third time) recalled at the delayed trial. More detailed description is presented in the supplement material.

Each cognitive test represents one or more cognitive subdomains which can be categorized under different cognitive domains. In the analyses we grouped cognitive tests into three cognitive domains: 1) memory functions (immediate and delayed verbal recall, and paired associates learning from CANTAB®), 2) executive functions (Trail Making Test for cognitive flexibility and spatial working memory test from CANTAB®), and 3) attention and information processing (reaction time, visual information processing and AST for sustained attention from CANTAB®).

2.4. Assessment of self-reported memory difficulties

Self-reported memory difficulties (memory, learning and attention) were inquired in the survey questionnaire.[47] The memory difficulties were inquired with the questions: 1) “My memory works…”, 2) “I can acquire new knowledge and learn new things…” and 3) “Usually, I can focus on things…” The response options were 1) “very well”, 2) “well”, 3) “satisfactorily”, 4) “poorly”, and 5) “very poorly”. The answers were dichotomized for the analyses into “well” (responses 1-2) and “suboptimal” (responses 3-5).

2.5. Assessment of covariates

Participants' date of birth, sex and occupational status were obtained from the pension insurance institute for the municipal sector in Finland. Occupational status was categorized based on the International Standard Classification of Occupations (ISCO)[48] into three groups according to the occupational titles: managers and professionals (ISCO classes 1-2), associate professionals and office workers (ISCO classes 3-4) and service and manual workers (ISCO classes 5-9). The rest of the covariates were derived from the questionnaires. Depressive symptoms were assessed with the Beck Depression Inventory (BDI), a widely used 21-item questionnaire to measure prevalent depression and its severity.[49] A cut-off of 10/63 points was used to indicate depression (10-18 mild depression, 19-29 moderate depression and 30-63 severe depression). Job strain was measured using scales of job control and job demands from the shorter version of the Job Content Questionnaire[50,51] using the median values from the entire FIREA cohort as the cutoff points (job control 3.7 and job demands 3.2) to identify the participant with job strain (a high "demands" and a low "control" score).

Chronic diseases including asthma, cardiovascular diseases, sleep apnea, diabetes and restless legs syndrome were assessed with a question 'Has your doctor ever told that you have or have had…?". Smoking was categorized into non-smokers (never and former) and current smokers. The participants reported their habitual frequency and amount of alcohol (beer, wine and spirits) consumption in weekly units of alcohol. Alcohol risk use was defined as >16 drinks/week for women and >24 drinks/week for men corresponding with the lower limit for heavy use of alcohol set by the Finnish Ministry of Health and Social Affairs.[52] Body mass index (BMI) was calculated from self-reported weight and height and

categorized into normal weight (<25 kg/m^2), overweight (25 – 30 kg/m^2) and obese (≥30 kg/m^2).

2.6. Statistical analyses

Characteristics of the study population by accelerometer-based sleep duration and self-reported sleep difficulties are shown as percentages for categorical variables and means and standard deviation (SD) for continuous variables. Differences between categorical variables were examined using Chi squared test and between continuous variables using analysis of variance (ANOVA).

In the main analyses, we examined the associations of accelerometer-based sleep duration and self-reported sleep difficulties with cognitive subdomains by comparing mean levels of the cognitive test results across categories of sleep indicators using analysis of variance and also conducted pairwise comparisons using Tukey's Post Hoc Test. All analyses were adjusted for age, sex, occupational status, depression and job strain.

During the accelerometer measurement period, nine participants had night shifts, which alters night-time sleep rhythm. Therefore, we conducted sensitivity analyses removing these participants from the analyses (n=280). Additionally, given the convenience of the large female subject representation in our study population, we conducted sensitivity analyses including only the female participants (N=236).

Finally, to examine selection into the current clinical sub-study, we examined whether self-reported sleep duration, sleep difficulties and memory-related difficulties as well as sociodemographic factors and health behaviors at baseline differed between the participants of the current study and those FIREA participants who responded only to the survey and were either still working or retired at the time of the baseline survey.

Differences between groups were examined using Chi squared test and between continuous variables using ANOVA.

All statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA).

3. Results

The mean age of the participants was 62.4 years (SD 1.02) and 83% of them were women**.** Accelerometer-based sleep duration was 7 h and 47 min (SD 44 min) on average, majority (81%) of the participants being categorized as mid-range sleepers. Altogether, 54% of the participants reported having any sleep difficulty, among which difficulties in maintaining sleep was found to be the most prevalent (47% reported difficulties). Characteristics of the study participants by accelerometer-based sleep duration and by subjective sleep difficulty are shown in the **Table 1**. Both short and long sleepers differed from mid-range sleepers only in terms of BMI, by being more often obese (p=0.007). Participants reporting any of the sleep difficulties were more likely to have restless legs (p=0.008), mild or moderate depression (p<0.0001), alcohol risk use (p=0.03) and job strain (p=0.03) compared to those without any sleep difficulty.

The mean cognitive test scores by accelerometer-based sleep duration are shown in **Table 2**. Persons with long sleep duration had poorer immediate verbal recall compared to mid-range sleepers (p=0.03) and short sleepers (p=0.01). There was also a tendency towards poorer performance in other memory and executive function (except for cognitive flexibility) tests in the long sleepers compared to the mid-range and short sleepers, but the results were statistically non-significant reflecting the small number of participants in the long sleeper category. In general, there were no differences in cognitive function between

the short and mid-range sleepers. The associations with cognitive tests were similar when using self-reported sleep duration (**Supplement Table 1**). Although the Pearson's correlation coefficient between accelerometer-based and self-reported sleep duration was only moderate ($r= 0.35$, $p<0.0001$), majority of the participants were in the mid-range category (71%) and the proportion of short sleeper was 27% and long-sleepers 3% based on self-reported sleep.

Table 3 shows mean cognitive test scores for each type of sleep difficulties. Both waking up too early in the morning and nonrestorative sleep were associated with lower performance in executive function tests; both types of sleep difficulties were associated with spatial working memory, while nonrestorative sleep associated additionally with cognitive flexibility. Difficulties in maintaining sleep during night was significantly associated with better immediate verbal recall, but not with any other memory functions or any of other cognitive subdomains. No significant associations were found for difficulties in falling asleep in respect to any cognitive subdomains.

The sensitivity analyses excluding the night shift workers (N=9) showed similar results as the main analyses for both accelerometer-based sleep duration as well as sleep difficulties **(Supplement Tables 2-3**). Also the results from the sensitivity analyses including only the female participants were essentially similar to the results from the main analyses (**Supplement Tables 5-6**).

We also examined selection into the study by comparing study participants to those FIREA participants who responded only to the survey and were either still working or retired at the time of the baseline survey **(Table 4).** The participants of the current study were younger, were less likely to have difficulties falling asleep, to have diabetes, to be current smokers, and to be obese than those survey participants who were still working. Study participants were also more likely to be younger, to have a non-manual occupation,

shorter sleep, to report more nonrestorative sleep, and were less likely to report difficulties falling asleep, to have diabetes, to be current smokers or to be obese than their retired counterparts. The study participants did not differ from the working or retired survey participants in terms of self-reported difficulties in memory functions.

4. Discussion

In this study of aging public sector workers from Finland, we examined the cross-sectional associations of accelerometer-based sleep duration and subjective sleep difficulties with performance in three cognitive domains. Self-reported sleep difficulties – waking up too early in the morning and nonrestorative sleep in particular – were found to associate with poorer executive functions. No associations with other cognitive subdomains were found. Sleep duration was not consistently associated with cognitive function, but the long sleepers tended to perform worse in memory function and executive function tests compared to the mid-range sleepers.

Our finding that sleep difficulties associate with executive functions is in line with some previous findings/studies.[31] Ling et. al. found an association between early morning awakening and poorer executive function among older adults. On the other hand, other studies have reported no association between sleep difficulties and executive function, but in these studies different sleep difficulty measures were used (daytime somnolence[32] and disturbed sleep measured by movements in bed[2]). Executive functions are an important cognitive domain in today's working life especially in occupations that require good organization skills, multitasking, planning and decision making. Sleep difficulties have also been specifically associated to working memory[28], attention shifting[28], abstract problem solving[28] and speed of processing[29,32], as well as general decline in cognition[7,10,12,53], but

we did not observe sleep difficulties to be associated with performance in any other cognitive domain. We observed no differences in memory function tests with one exception. Those who had difficulties in maintaining sleep during the night performed better in the immediate verbal recall test. In addition, short sleepers had slightly greater, albeit non-significant, immediate recall than mid-range sleepers. Despite the several confounding factors taken into account in our statistical models, the possibility of residual or unmeasured confounding still remains, and might explain this somewhat unexpected association found between difficulties in maintaining sleep and better immediate verbal recall test. Moreover, because large number of statistical tests were conducted in this study, there is also a possibility that the found association is a spurious finding.

Although there is some prior evidence that both short and long sleep duration, based on objective and subjective assessment, are associated with lower cognitive function[7-9,16], some other studies have found no association between sleep duration and cognition.[13,19] It has even been suggested that sleep duration, especially when self-reported, might not be as important a factor as previously thought in regard to cognitive decline.[19] Interestingly, even if we found only some statistically significant associations, our results systematically showed lower cognitive function among the long-sleepers compared to mid-range or short-sleepers in all studied cognitive subdomains except cognitive flexibility. This is in accordance with two previous studies which found an association between long sleep duration and global cognitive function using accelerometers to measure sleep duration.[16,17] However, since our study population was still in working life at the time of the measurements, they had limited possibility to extend their sleep time and therefore the number of long-sleepers was small, which reduces statistical power in our analyses.

Our study population consisted of relatively healthy aging workers in their 60s, which implies that those with obvious cognitive impairment were not in employment anymore. This healthy worker bias could explain why we did not observe strong associations between sleep characteristics and cognition. To examine the role of selection on our findings, we compared FIREA participants who only responded to the survey at baseline and were either still working or already retired. We found that participants in our study population were slightly healthier, in terms of diabetes, obesity and smoking, than those who only responded to the survey but were still also working. However, participants who underwent cognitive testing were younger, they had higher occupational position, less diabetes, less smoking and lower BMI compared to the survey participants who had retired, but no difference was observed in self-reported memory difficulties. On the other hand, retired FIREA study participants reported less short sleep and less difficulties in non-restorative sleep, which is in line with our previous observations on improvement in sleep after retirement[54,55]. Taken together, the results of this study may be quite well generalizable into working individuals in their 60s.

This study has several strengths. The study population was homogenous in terms of age and participants appeared to be similar in terms of their sleep duration, sleep difficulties and cognitive complaints compared to survey participants. The study included both accelerometer-based and subjective sleep measurements. The accelerometer measures were obtained on average for seven days, which is a longer time period than used in most previous studies.[13,16-19] We were able to control for important confounders, such as depression. Finally, cognitive function was assessed using an extensive cognitive test battery including both computer-based and paper-and-pencil tests enabling us to examine different cognitive domains as opposed to just gathering an indicator for general cognitive function.

There are also some limitations that need to be addressed. The study design was cross-sectional, and therefore the causality between sleep and cognitive function cannot be established based on our results. We used accelerometers to examine the sleep duration. However, we did not have information about wake after sleep onset meaning we could not exclude wake during the night from the total time in bed. In addition to accelerometer, we used self-report to measure sleep duration. Although the associations with cognitive tests were very similar using the two different measurements, the correlation between the measurements was only moderate, which is also observed in other studies[56]. One explanation for this could be that regarding the self-reported sleep duration we measured usual/habitual sleep duration, which might be difficult to estimate accurately. In addition, self-reported sleep duration variable was measured with 30 minutes intervals, which makes it somewhat inaccurate. Although we did adjust for multiple potential confounding factors, it is possible that there are some remaining confounding factors that may have affected the results. Because of the healthy worker bias, we do not know if those with more severe sleep problems would be at risk of cognitive decline.

In conclusion, we found that waking up too early in the morning and nonrestorative sleep are associated with lower executive functions in a population of relatively healthy individuals who are still in working life. Although the found associations are partly weak and non-significant, it is still concerning that some associations are already visible in a cognitively healthy late middle-aged population. Prospective studies are needed to better understand associations and causality between sleep characteristics and cognitive function.

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Conflict of Interest

Adam Spira received an honorarium from Springer Nature Switzerland AG for Guest Editing a Special Issue of *Current Sleep Medicine Reports*. The other authors declare no conflict of interest.

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Table 1. Characteristics of the study population by sleep indicators.

	Accelerometer-based sleep duration				Sleep difficulties		
	Short <7h (N=38)	Mid-range 7-9h (N=227)	Long ≥9h (N=14)		No difficulties (N=131)	Difficulties (N=156)	
	Mean (SD)	Mean (SD)	Mean (SD)	p-value	Mean (SD)	Mean (SD)	p-value
Age	62.58 (0.95)	62.34 (1.02)	62.21 (1.25)	0.43	62.35 (1.01)	62.37 (1.03)	0.97
	%	%	%		%	%	
Female	87	83	71	0.43	79	85	0.19
Occupation				0.88			0.59
Upper-grade non-manual	34	36	29		32	38	
Lower-grade non-manual	37	34	29		35	33	
Manual or service work	29	30	43		33	29	
Chronic diseases							
Asthma	15	13	8.3	0.84	10	15	0.26
Cardiovascular disease	3.0	5.2	8.3	0.76	5.0	4.8	0.93
Sleep apnea	3.0	7.7	0	0.39	4.2	9.0	0.12
Diabetes	9.4	5.2	0	0.44	4.1	6.3	0.44
Restless legs syndrome	9.1	9.6	7.7	0.97	4.2	14	0.0076
Mild or moderate depression	21	16	7.1	0.47	5.3	25	<.0001
Current smoker	8.6	5.0	0	0.080	4.7	5.2	0.75
Alcohol risk use	16	8.9	21	0.15	6.1	14	0.027
BMI				0.0065			0.53
Normal weight	44	44	23		40	46	
Overweight	25	45	46		43	40	
Obese	31	11	31		17	14	
Job strain	23	24	7	0.35	16	27	0.031

Table 2. Associations between accelerometer-based sleep duration and cognitive domains. Analyses are adjusted for age, sex, occupational position, depression and job strain.

	Short <7h (N=38)			**Mid-range 7-9h (N=227)**			**Long ≥9h (N=14)**			Short vs. mid-range, p-value	Long vs. mid-range, p-value	Short vs. long, p-value
	Mean	95% CI		**Mean**	95% CI		**Mean**	95% CI				
Memory function												
Verbal recall, immediate[a]	**6.45**	5.88	7.01	**6.17**	5.84	6.50	**5.08**	4.24	5.93	0.57	0.025	0.013
Verbal recall, delayed[a]	**8.17**	7.62	8.71	**8.32**	8.00	8.64	**7.71**	6.89	8.52	0.84	0.28	0.57
Verbal recall, percent[a]	**87.98**	83.02	92.94	**92.07**	89.16	94.99	**86.34**	78.96	93.72	0.20	0.26	0.92
Paired associates learning[b]	**0.01**	-0.24	0.25	**-0.04**	-0.18	0.11	**-0.19**	-0.56	0.17	0.93	0.67	0.61
Executive function												
Cognitive flexibility[c]	**43.82**	35.11	52.53	**49.02**	43.90	54.14	**44.30**	31.34	57.26	0.43	0.74	1.00
Spatial working memory[b]	**0.06**	-0.16	0.28	**0.03**	-0.10	0.16	**-0.15**	-0.48	0.17	0.97	0.48	0.49
Attention and information processing												
Visual information processing[b]	**0.15**	-0.11	0.41	**0.15**	0.00	0.30	**0.13**	-0.26	0.51	1.00	0.99	1.00
Sustained attention[b]	**-0.04**	-0.28	0.20	**0.12**	-0.02	0.26	**0.15**	-0.20	0.51	0.36	0.98	0.61

Notes: [a] CERAD, word recall; [b] CANTAB®; [c] Trail Making Test, B-A; CI=confidence interval

Table 3. Associations between sleep difficulties and cognitive domains. Analyses are adjusted for age, sex, occupational position, depression and job strain.

	Falling asleep							**Maintaining sleep**						
	No difficulties (N=252)			**Difficulties (N=28)**				**No difficulties (N=150)**			**Difficulties (N=134)**			
	Mean	95% CI		**Mean**	95% CI		p-value	**Mean**	95% CI		**Mean**	95% CI		p-value
Memory function														
Verbal recall, immediate[a]	**6.06**	5.72	6.40	**6.25**	5.64	6.86	0.52	**5.90**	5.51	6.30	**6.30**	5.94	6.65	0.037
Verbal recall, delayed[a]	**8.20**	7.87	8.53	**8.49**	7.89	9.08	0.34	**8.16**	7.79	8.52	**8.40**	8.07	8.73	0.16
Verbal recall, percent[a]	**90.62**	87.60	93.64	**93.14**	87.66	98.62	0.36	**90.34**	87.00	93.68	**92.58**	89.57	95.59	0.16
Paired associates learning[b]	**-0.03**	-0.18	0.12	**-0.18**	-0.45	0.09	0.26	**-0.07**	-0.24	0.11	**-0.04**	-0.19	0.12	0.74
Executive function														
Cognitive flexibility[c]	**47.99**	42.76	53.21	**52.30**	42.74	61.86	0.37	**47.45**	41.44	53.46	**48.54**	43.12	53.95	0.71
Spatial working memory[b]	**0.05**	-0.08	0.18	**-0.06**	-0.30	0.18	0.37	**0.12**	-0.03	0.27	**0.01**	-0.13	0.14	0.14
Attention and information processing														
Visual information processing[b]	**0.12**	-0.03	0.28	**0.24**	-0.05	0.53	0.42	**0.13**	-0.05	0.31	**0.16**	0.00	0.33	0.72
Sustained attention[b]	**0.09**	-0.06	0.25	**0.05**	-0.24	0.34	0.76	**0.06**	-0.13	0.24	**0.13**	-0.03	0.29	0.41

	Waking up too early in the morning							**Nonrestorative sleep**						
	No difficulties (N=199)			**Difficulties (N=83)**				**No difficulties (N=212)**			**Difficulties (N=71)**			
	Mean	95% CI		**Mean**	95% CI		p-value	**Mean**	95% CI		**Mean**	95% CI		p-value
Memory function														
Verbal recall, immediate[a]	**6.04**	5.67	6.41	**6.20**	5.80	6.60	0.45	**6.04**	5.68	6.40	**6.34**	5.91	6.77	0.18
Verbal recall, delayed[a]	**8.23**	7.87	8.58	**8.25**	7.87	8.63	0.94	**8.23**	7.89	8.58	**8.36**	7.95	8.77	0.55
Verbal recall, percent[a]	**90.90**	87.62	94.17	**91.49**	87.99	95.00	0.74	**91.63**	88.44	94.82	**90.76**	86.99	94.53	0.66
Paired associates learning[b]	**-0.04**	-0.20	0.12	**-0.05**	-0.23	0.12	0.85	**-0.03**	-0.19	0.13	**-0.07**	-0.26	0.11	0.64
Executive function														
Cognitive flexibility[c]	**48.63**	42.90	54.36	**48.06**	41.90	54.22	0.86	**45.66**	40.18	51.14	**52.87**	46.35	59.39	0.036
Spatial working memory[b]	**0.14**	0.0006	0.29	**-0.08**	-0.24	0.07	0.005	**0.10**	-0.04	0.23	**-0.07**	-0.24	0.09	0.056
Attention and information processing														
Visual information processing[b]	**0.11**	-0.06	0.28	**0.14**	-0.05	0.32	0.78	**0.16**	-0.01	0.32	**0.11**	-0.09	0.31	0.68
Sustained attention[b]	**0.11**	-0.06	0.28	**0.08**	-0.10	0.27	0.78	**0.15**	-0.02	0.32	**0.02**	-0.17	0.22	0.23

Notes: [a] CERAD, word recall; [b] CANTAB®; [c] Trail Making Test, B-A; CI=confindence interval.

Table 4. Comparison between study population and the FIREA survey participants by working status.

	Participants who underwent cognitive testing (N=289)	Survey participants still in working life (N=4657)		Survey participants who have retired (N=1327)	
	Mean (SD)	Mean (SD)	p-value*	Mean (SD)	p-value**
Age	62.37 (1.02)	62.54 (1.21)	0.0014	63.50 (0.77)	<.0001
	%	%		%	
Female	83	82	0.64	85	0.23
Occupational position			0.063		<.0001
Upper-grade non-manual	35	32		23	
Lower-grade non-manual	34	30		26	
Manual or service work	31	38		51	
Sleep duration			0.78		<.0001
Short ≤6.5h	26	28		18	
Mid-range 7-8.5h	71	69		73	
Long ≥9h	2.4	2.3		9.0	
Any sleep difficulties	54	51	0.32	53	0.78
Falling asleep	10	14	0.037	18	0.0009
Maintaining sleep	47	45	0.49	49	0.54
Waking up too early in the morning	29	28	0.61	28	0.62
Nonrestorative sleep	25	23	0.35	17	0.0028
Self-reported difficulties in memory function					
Suboptimal memory	21	20	0.79	24	0.25
Suboptimal learning	36	35	0.84	40	0.25
Suboptimal attention	24	23	0.56	26	0.57
Chronic diseases					
Asthma	13	12	0.97	15	0.24
Cardiovascular disease	4.9	5.5	0.69	8.5	0.052
Sleep apnea	6.8	5.7	0.44	6.2	0.68
Diabetes	5.3	10	0.0073	12	0.0011
Restless legs syndrome	9.4	9.3	0.94	12	0.21
Depression	17	16	0.72	20	0.28
Current smoker	5.0	11	0.0068	14	0.0001
Alcohol risk use	10	8.5	0.25	10	0.92
BMI			0.050		0.0010
Normal weight	43	39		35	
Overweight	41	40		40	
Obese	15	21		25	

*Comparisons between participants who underwent cognitive testing and those survey participants who are still working.

** Comparisons between participants who underwent cognitive testing and those survey participants who are retired.

Supplement Table 1. Associations between self-reported sleep duration and cognitive domains. Analyses are adjusted for age, sex, occupational position, depression and job strain.

	Short ≤6.5h (N=76)			**Mid-range 7-8.5h (N=204)**			**Long ≥9h (N=7)**			Short vs. mid-range, p-value	Long vs. mid-range, p-value	Short vs. long, p-value
	Mean	95% CI		**Mean**	95% CI		**Mean**	95% CI				
Memory function												
Verbal recall, immediate[a]	**6.32**	5.91	6.73	**6.04**	5.67	6.40	**5.83**	4.68	6.98	0.39	0.93	0.70
Verbal recall, delayed[a]	**8.33**	7.94	8.73	**8.26**	7.91	8.60	**7.57**	6.48	8.67	0.92	0.44	0.38
Verbal recall, percent[a]	**92.01**	88.40	95.62	**90.72**	87.52	93.92	**90.10**	80.03	100.18	0.77	0.99	0.93
Paired associates learning[b]	**-0.02**	-0.20	0.16	**-0.06**	-0.22	0.10	**-0.22**	-0.71	0.28	0.93	0.80	0.73
Executive function												
Cognitive flexibility[c]	**48.27**	42.00	54.53	**48.27**	42.72	53.82	**42.00**	24.57	59.42	1.00	0.76	0.77
Spatial working memory[b]	**0.003**	-0.16	0.16	**0.06**	-0.08	0.20	**0.23**	-0.21	0.67	0.80	0.71	0.58
Attention and information processing												
Visual information processing[b]	**0.13**	-0.06	0.32	**0.15**	-0.01	0.32	**0.17**	-0.36	0.69	0.96	1.00	0.99
Sustained attention[b]	**0.04**	-0.15	0.23	**0.14**	-0.03	0.31	**0.27**	-0.26	0.79	0.57	0.89	0.69

Notes: [a] CERAD, word recall; [b] CANTAB®; [c] Trail Making Test, B-A; CI= confidence intervals

Supplement Table 2. Sensitivity analyses. Associations between accelerometer-based sleep duration and cognitive domains excluding night-shift workers (n=9). Analyses are adjusted for age, sex, occupational position, depression and job strain.

	Short <7h (N=35)			**Mid-range 7-9h (N=222)**			**Long ≥9h (N=14)**			Short vs. mid-range, p-value	Long vs. mid-range, p-value	Short vs. long, p-value
	Mean		95% CI	**Mean**		95% CI	**Mean**		95% CI			
Memory function												
Verbal recall, immediate[a]	**6.44**	5.86	7.03	**6.16**	5.83	6.50	**5.07**	4.22	5.92	0.59	0.03	0.01
Verbal recall, delayed[a]	**8.19**	7.62	8.76	**8.32**	8.00	8.65	**7.70**	6.88	8.53	0.88	0.28	0.56
Verbal recall, percent[a]	**88.43**	83.27	93.60	**91.93**	88.99	94.88	**86.19**	78.74	93.64	0.35	0.26	0.86
Paired associates learning[b]	**-0.01**	-0.27	0.24	**-0.04**	-0.18	0.11	**-0.19**	-0.56	0.17	0.98	0.65	0.67
Executive function												
Cognitive flexibility[c]	**45.10**	36.24	53.96	**48.95**	43.89	54.01	**44.79**	32.00	57.58	0.65	0.79	1.00
Spatial working memory[b]	**0.00**	-0.22	0.23	**0.04**	-0.09	0.17	**-0.15**	-0.48	0.17	0.95	0.47	0.68
Attention and information processing												
Visual information processing[b]	**0.12**	-0.15	0.39	**0.15**	0.00	0.31	**0.13**	-0.26	0.51	0.96	0.99	1.00
Sustained attention[b]	**-0.09**	-0.34	0.16	**0.12**	-0.02	0.27	**0.16**	-0.20	0.52	0.17	0.98	0.44

Notes: [a] CERAD, word recall; [b] CANTAB®; [c] Trail Making Test, B-A; CI= confidence intervals

Supplement Table 3. Sensitivity analyses. Associations between sleep difficulties and cognitive domains excluding night-shift workers (n=9). Analyses are adjusted for age, sex, occupational position, depression and job strain.

	Falling asleep							Maintaining sleep						
	No difficulties (N=243)			**Difficulties (N=28)**				**No difficulties (N=143)**			**Difficulties (N=132)**			
	Mean	95% CI		**Mean**	95% CI		p-value	**Mean**	95% CI		**Mean**	95% CI		p-value
Memory function														
Verbal recall, immediate[a]	**6.05**	5.71	6.39	**6.24**	5.63	6.86	0.52	**5.90**	5.50	6.30	**6.28**	5.93	6.64	0.05
Verbal recall, delayed[a]	**8.21**	7.88	8.54	**8.49**	7.88	9.09	0.36	**8.16**	7.79	8.53	**8.40**	8.07	8.73	0.18
Verbal recall, percent[a]	**90.57**	87.52	93.63	**93.10**	87.57	98.63	0.36	**90.11**	86.71	93.51	**92.65**	89.61	95.69	0.12
Paired associates learning[b]	**-0.03**	-0.18	0.12	**-0.18**	-0.45	0.09	0.27	**-0.06**	-0.23	0.12	**-0.05**	-0.20	0.11	0.91
Executive function														
Cognitive flexibility[c]	**48.12**	42.95	53.29	**52.50**	43.07	61.93	0.36	**47.02**	41.04	53.00	**49.03**	43.68	54.38	0.49
Spatial working memory[b]	**0.04**	-0.09	0.18	**-0.06**	-0.30	0.19	0.40	**0.11**	-0.04	0.26	**0.01**	-0.13	0.14	0.15
Attention and information processing														
Visual information processing[b]	**0.12**	-0.04	0.28	**0.24**	-0.05	0.53	0.40	**0.13**	-0.06	0.31	**0.17**	0.00	0.33	0.64
Sustained attention[b]	**0.09**	-0.07	0.25	**0.06**	-0.24	0.35	0.83	**0.04**	-0.15	0.22	**0.13**	-0.03	0.30	0.28

	Waking up too early in the morning							Nonrestorative sleep						
	No difficulties (N=191)			**Difficulties (N=82)**				**No difficulties (N=204)**			**Difficulties (N=70)**			
	Mean	95% CI		**Mean**	95% CI		p-value	**Mean**	95% CI		**Mean**	95% CI		p-value
Memory function														
Verbal recall, immediate[a]	**6.04**	5.66	6.41	**6.19**	5.78	6.59	0.49	**6.03**	5.66	6.39	**6.33**	5.90	6.76	0.19
Verbal recall, delayed[a]	**8.24**	7.87	8.60	**8.25**	7.87	8.64	0.93	**8.24**	7.88	8.59	**8.37**	7.95	8.78	0.54
Verbal recall, percent[a]	**90.77**	87.45	94.09	**91.57**	88.03	95.11	0.67	**91.51**	88.27	94.75	**90.87**	87.05	94.69	0.75
Paired associates learning[b]	**-0.03**	-0.19	0.13	**-0.07**	-0.24	0.10	0.67	**-0.02**	-0.18	0.14	**-0.09**	-0.28	0.10	0.48
Executive function														
Cognitive flexibility[c]	**48.37**	42.68	54.05	**48.75**	42.65	54.84	0.91	**45.32**	39.90	50.74	**53.74**	47.31	60.18	0.01
Spatial working memory[b]	**0.14**	0.00	0.29	**-0.09**	-0.24	0.06	0.00	**0.10**	-0.04	0.23	**-0.08**	-0.24	0.09	0.05
Attention and information processing														
Visual information processing[b]	**0.12**	-0.06	0.29	**0.13**	-0.05	0.32	0.89	**0.16**	-0.01	0.33	**0.10**	-0.10	0.30	0.57
Sustained attention[b]	**0.10**	-0.07	0.28	**0.08**	-0.11	0.27	0.81	**0.15**	-0.02	0.32	**0.02**	-0.18	0.22	0.23

Notes: [a] CERAD, word recall; [b] CANTAB®; [c] Trail Making Test, B-A; CI= confidence intervals

Supplement Table 4. Sensitivity analyses. Associations between self-reported sleep duration and cognitive domains excluding night-shift workers (n=9). Analyses are adjusted for age, sex, occupational position, depression and job strain.

	Short ≤6.5h (N=75)			**Mid-range 7-8.5h (N=196)**			**Long ≥9h (N=7)**			Short vs. mid-range, p-value	Long vs. mid-range, p-value	Short vs. long, p-value
	Mean	95% CI		**Mean**	95% CI		**Mean**	95% CI				
Memory function												
Verbal recall, immediate[a]	**6.30**	5.89	6.72	**6.03**	5.66	6.40	**5.83**	4.67	6.98	0.41	0.94	0.71
Verbal recall, delayed[a]	**8.34**	7.94	8.74	**8.26**	7.91	8.62	**7.57**	6.46	8.68	0.92	0.43	0.38
Verbal recall, percent[a]	**92.14**	88.49	95.79	**90.56**	87.32	93.81	**90.05**	79.90	100.21	0.69	0.99	0.92
Paired associates learning[b]	**-0.03**	-0.21	0.14	**-0.05**	-0.21	0.10	**-0.21**	-0.70	0.28	0.98	0.80	0.77
Executive function												
Cognitive flexibility[c]	**48.85**	42.66	55.04	**48.13**	42.62	53.64	**41.97**	24.80	59.15	0.97	0.76	0.72
Spatial working memory[b]	**0.00**	-0.16	0.16	**0.05**	-0.09	0.19	**0.24**	-0.20	0.67	0.81	0.68	0.55
Attention and information processing												
Visual information processing[b]	**0.12**	-0.07	0.31	**0.16**	-0.01	0.33	**0.18**	-0.35	0.70	0.94	1.00	0.98
Sustained attention[b]	**0.04**	-0.15	0.23	**0.14**	-0.03	0.31	**0.28**	-0.25	0.81	0.60	0.86	0.66

Notes: [a] CERAD, word recall; [b] CANTAB®; [c] Trail Making Test, B-A; CI= confidence intervals

Supplement Table 5. Sensitivity analyses. Associations between accelerometer-based sleep duration and cognitive domains among female participants (n=236). Analyses are adjusted for age, occupational position, depression and job strain.

	Short (N=33)			Mid-range (N=188)			Long (N=10)			Pairwise comparisons		
	Mean	95% CI		**Mean**	95% CI		**Mean**	95% CI		Short vs. mid-range	Long vs. mid-range	Short vs. long
Memory function												
Verbal recall, immediate[a]	**6.61**	6.04	7.19	**6.41**	6.10	6.72	**5.25**	4.24	6.25	0.77	0.053	0.041
Verbal recall, delayed[a]	**8.30**	7.80	8.81	**8.60**	8.33	8.88	**8.17**	7.29	9.05	0.48	0.59	0.96
Verbal recall, percent[a]	**88.89**	84.35	93.43	**94.30**	91.85	96.74	**89.76**	81.83	97.69	0.06	0.48	0.98
Paired associates learning[b]	**0.07**	-0.18	0.32	**0.02**	-0.11	0.16	**-0.11**	-0.54	0.33	0.93	0.82	0.74
Executive function												
Cognitive flexibility[c]	**43.37**	34.70	52.04	**47.71**	43.02	52.40	**46.09**	30.94	61.23	0.60	0.97	0.94
Spatial working memory[b]	**0.05**	-0.17	0.27	**-0.01**	-0.13	0.11	**-0.15**	-0.53	0.24	0.89	0.75	0.64
Attention and information processing												
Visual information processing[b]	**-0.05**	-0.32	0.21	**-0.02**	-0.16	0.13	**0.00**	-0.47	0.46	0.96	1.00	0.98
Sustained attention[b]	**-0.16**	-0.41	0.09	**0.04**	-0.09	0.18	**0.21**	-0.22	0.65	0.27	0.71	0.29

Notes: [a] CERAD, word recall; [b] CANTAB®; [c] Trail Making Test, B-A; CI=confidence intervals

Supplement Table 6. Sensitivity analyses. Associations between sleep difficulties and cognitive domains among female participants (n=236). Analyses are adjusted for age, occupational position, depression and job strain.

	Falling asleep							Maintaining sleep						
	No difficulties (N=206)			**Difficulties (N=25)**				**No difficulties (N=123)**			**Difficulties (N=113)**			
	Mean	95% CI		**Mean**	95% CI		p-value	**Mean**	95% CI		**Mean**	95% CI		p-value
Memory function														
Verbal recall, immediate[a]	**6.40**	6.07	6.72	**6.42**	5.80	7.04	0.95	**6.23**	5.84	6.63	**6.52**	6.19	6.85	0.17
Verbal recall, delayed[a]	**8.50**	8.21	8.79	**8.77**	8.22	9.33	0.35	**8.49**	8.14	8.84	**8.55**	8.26	8.84	0.75
Verbal recall, percent[a]	**92.65**	90.00	95.29	**95.69**	90.59	100.78	0.27	**92.97**	89.79	96.16	**93.48**	90.81	96.15	0.76
Paired associates learning[b]	**0.04**	-0.10	0.18	**-0.11**	-0.39	0.16	0.29	**0.00**	-0.17	0.17	**0.02**	-0.13	0.16	0.82
Executive function														
Cognitive flexibility[c]	**46.77**	41.84	51.69	**50.99**	41.39	60.59	0.41	**45.84**	39.91	51.78	**48.03**	43.04	53.03	0.49
Spatial working memory[b]	**0.03**	-0.09	0.16	**-0.16**	-0.40	0.09	0.15	**0.06**	-0.09	0.21	**-0.01**	-0.14	0.11	0.34
Attention and information processing														
Visual information processing[b]	**-0.04**	-0.19	0.11	**0.09**	-0.21	0.39	0.40	**-0.04**	-0.22	0.15	**-0.03**	-0.18	0.13	0.91
Sustained attention[b]	**-0.01**	-0.16	0.15	**-0.01**	-0.32	0.29	0.96	**-0.05**	-0.24	0.14	**0.04**	-0.12	0.20	0.39

	Waking up too early in the morning							Nonrestorative sleep						
	No difficulties (N=164)			**Difficulties (N=70)**				**No difficulties (N=171)**			**Difficulties (N=63)**			
	Mean	95% CI		**Mean**	95% CI		p-value	**Mean**	95% CI		**Mean**	95% CI		p-value
Memory function														
Verbal recall, immediate[a]	**6.37**	6.01	6.74	**6.55**	6.16	6.93	0.45	**6.22**	5.86	6.58	**6.71**	6.31	7.11	0.042
Verbal recall, delayed[a]	**8.60**	8.29	8.92	**8.46**	8.12	8.80	0.49	**8.47**	8.15	8.78	**8.66**	8.31	9.01	0.37
Verbal recall, percent[a]	**93.50**	90.61	96.40	**93.26**	90.15	96.36	0.89	**93.44**	90.51	96.38	**93.14**	89.90	96.38	0.88
Paired associates learning[b]	**0.01**	-0.14	0.17	**0.02**	-0.15	0.18	0.98	**0.00**	-0.16	0.16	**0.02**	-0.16	0.20	0.83
Executive function														
Cognitive flexibility[c]	**46.62**	41.15	52.08	**47.56**	41.63	53.49	0.79	**43.17**	37.77	48.57	**52.15**	46.12	58.18	0.015
Spatial working memory[b]	**0.11**	-0.03	0.25	**-0.10**	-0.25	0.05	0.020	**0.06**	-0.08	0.20	**-0.06**	-0.22	0.09	0.19
Attention and information processing														
Visual information processing[b]	**-0.03**	-0.20	0.14	**-0.05**	-0.24	0.13	0.84	**0.00**	-0.17	0.17	**-0.07**	-0.26	0.13	0.58
Sustained attention[b]	**0.02**	-0.16	0.19	**-0.01**	-0.20	0.17	0.80	**0.06**	-0.12	0.23	**-0.05**	-0.25	0.14	0.35

Notes: [a] CERAD, word recall; [b] CANTAB®; [c] Trail Making Test, B-A; CI=confidence intervals

Teräs T et al. Associations of objective and subjective sleep with cognitive function in late mid-life: The Finnish Retirement and Aging Study

Supplemental material

Detailed description of cognitive assessment in the FIREA study

Cambridge Neuropsychological Test Automated Battery, CANTAB®

The Motor Screening Task (MOT) is the first test given to the participants. Its recommended use is to assess whether participant has lack of comprehension or some sensorimotor deficits, such as problems with sight, movement or following instructions. In this study, it is used as a practice exercise before the actual, more difficult tests. In this part, the participants also became familiar with the equipment and procedures. During the MOT red crosses appear in different locations on the screen. The participants were instructed to touch the crosses as quickly and precisely as possible.

In *the Paired Associates Learning (PAL)* test there are 5 stages where 6 or 8 eight boxes appear on the screen with 2, 2, 3, 6 and 8 patterns hidden in them. The boxes are revealed one by one. In the first three stages some of the boxes are empty. Afterwards a pattern is shown in the middle of the screen and the participant is instructed to touch the box with the same pattern in it. When the participant has correctly found all corresponding patterns in the stage the test moves on to the next one. In case of an error the patterns in the boxes are revealed a second time and the participant will try to recall them again. The test will not move onto the next stage before all the patterns and their boxes are recalled correctly. After 10 attempts the test is terminated.

In *the Spatial Working Memory (SWM)* test 4 to 8 boxes appear in different locations on the screen. The participant is supposed to find tokens hidden inside the boxes and move those to a panel on the right-hand side of the screen. The computer hides only one token at the time but does not hide one twice in the same box. Therefore, once a box containing a token is found the participant is not supposed to revisit the same box again. Once a token is found in all the boxes, the test moves on to the next phase.

In *the Rapid Visual Information (RVP)* test the participant is supposed to react to a certain number sequence. The sequence (*e.g.* 3-7-5) is presented on the screen next to a box showing numbers from 2 to 9 one at the time. There are 100 numbers displayed per minute. When the sequence is presented the participant should touch the screen. There are two stages in this test: first two minutes are a practice round and the following three minutes are the actual test. In the practice round the participant is given visual cues when the sequence is shown (*i.e.* red numbers, yellow underline) and a voice signal when the sequence is correctly noted. The cues are gradually removed. As the RVP proceeds to the actual test phase, two more sequences are added (*i.e.* 3-7-5, 2-4-6, 4-6-8) and no cues are given.

The idea of the *Attention Switching Task (AST)* is to focus on the task at hand and to ignore all irrelevant given information. During the AST on either side of the screen (left or right) would appear an arrow pointing to either left or right. For each trial, there would be a cue at the top of the screen for whether the participant should focus on the location or the direction of the arrow with following instructions: “side on which the arrow appeared” or “direction in which the arrow was pointing”. According the instructions the participant would press either right or left button. The stimuli could be congruent (*e.g.* the arrow on the left-hand side pointing to left) or incongruent (*e.g.* the arrow on the right-hand side pointing to left), the latter requiring higher cognitive demand.

Paper-and-pencil tests

Trail making test[1] *(TMT)* part A consisted of tracing randomly placed numbers on paper from 1 to 25 in the correct order, reflecting participant's speed of processing. In part B numbers and letters alternated in a numeric, alphabetical order (1-A-2-B-3-C, etc.). In case of an error the participant was informed and had a chance to correct it immediately. Shorter time to complete the test indicated better cognition. Time in seconds was taken to complete Trail making test part A and B. Overall TMT score (TMT B-A) was calculated as the difference between TMT A and B times. This reflects the participant's cognitive flexibility.

In verbal recall[2] from the Consortium to Establish a Registry for Alzheimer's Disease (CERAD)[3] the participants were shown ten words one by one, asked to read them out loud and to recall as many as they could right afterwards. This was repeated three times. The delayed version was observed five minutes later after conducting short physical function test in meanwhile. This time, the list was not shown, and the participants were asked to recall as many of the words as they could. The variables used in the analyses were the number of words remembered correctly the first try and at the delayed trial and the percentage of the learned words (at the third time) recalled at the delayed trial.

Self-reported sleep duration

In the addition of the accelerometer based sleep duration we also analysed self-reported sleep duration. Information on subjective usual sleep duration was derived from questionnaires. Sleep duration was assessed with the question "How many hours do you usually sleep in 24 hours?" with response categories: 6 hours or less, 6.5 hours, 7 hours,

7.5 hours, 8 hours, 8.5 hours, 9 hours, 9.5 hours, and 10 hours or more. For analyses, the sleep duration was categorized into three groups: short (6.5 hours or less), mid-range (7-8.5 hours), and long sleepers (9 hours or more).

The mean cognitive test scores by self-reported sleep duration are shown in the **Supplemental Table 1**. Although there aren't any statistically significant associations, long sleepers did have a tendency to performe worse in memory function tests and cognitive flexibility. These results are similar as in accelerometer-based sleep duration. We also conducted the generalizibilty analyses with the self-reported sleep duration (**Supplement Table 4**). The removal of the night-shift workers did not affect the results.

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