Enni Tyynismaa

DAILY PHYSICAL ACTIVITY PATTERNS AND COGNITIVE FUNCTION IN OLDER WORKERS

Syventävien opintojen kirjallinen työ

Kevätlukukausi 2024

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Lääketieteellinen tiedekunta

Kansanterveystiede

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Abstract

Background: The changes in the body caused by normal aging can lead to a decline in cognitive function. Physical activity is recognized to be a factor that reduces the possible negative impacts on cognitive functioning appearing with aging. The aim of the thesis is to conduct a literature review on the association between objectively measured physical activity and cognitive functioning in late adulthood and in addition, to investigate the association between daily physical activity patterns and cognitive function.

Methods: The research is based on the study population consisting of participants from the Finnish Retirement and Aging Study (FIREA). Physical activity was measured with triaxial ActiGraph accelerometer, that measure activity as acceleration of the body part the device is attached to. In this thesis previously conducted latent class trajectory analysis was used to characterize participants into six different groups according to their daily activity behavior. Cognitive function was measured with neuropsychological test battery including five tests from Cambridge Neuropsychological Test Automated Battery (CANTAB®). Each cognitive test represents one or more cognitive subdomains which can be categorized under different cognitive domains.

Results: There was statistically significantly better performance in information processing test in “Low throughout the day” group compared to “High during the day and decrease in the evening” group. In sustained attention test “Highest during the day and active in the evening” group had poorer performance compared to group 2 (p=0.014) and “Moderate during the day and decrease in the evening” group (p=0.018). In any other cognitive test, there were no significant difference found between the trajectories.

Conclusions: The results suggest that those who are physically active during free time have better performance in cognitive tests than those who are physically active during working hours. Leisure-time physical activity seems to be more beneficial than work-time physical activity among older workers.

Keywords: accelerometer, physical activity, physical activity pattern, cognitive function

CONTENTS

1 INTRODUCTION

Mental and physical health are promoted and protected by regular physical activity, which also helps to reduce the risk of many chronic diseases (Sofi et al. 2011) and is beneficial for all people regardless of age or ability (*Global Status Report on Physical Activity 2022* 2022). Nonetheless, latest global estimates indicate that 27.5 % of the world's adult population (adults aged over 18) do not spend enough time in physical activity to improve and protect their health compared to physical activity guidelines by World Health Organization (Guthold et al. 2018). Also, both men and women become even less active when aging (*Global Status Report on Physical Activity 2022* 2022).

In the everyday life of older people cognitive functioning plays an important role. The changes in the body caused by normal aging can lead to a decline in cognitive function, for example in memory, problem-solving activities and speed processing. (Orgeta et al. 2019; Klimova, Valis, and Kuca 2017) Cognitive decline seems to be influenced by many different risk factors, not just aging (Barnes and Yaffe 2011). There are non-modifiable risk factors including age, gender, genetics, race and ethnicity and modifiable risk factors such as diabetes, head injuries, lifestyle factors including smoking, heavy alcohol use, sleep and physical activity (I. J. Deary et al. 2009; Norton et al. 2014).

Regular physical activity is known to be an effective way to improve cardiovascular health and to promote protective effects on the brain (Erickson et al. 2019). Furthermore, physical activity is recognized to be a factor that reduces the possible negative impacts on cognitive functioning appearing with aging (Livingston et al. 2020). It has been shown in the studies that exercise is associated with lower risk for dementia, and there is also convincing evidence of physical activity being a protective factor in clinically diagnosed Alzheimer's disease (Livingston et al. 2017; Hersi et al. 2017). A recent systematic review analyzed studies that investigated the association between accelerometer-measured physical activity and cognitive function (Oliveira et al. 2023). The review indicates there is association between regular physical activity and better performance in cognitive tasks among older adults. The association was shown particularly in case of moderate to vigorous physical activity.

It is important to explore and identify the factors predisposing to the deterioration of cognitive function in order to find and execute ways to prevent the cognitive decline, to detect changes in cognition at an early stage and to be able to target interventions to risk groups. The amount of older people is increasing, and so is increasing the amount of those living with dementia. There are predictions in which it is estimated that in 2050 the population of older adults will exceed 2 billion people (United Nations 2019). Dementia has a remarkable effect in individuals and their families. It also affects the economy, with global costs estimated at about US$1 trillion annually. ("World Alzheimer Report 2018 - The State of the Art of Dementia Research: New Frontiers," n.d.) In this light it is of primary importance to strive to develop ways to increase the functional life years of individuals and to reduce the burden caused by cognitive impairment.

2 STUDY AIMS

The aim of the thesis is to conduct a literature review on the association between objectively measured physical activity and cognitive functioning in late adulthood. In addition, I investigate the association between daily physical activity pattern and cognitive function in older workers in the Finnish Retirement and Aging (FIREA) dataset.

3 LITERATURE REVIEW

3.1 Physical activity

Physical activity is defined by the WHO as any bodily movement produced by skeletal muscles that requires energy expenditure. Based on the intensity of energy expenditure physical activity can be divided into different intensity categories. These are, from the lowest energy expenditure to the highest energy expenditure, sleep, sedentary behavior (SB), light physical activity (LPA), moderate physical activity (MPA) and vigorous physical activity (VPA). Physical activity can also be thought taking place in different domains of which most referred to are occupational, recreational, domestic and transportational (Barnett et al. 2014).

As previously stated, 27.5 % of the world's adult population (adults aged over 18) do not spend enough time in physical activity to improve and protect their health compared to physical activity guidelines by WHO (Guthold et al. 2018). Despite the recognized fact, that physical activity is important for preserving health, mobility and well-being in older age (Chodzko-Zajko et al. 2009), adults over the age of 60 is the least active group of the adult population (Troiano et al. 2008). A study by Pulakka et al. 2019 described daily patterns of physical activity based on accelerometer measurements in aging workers, and it was shown that the level and patterns of physical activity differ by age, gender and occupational category (Pulakka et al. 2019).

3.2 Cognitive function

Cognitive functioning refers to functions related to human information processing. General cognitive ability is also called intelligence, and the commonly used quantity that reflects this is the IQ. General cognitive ability can be divided into different domains, such as reasoning, processing speed, executive function, memory and spatial ability. (Salthouse 2004) Cognitive domains are not independent, but dependent on each other. An individual who performs well in one test measuring cognitive functioning usually performs well in tests measuring other domains too (Ian J. Deary, Penke, and Johnson 2010).

In the population both general cognitive ability and cognitive domains differences approximately follow a normal distribution, but there is an exception with a slight excess at the lower end of the distribution (Vuoksimaa 2019). There are differences in cognition between individuals throughout life, and the average deterioration of cognitive functions in aging cannot be explained solely by the fact that the differences between individuals increase in old age (Salthouse 2004).

Cognitive aging refers to changes in information processing functions in normal aging. In old age, general cognitive ability declines slightly on average, but intelligence measured as a child predicts cognitive ability through life to over 90 years of age, and the individual's performance compared to others of the same age remains very similar (Ian J. Deary, Pattie, and Starr 2013). Significant changes occur in the cognitive domains, but the changes differ from each other between domains. In general, processing speed starts to decline first, around the age of 30-40, and the decline continues through old age. In middle age starts the deterioration in many domains, and the deterioration accelerates after about 60 years of age. (Hughes et al. 2018) On average, 60% of changes in cognition are explained by changes common to different domains of cognition (Tucker-Drob, Brandmaier, and Lindenberger 2019). However, changes in cognition are very individual, and the baseline affects the cognitive performance throughout life.

When trying to distinguish between normal cognitive aging and memory disorders, neuropsychological assessment is used. Normal cognitive aging means a person performs averagely on tests measuring cognition in relation to age and educational level. Dementia means there is an objectively determined deterioration of cognition that affects coping with everyday activities. When there is a decline in some area of cognition, but the definition of dementia is not met and the person is able to perform everyday activities independently, it is defined to be a mild cognitive impairment. This heterogeneous condition can be permanent or reversible. However, mild cognitive impairment increases the risk of memory disease. (Vuoksimaa 2019)

There are around 50 million people living with dementia worldwide. The number is expected to increase especially in low-income countries and middle-income countries and reach 152 million by 2050. (Livingston et al. 2020) Based on international epidemiological studies it has earlier been estimated that there are 200 000 people with mildly impaired information processing in Finland (Lobo 2000). More than 150 000 people in Finland have a diagnosed memory disorder (Roitto et al.

2016), but a significant part of memory disorders go undiagnosed (“Muistisairaudet: Käypä Hoito -Suositus” 2023).

As previously stated, cognitive decline seems to be influenced by many different risk factors, both non-modifiable and modifiable. The Lancet Commission’s 2020 report on dementia presents 12 potentially modifiable risk factors for dementia, supported by convincing evidence. The risk factors presented are air pollution, depression, diabetes, excessive alcohol consumption, hearing impairment, hypertension, less education, low social contact, obesity, physical inactivity, smoking and traumatic brain injury. These 12 risk factors account for around 40% of worldwide dementias. Thus, in theory, this proportion could be prevented or delayed. (Livingston et al. 2020)

3.3 Association between physical activity and cognitive function

Research around the topic has tried to clarify the connection between physical activity and cognitive functioning. The association seems to depend on the dose of physical activity and the domain of cognition under investigation. Factors defining the dose are the volume, duration, frequency and intensity of physical activity. There are potential moderators of the relationship between physical activity and cognitive function also. It is suggested that the relationship varies, among other factors, as a function of body composition, fitness level, sex, and health status. (Erickson et al. 2019)

All twelve studies analyzed the association between objectively measured physical activity and cognitive function assessed by specific tests (Amagasa et al. 2020; Bangen et al. 2023; Halloway et al. 2020; Hsiao et al. 2022; Hyodo et al. 2023; Kerr et al. 2013; Oliveira et al. 2023; Phillips et al. 2016; Sewell et al. 2023, 23; Wu et al. 2020; Zhu et al. 2015; 2017). Studies included eight cross-sectional studies, three longitudinal studies and one systematic review. Follow-up times in longitudinal studies were at the maximum eight years.

In the literature investigated for the review section it was widely shown a positive relationship between physical activity and cognitive functioning. A cross-sectional study by Wu et al. 2020 suggests that absolute time spent in light PA, moderate-to-vigorous PA and total PA all had a linear relationship with cognitive performance. With MVPA (moderate-to-vigorous-intensity physical activity) and TPA the association was shown both in males and females, but with LPA the association was shown only in females.

Benefits of physical activity on brain structure, function and cognition in aging are widely supported in literature. Yet the mechanisms by which physical activity may preserve cerebrovascular health have rarely been studied. (Bangen et al. 2023) Regional cerebral blood flow (CBF) and white matter hyperintensity (WMH) volume are indicators of cerebrovascular health that have previously been studied by Zlatar, Hays et al. 2019 (Zlatar et al. 2019). In the study it was shown that in older adults with normal cognition accelerometer-measured light physical activity and moderate to vigorous physical activity are associated with greater cerebral blood flow in the frontal lobe.

What remains unknown is the dose of physical activity needed to improve cognitive function (Erickson et al. 2019). Nine studies were able to demonstrate the positive association between MVPA and cognitive performance (Amagasa et al. 2020; Bangen et al. 2023; Hsiao et al. 2022; Kerr et al. 2013; Oliveira et al. 2023; Phillips et al. 2016; Wu et al. 2020; Zhu et al. 2015; 2017), and four of these also suggested that there is no any association between LPA and cognitive performance at all (Amagasa et al. 2020; Bangen et al. 2023; Zhu et al. 2015; 2017). Nonetheless, also the association between LPA and cognitive performance emerged in several studies (Hsiao et al. 2022; Hyodo et al. 2023; Kerr et al. 2013; Oliveira et al. 2023; Wu et al. 2020).

Contrary to this the cross-sectional-study by Hyodo et al. 2023 (Hyodo et al. 2023) studying the association between intensity or accumulating pattern of physical activity and executive function in older adults suggests that greater time spent in BLPA (bouted light-intensity physical activity) was associated with better performance in Stroop task measuring inhibitory control, but association was not found with non-BLPA or any variable related to time spent in MVPA. Neither LPA nor MVPA were significantly associated with performance in N-back task measuring working memory or task-switching task measuring cognitive flexibility.

Table 1. Compilation of reviewed research studying physical activity and cognitive funtion.

Study	Number of participants (age)	Variables/measurements	Research layout	Main results
(Amagasa et al. 2020)	n=511 (73.4±5.6 years)	Physical activity: SB, LPA, total MVPA, sporadic MVPA, bouted MVPA Cognitive function: MMSE-J	cross-sectional study	Relative to the overall mean the proportion of time spent in total MVPA was reduced by 39.1 % in the group of those with cognitive function decline (CFD) and increased by 5.3 % in the group of those with normal cognitive function (NCF). Greater proportion of time spent in total MVPA was significantly associated with lower probability of CFD.
(Bangen et al. 2023)	n=43 (71.8±4.2 years)	Physical activity: SED, all light PA, moderate-to vigorous PA Cognitive function: MDRS, NIH Toolbox, RAVLT, SCWT, WMS-R, TMT, verbal fluency tests (F-A-S and animals)	cross-sectional study	Greater time spent in moderate-to-vigorous PA was associated with better memory and executive functioning. Greater time spent in all light PA was not associated with performance on cognitive measures.
(Halloway et al. 2020)	n=742 (79.3±7.3 years)	Physical activity: total daily physical activity Cognitive function: episodic memory, semantic memory, working memory, perceptual speed, visuospatial ability, global cognition	longitudinal study, follow-up for 4 years	Interaction between physical activity and cognitive activity at the first time point had a significant effect on higher levels of working memory. Interaction between changes in physical activity and changes in cognitive activity had a significant effect on higher levels of semantic memory.
(Hsiao et al. 2022)	n=145 (81.2±6.8 years)	Physical activity: total PA, LPA, MVPA Cognitive function: Chinese version of the MMSE	cross-sectional study	Both LPA and MVPA was significantly associated with cognitive function. Compared to those engaging in LPA <3 h/day there was a reduced risk of cognitive impairment among those engaging in LPA ≥3 h/day.

Study	Number of participants (age)	Variables/measurements	Research layout	Main results
(Hyodo et al. 2023)	n=76 (75.8±5.1 years)	Physical activity: SB, LPA, MVPA, BLPA, BMVPA, non-BLPA, non-BMVPA, sleep Cognitive function: Stroop task measuring inhibitory control, N-back task measuring working memory, task-switching task measuring cognitive flexibility	cross-sectional study	Greater time spent in BLPA was associated with better performance in Stroop task. Association was not found with non-BLPA or any variable related to time spent in MVPA. LPA or MVPA were not significantly associated with performance in N-back task or task-switching task.
(Kerr et al. 2013)	n=215 (83.4±6.6 years)	Physical activity: LLPA, HLPA, MVPA Cognitive function: TMT	cross-sectional study	HLPA was significantly associated with shorter time to complete TMT A, B and B minus A in unadjusted models. MVPA was significantly associated with shorter time to complete TMT B and B minus A in adjusted models.
(Oliveira et al. 2023)	23 studies were included in qualitative synthesis		systematic review	The review indicated that regular physical activity, especially MVPA, is associated with better cognitive function in older adults.
(Phillips et al. 2016)	n=51 (70.1±7.0 years)	Physical activity: total number of daily steps, MVPA Cognitive function: everyday cognition – DECA, inductive reasoning – the Letter Series task, speed of processing – the WAIS-R Digit Symbol Substitution task	cross-sectional/micro longitudinal study	According to effect size estimates physical activity explained 0-24 % of within-person variability in cognitive function depending on cognitive task, physical activity dose and timing.

Study	Number of participants (age)	Variables/measurements	Research layout	Main results
(Sewell et al. 2023)	n=199 (68.7±5.9 years)	Physical activity: total counts reflecting total physical activity, peak counts reflecting physical activity intensity, daily kilocalories reflecting energy expenditure Cognitive function: episodic recall memory, executive function, attention and processing speed, global cognition (AIBL PACC score)	Longitudinal study, follow-up for 8 years	Participants with higher physical activity intensity and total physical activity at baseline had better global cognition over the follow-up period. Higher total physical activity predicted also improved episodic recall memory over time. Greater energy expenditure predicted better episodic recall memory and global cognition over time.
(Wu et al. 2020)	n=308 (68.7±5.4 years)	Physical activity: SED, LPA, MVPA, TPA Cognitive function: MoCA	Cross-sectional study	LPA, MVPA and TPA had a linear relationship with cognitive performance. With MVPA and TPA the association was shown both in males and females, but with LPA the association was shown only in females.
(Zhu et al. 2015)	n=7098 (70.1±8.5 years)	Physical activity: SED, LPA, MVPA, SED%, LPA%, MVPA% Cognitive function: SIS, WLL, AF, LF, MoCA recall and orientation	Cross-sectional study	Participants in the lowest MVPA% quartile were more likely to be cognitively impaired than participants in the highest MVPA% quartile. MVPA% had a significant association with executive function and memory z-scores.
(Zhu et al. 2017)	n=6452 (in the beginning 69.7±8.5 years)	Physical activity: SED, LPA, MVPA, SED%, LPA%, MVPA% Cognitive function: SIS, WLL, AF, LF, MoCA recall and orientation	Longitudinal study, follow-up for 2.9±1.1 years	Compared to the lowest MVPA% quartile participants in higher MVPA% quartiles had better maintenance in executive function and memory and a lower risk of cognitive impairment.

SB = SED = sedentary behavior, LPA = light-intensity physical activity, MVPA = moderate-to-vigorous-intensity physical activity, TPA = total physical activity, LLPA = low light-intensity physical activity, HLPA = high light-intensity physical activity, BLPA = bouted light-intensity physical activity, BMVPA = bouted moderate-to-vigorous-intensity physical activity, SED% = proportion of total accelerometer wear time spent in SED, LPA% = proportion of total accelerometer wear time spent in LPA, MVPA% = proportion of total accelerometer wear time spent in MVPA, MMSE = the Mini-Mental State Examination, MMSE-J = Japanese version of the Mini-Mental State Examination, MDRS = the Mattis Dementia Rating Scale, NIH Toolbox = the National Institutes of Health Toolbox Cognition Battery, RAVLT = the Rey Auditory Verbal Learning Test, SCWT = the Stroop Color and Word Test, WMS-R = the Wechsler Memory Scale-Revised, TMT = the Trail Making Test, DECA = the Daily Everyday Cognitive Assessment, WAIS-R = the Wechsler Adult Intelligence Scale, AIBL = the Australian Imaging, Biomarkers and Lifestyle study, AIBL PACC = the AIBL Preclinical Alzheimer's Cognitive Composite, SIS = the Six-Item Screener, WLL = the Word List Learning (CERAD), AF = animal fluency (CERAD), LF = letter fluency, MoCA = the Montreal Cognitive Assessment

4 MATERIALS AND METHODS

4.1 Participants

The research is based on the study population consisting of participants from the Finnish Retirement and Aging Study (FIREA). (Stenholm et al. 2023) It is an ongoing longitudinal cohort study in the Department of Public Health established in 2013. Participants are older adults in Finland. They were first contacted and sent a questionnaire 18 months prior to their estimated retirement date. After responding to the questionnaire, Finnish-speaking participants who intended to retire between 2017 and 2019, lived in the Southwest Finland and were still working, were invited to participate in a clinical sub-study (n=773). Of them, 290 (38%) participated in the clinical sub-study between September 2015 and May 2018. 281 participants provided accelerometer data on at least four valid days with ≥10 hours of waking wear time and of them 262 participants performed cognitive testing. Informed consent was obtained from all the participants. The FIREA study was conducted in line with the Declaration of Helsinki and was approved by the Ethics Committee of Hospital District of Southwest Finland.

4.2 Methods

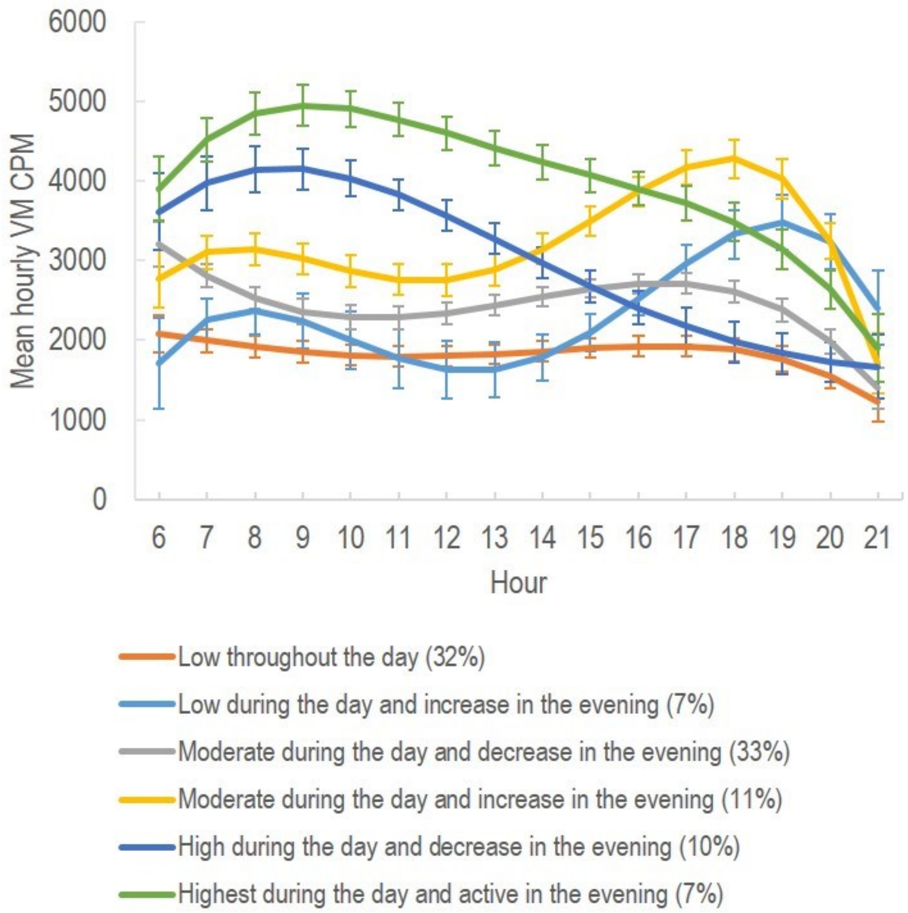
4.2.1 Accelerometer measurements

Physical activity was measured with triaxial ActiGraph wActiSleep-BT accelerometers (ActiGraph, Pensacola, Florida, USA), that measure activity as acceleration of the body part the device is attached to. (Pulakka et al. 2020) Measuring was done at least for seven days and nights, 24 hours per day. The participants got the instructions on wearing the accelerometer both oral and written. The accelerometer was instructed to be worn on non-dominant wrist at all times, also during water-based activities, but removed for sauna bathing. Participants were also asked to register working days and each work shift in an accompanying log during the time they wore the device.

Data from the accelerometers was downloaded and converted into 60 second epochs in the ActiLife software, version 6.13 (ActiGraph, Pensacola, Florida, US). The vector magnitude (VM) counts per minute (CPM), which was calculated as the square root of the sum of squared activity counts of the three axes, was used. Wake wear time between the first and last time registered in the participant's log. Non-wear time, sleep time and hours with less than 60 minutes of wear time were excluded. A valid measurement day was defined as minimum of 10 hours of wake wear time (Migueles et al. 2017). Mean VM CPM (vector magnitude counts per minute) for each hour of the day (hours between 6:00 and 22:00) was used for the trajectory analyses.

In this thesis previously conducted latent class trajectory analysis was used to characterize participants into different groups according to their daily activity behavior (Stenholm et al. 2021). The participants were divided into six different groups based on the variation in physical activity level on workdays including working hours and evening hours. These groups are “Low during the day and increase in the evening”, “Low throughout the day”, “Moderate during the day and decrease in the evening”, “Moderate during the day and increase in the evening”, “High during the day and decrease in the evening” and “Highest during the day and active in the evening”. These trajectories of daily physical activity are shown in Figure 1.

Figure 1. Trajectories of daily physical activity on workdays. (Stenholm et al. 2021)



4.2.2 Assessment of cognition

Cognitive function was measured with neuropsychological test battery including five tests from Cambridge Neuropsychological Test Automated Battery (CANTAB®). The tests were conducted by a trained study nurse during a clinical study visit. CANTAB® is a standardized computer-based method for assessing cognitive function, and it is widely used in clinical trials and research purposes (Rovio et al. 2016; Waller et al. 2016). 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. Each CANTAB® test produces several outcome variables. Each cognitive test represents one or more cognitive subdomains which can be categorized under different cognitive domains.

The tests used in this study were Paired Associates Learning (PAL) for visual memory and learning, Spatial Working Memory (SWM) for working memory, Rapid Visual Information Processing (RVP) for information processing, Attention Switching Task (AST) for sustained attention and Reaction Time (RTI) for reaction time. More thorough description of the tests can be found elsewhere (Teräs et al. 2020).

4.2.3 Assessment of covariates

Date of birth, gender and occupational title were obtained from the register of pension institute Keva. The occupational titles were coded according to the International Standard Classification of Occupations (ISCO) and categorized into 3 groups: high (ISCO classes 1–2, managers and professionals), intermediate (ISCO classes 3–4, associate professionals and office workers), and low (ISCO classes 5–9, service and manual workers). Smoking (current vs. former and never), alcohol risk use (>24 units for men and >16 units for women) and hypertension were defined using the information from the questionnaire. Body mass index was calculated from measured height and weight. Psychological distress was assessed by the 12-item General Health Questionnaire, that measures the symptoms of common mental health problems. Sleep difficulties were evaluated with Jenkins Sleep Problem Scale, a four-item survey including questions about falling asleep, maintaining sleep during the night, waking up too early in the morning, and nonrestorative sleep (Jenkins et al. 1988). The response categories for each item were 1) never, 2) 1-3 nights per month, 3) 1 night per week, 4) 2-4 nights per week, 5) 5-6 nights per week, and 6) nearly every night. Sleep difficulty was defined as any of the items occurring at least 2-4 night per week.

4.2.4 Statistical analysis

Characteristics of the study population are presented in Table 2 as mean values and standard deviations for the continuous variables and percentages for the categorical variables. We examined differences in cognitive subdomains by comparing mean levels of the cognitive test results between the trajectories of daily physical activity on workdays by using ANCOVA. We adjusted the model for age, gender, BMI, smoking, alcohol risk use, hypertension, occupational status, psychological distress and sleep difficulties. We chose the covariates listed above, because the association between physical activity and cognitive function can be confounded by them. Statistical analyses were conducted using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA).

5 RESULTS

Characteristics of the study population are shown in Table 2. The average age of the subjects was 62.4 *(SD 1.0)* years, and 82 % of them were women. Average BMI was 26.3 *(SD 4.7)*, 5% of the study population were smoking, 10 % had alcohol risk use, and 30 % had hypertension. The participants were distributed in different groups according to the occupational status 38 % of them having high occupational status, 34 % having intermediate occupational status and 27 % having low occupational status. 13 % of the participants suffered from psychological distress and 30 % had sleep difficulties.

Table 2. Characteristics of the study population.

	Total *(n=262)*
Age, mean *(SD)*	62.4 *(1.0)*
Women, %	82
BMI, mean *(SD)*	26.3 *(4.7)*
Smoking, %	5
Alcohol risk use, %	10
Hypertension, %	30
Occupational status, %	
High	38
Intermediate	34
Low	27
Psychological distress, %	13
Sleep difficulties, %	30

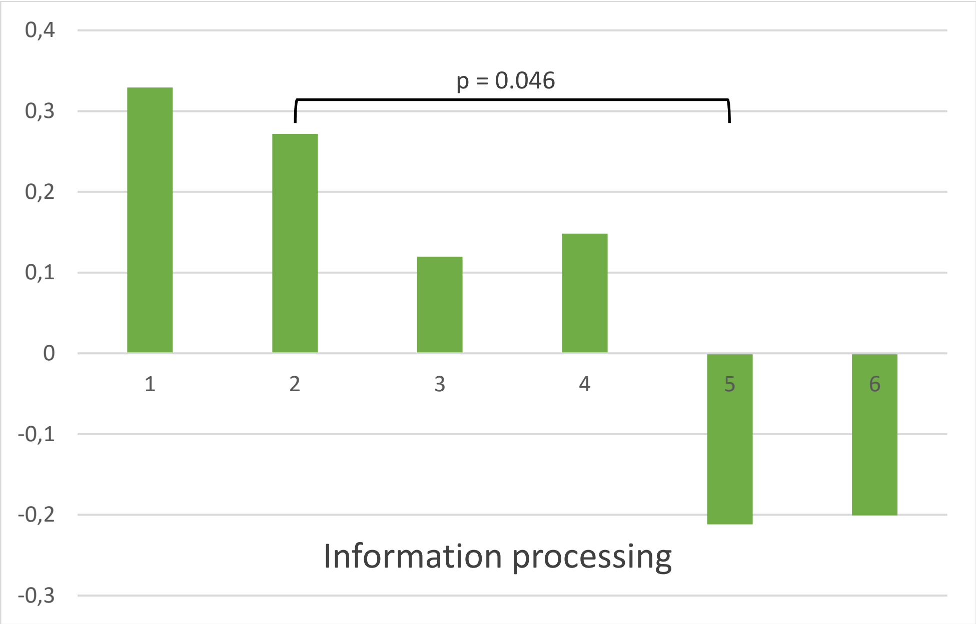
The mean scores of cognitive tests by different trajectory groups of daily physical activity are shown in Table 3. In addition, the mean scores of each individual cognitive test are presented in Figures 2-6. As shown in Figure 2, group 2 (Low throughout the day) performed statistically significantly better in information processing test compared to group 5 (High during the day and decrease in the evening). The mean score of information processing test was highest in group 1 (Low during the day and increase in the evening), but no significant difference was found compared to any other group. In sustained attention test (Figure 3) group 6 (Highest during the day and active in the evening) had poorer performance compared to group 2 (p=0.014) and group 3 (Moderate during the day and decrease in the evening) (p=0.018). In any other cognitive test (visual memory and learning [Figure 4], working memory [Figure 5], reaction time [Figure 6]) no significant difference was found between the trajectories. Nonetheless, group 1 had the highest mean scores in information processing, visual memory and learning, working memory and reaction time tests.

Table 3. The mean scores of cognitive tests by different trajectory groups of daily physical activity.

	Low during the day and increase in the evening (n=18)		Low throughout the day (n=87)		Moderate during the day and decreasing the evening (n=85)		Moderate during the day and increase in the evening (n=31)		High during the day and decrease in the evening (n=24)		Highest during the day and active in the evening (n=17)	
	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI
Visual memory and learning	0.18	-0.23 - 0.59	-0.046	-0.33 - 0.24	-0.036	-0.30 - 0.23	-0.04	-0.39 - 0.31	-0.27	-0.66 - 0.12	-0.12	-0.54 - 0.30
Working memory	0.17	-0.17 - 0.51	0.012	-0.22 - 0.25	-0.047	-0.27 - 0.18	0.024	-0.26 - 0.31	-0.11	-0.43 - 0.21	-0.057	-0.40 - 0.28
Information processing	0.33	-0.07 - 0.73	0.27	-0.01 - 0.55	0.12	-0.15 - 0.39	0.15	-0.19 - 0.49	-0.21	-0.59 - 0.16	-0.2	-0.60 - 0.20
Sustained attention	0.17	-0.19 - 0.54	0.21	-0.04 - 0.47	0.16	-0.09 - 0.41	0.075	-0.24 - 0.39	-0.078	-0.42 - 0.27	-0.39	-0.76 - -0.02
Reaction time	0.38	0.07 - 0.69	0.075	-0.14 - 0.29	0.14	-0.07 - 0.35	0.22	-0.05 - 0.48	0.085	-0.21 - 0.38	0.15	-0.17 - 0.46

Notes: Results are adjusted for age, gender, BMI, smoking, alcohol risk use, hypertension, occupational status, psychological distress and sleep difficulties.

Figure 2. The mean scores in information processing test.



1 Low during the day and increase in the evening

2 Low throughout the day

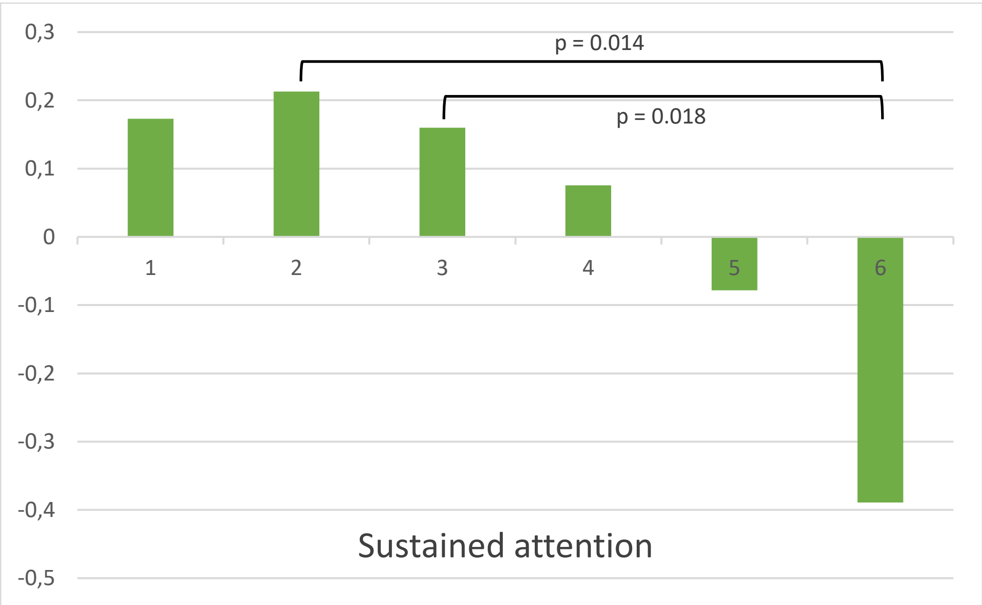
3 Moderate during the day and decrease in the evening

4 Moderate during the day and increase in the evening

5 High during the day and decrease in the evening

6 Highest during the day and active in the evening

Figure 3. The mean scores in sustained attention test.



1 Low during the day and increase in the evening

2 Low throughout the day

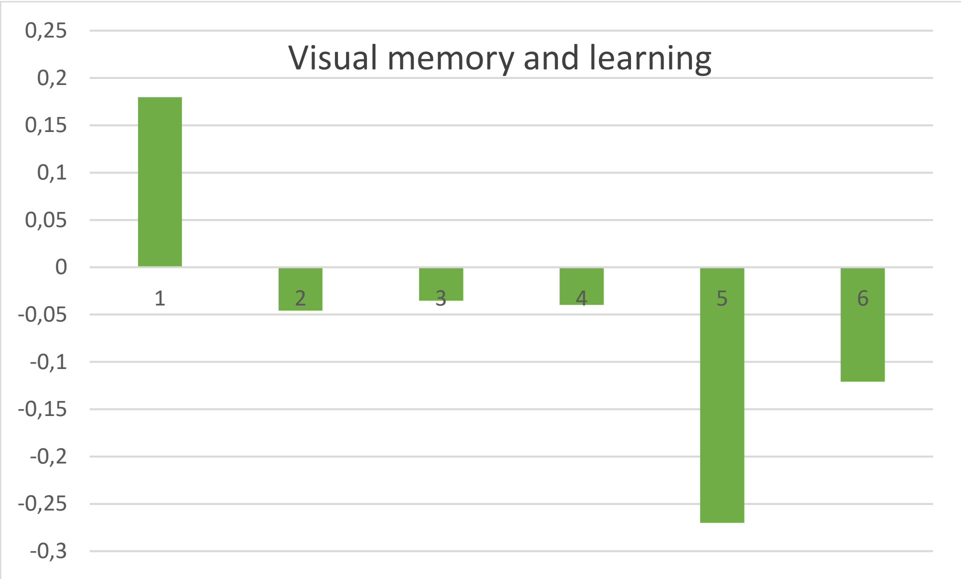
3 Moderate during the day and decrease in the evening

4 Moderate during the day and increase in the evening

5 High during the day and decrease in the evening

6 Highest during the day and active in the evening

Figure 4. The mean scores in visual memory and learning test.



1 Low during the day and increase in the evening

2 Low throughout the day

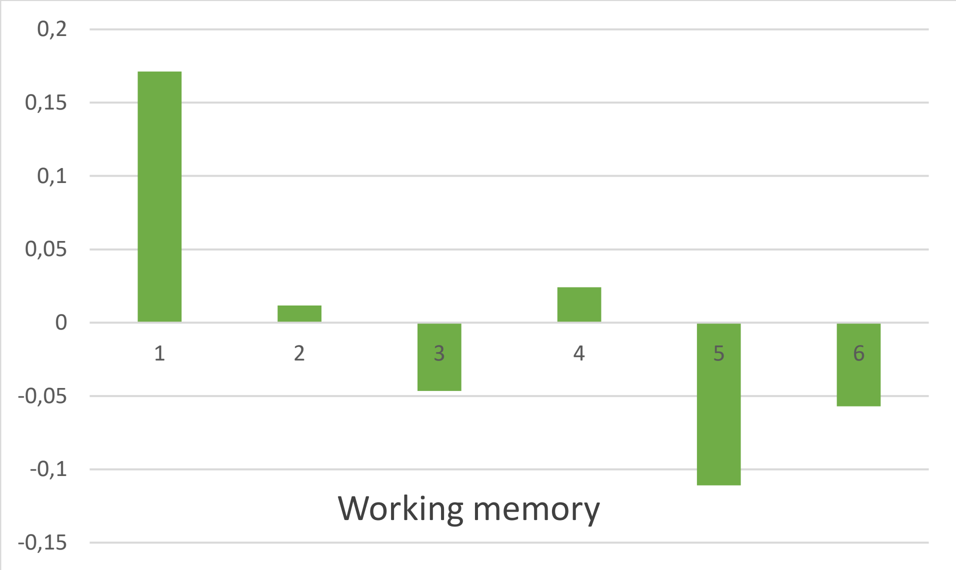
3 Moderate during the day and decrease in the evening

4 Moderate during the day and increase in the evening

5 High during the day and decrease in the evening

6 Highest during the day and active in the evening

Figure 5. The mean scores in working memory test.



1 Low during the day and increase in the evening

2 Low throughout the day

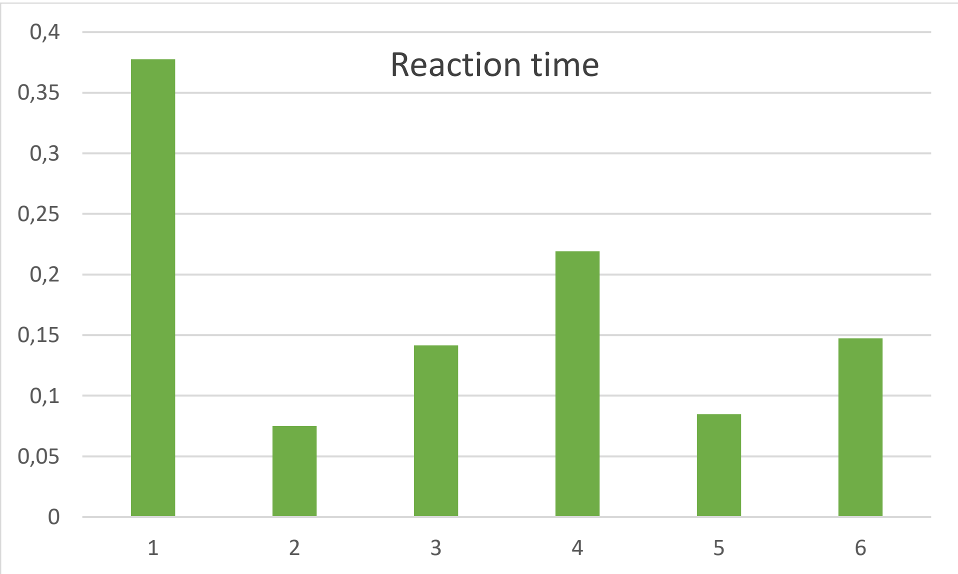
3 Moderate during the day and decrease in the evening

4 Moderate during the day and increase in the evening

5 High during the day and decrease in the evening

6 Highest during the day and active in the evening

Figure 6. The mean scores in reaction time test.



1 Low during the day and increase in the evening

2 Low throughout the day

3 Moderate during the day and decrease in the evening

4 Moderate during the day and increase in the evening

5 High during the day and decrease in the evening

6 Highest during the day and active in the evening

6 DISCUSSION

This cross-sectional study investigated the relationship between physical activity and cognitive function in older workers. The study specifically examined the performance in cognitive tests of people in different trajectory groups of daily physical activity. Participants with low physical activity throughout the day performed statistically significantly better in cognitive test measuring information processing compared to participants with high physical activity during the day and decrease in the evening. Also, those with low physical activity throughout the day and those with moderate physical activity during the day and decrease in the evening performed statistically significantly better in cognitive test measuring sustained attention. In any other cognitive test, there were no significant differences found between the trajectory groups of daily physical activity. Nonetheless, the people with low physical activity during the day and increase in the evening had the highest mean scores in information processing, visual memory and learning, working memory and reaction time tests.

Previous literature has indicated an association between regular physical activity and better performance in cognitive tasks among older adults. Some studies indicate that the positive relationship between physical activity and cognitive functioning only emerges when the time spent in physical activity is long enough or when the intensity is high enough. In the study by Hsiao et al. 2022 it was shown that only those engaging in light physical activity at least three hours a day had reduced chance of cognitive impairment. The same association was not found in those engaging in light physical activity less than three hours a day. In turn, the study by Kerr et al. 2013 found that high light-intensity physical activity and moderate-to-vigorous-intensity physical activity are statistically significantly associated with better performance in cognitive tests, but there is no association between low light-intensity physical activity and cognitive tests.

As previously stated, some studies even indicate that better cognitive performance is only associated with MVPA and not with any other intensity of physical activity. A cross-sectional study and later a longitudinal study has been conducted in The Reasons for Geographic and Racial Differences in Stroke (REGARDS) study cohort from United States. In the cross-sectional study by Zhu et al. 2015 it was stated that the participants in the lowest MVPA% quartile were more likely to be cognitively impaired than the participants in the highest MVPA% quartile. Also, MVPA% had a significant association with executive function and memory z-scores. In this study LPA% or SED% had no significant association with cognitive function. In the longitudinal study with follow-up time for an average of three years the participants in higher MVPA% quartiles had better maintenance in executive function and memory and a lower risk of cognitive impairment compared to the participants in the lowest MVPA% quartile.

Previous research has considered the volume and intensity of physical activity throughout the day without the information about how physical activity is distributed during the day. In contrast, this study considered the pattern of physical activity during the working days, and the consistency of physical activity is known. The mean scores of the cognitive test assessing reaction time are higher with those who are physically active in the evening compared to those who have similar daytime activity but who are not physically active in the evening. Roughly, in many cognitive tests the mean scores of the trajectory groups deteriorated when the amount of physical activity increased. However, no statistically significant differences were found from most of the tests or between most of the groups.

Additional value of this study is that cognition was examined and measured versatilely in several different domains, and it has been assessed with tests that do not show a ceiling effect. The research population is strictly delimited in terms of age, so the association can be reliably studied precisely in people of this age. Also, 82 % of the participants were women. The strict delimitation of study population may impair the generalizability of the results, and the population is also small.

Thus, further research is needed in the future with larger materials that also include men. It is a cross-sectional study, so the information is only available for one time point, and the benefits of a longitudinal study and follow-up are not sought. Interesting topics for the research in the future would be, for example, how the distribution and patterns of physical activity change after retirement or how the cognition changes in different groups during the aging.

In conclusion, there was an indication, that those who are physically active during free time have better performance in cognitive tests than those who are physically active during working hours. This is probably influenced by the lower level of education of people doing more physically active work. Consequently, leisure-time physical activity seems to be more beneficial than work-time physical activity among older workers, but future longitudinal studies are needed to confirm the findings.

REFERENCES

Amagasa, Shiho, Shigeru Inoue, Hiroshi Murayama, Takeo Fujiwara, Hiroyuki Kikuchi, Noritoshi Fukushima, Masaki Machida, Sebastien Chastin, Neville Owen, and Yugo Shobugawa. 2020. “Associations of Sedentary and Physically-Active Behaviors With Cognitive-Function Decline in Community-Dwelling Older Adults: Compositional Data Analysis From the NEIGE Study.” *Journal of Epidemiology* 30 (11): 503–8. https://doi.org/10.2188/jea.JE20190141.

Bangen, Katherine J., Amanda T. Calcetas, Kelsey R. Thomas, Christina Wierenga, Christine N. Smith, Maria Bordyug, Einat K. Brenner, et al. 2023. “Greater Accelerometer-Measured Physical Activity Is Associated with Better Cognition and Cerebrovascular Health in Older Adults.” *Journal of the International Neuropsychological Society* 29 (9): 859–69. https://doi.org/10.1017/S1355617723000140.

Barnes, Deborah E, and Kristine Yaffe. 2011. “The Projected Effect of Risk Factor Reduction on Alzheimer’s Disease Prevalence.” *The Lancet Neurology* 10 (9): 819–28. https://doi.org/10.1016/S1474-4422(11)70072-2.

Barnett, Inka, Esther Van Sluijs, David Ogilvie, and Nicholas J Wareham. 2014. “Changes in Household, Transport and Recreational Physical Activity and Television Viewing Time across the Transition to Retirement: Longitudinal Evidence from the EPIC-Norfolk Cohort.” *Journal of Epidemiology and Community Health* 68 (8): 747–53. https://doi.org/10.1136/jech-2013-203225.

Chodzko-Zajko, Wojtek J., David N. Proctor, Maria A. Fiatarone Singh, Christopher T. Minson, Claudio R. Nigg, George J. Salem, and James S. Skinner. 2009. “Exercise and Physical Activity for Older Adults.” *Medicine & Science in Sports & Exercise* 41 (7): 1510–30. https://doi.org/10.1249/MSS.0b013e3181a0c95c.

Deary, I. J., J. Corley, A. J. Gow, S. E. Harris, L. M. Houlihan, R. E. Marioni, L. Penke, S. B. Rafnsson, and J. M. Starr. 2009. “Age-Associated Cognitive Decline.” *British Medical Bulletin* 92 (1): 135–52. https://doi.org/10.1093/bmb/ldp033.

Deary, Ian J., Alison Pattie, and John M. Starr. 2013. “The Stability of Intelligence From Age 11 to Age 90 Years: The Lothian Birth Cohort of 1921.” *Psychological Science* 24 (12): 2361–68. https://doi.org/10.1177/0956797613486487.

Deary, Ian J., Lars Penke, and Wendy Johnson. 2010. “The Neuroscience of Human Intelligence Differences.” *Nature Reviews Neuroscience* 11 (3): 201–11. https://doi.org/10.1038/nrn2793.

Erickson, Kirk I., Charles Hillman, Chelsea M. Stillman, Rachel M. Ballard, Bonny Bloodgood, David E. Conroy, Richard Macko, David X. Marquez, Steven J. Petruzzello, and Kenneth E. Powell. 2019. “Physical Activity, Cognition, and Brain Outcomes: A Review of the 2018 Physical Activity Guidelines.” *Medicine & Science in Sports & Exercise* 51 (6): 1242–51. https://doi.org/10.1249/MSS.0000000000001936.

Global Status Report on Physical Activity 2022. 2022. S.l.: s.n.

Guthold, Regina, Gretchen A Stevens, Leanne M Riley, and Fiona C Bull. 2018. “Worldwide Trends in Insufficient Physical Activity from 2001 to 2016: A Pooled Analysis of 358 Population-Based Surveys with 1·9 Million Participants.” *The Lancet Global Health* 6 (10): e1077–86. https://doi.org/10.1016/S2214-109X(18)30357-7.

Halloway, Shannon, Michael E. Schoeny, JoEllen Wilbur, and Lisa L. Barnes. 2020. “Interactive Effects of Physical Activity and Cognitive Activity on Cognition in Older Adults Without Mild Cognitive Impairment or Dementia.” *Journal of Aging and Health* 32 (9): 1008–16. https://doi.org/10.1177/0898264319875570.

Hersi, Mona, Brittany Irvine, Pallavi Gupta, James Gomes, Nicholas Birkett, and Daniel Krewski. 2017. “Risk Factors Associated with the Onset and Progression of Alzheimer’s Disease: A Systematic Review of the Evidence.” *NeuroToxicology* 61 (July): 143–87. https://doi.org/10.1016/j.neuro.2017.03.006.

Hsiao, C., C.-J. Wen, H.-Y. Yen, Ming-Chun Hsueh, and Y. Liao. 2022. “Association between Accelerometer-Measured Light-Intensity Physical Activity and Cognitive Function in Older Adults.” *The Journal of Nutrition, Health and Aging* 26 (3): 230–35. https://doi.org/10.1007/s12603-022-1749-0.

Hughes, Matthew L., Stefan Agrigoroaei, Minjeong Jeon, Molly Bruzzese, and Margie E. Lachman. 2018. “Change in Cognitive Performance From Midlife Into Old Age: Findings from the Midlife in the United States (MIDUS) Study.” *Journal of the International Neuropsychological Society* 24 (8): 805–20. https://doi.org/10.1017/S1355617718000425.

Hyodo, Kazuki, Naruki Kitano, Aiko Ueno, Daisuke Yamaguchi, Yuya Watanabe, Takayuki Noda, Sumiyo Nishida, Yuko Kai, and Takashi Arao. 2023. “Association between Intensity or Accumulating Pattern of Physical Activity and Executive Function in Community-Dwelling Older Adults: A Cross-Sectional Study with Compositional Data Analysis.” *Frontiers in Human Neuroscience* 16 (January): 1018087. https://doi.org/10.3389/fnhum.2022.1018087.

Jenkins, C.David, Babette-Ann Stanton, Steve J. Niemcryk, and Robert M. Rose. 1988. “A Scale for the Estimation of Sleep Problems in Clinical Research.” *Journal of Clinical Epidemiology* 41 (4): 313–21. https://doi.org/10.1016/0895-4356(88)90138-2.

Kerr, Jacqueline, Simon J. Marshall, Ruth E. Patterson, Catherine R. Marinac, Loki Natarajan, Dori Rosenberg, Kari Wasilenko, and Katie Crist. 2013. “Objectively Measured Physical Activity Is Related to Cognitive Function in Older Adults.” *Journal of the American Geriatrics Society* 61 (11): 1927–31. https://doi.org/10.1111/jgs.12524.

Klimova, Blanka, Martin Valis, and Kamil Kuca. 2017. “Cognitive Decline in Normal Aging and Its Prevention: A Review on Non-Pharmacological Lifestyle Strategies.” *Clinical Interventions in Aging* Volume 12 (May): 903–10. https://doi.org/10.2147/CIA.S132963.

Livingston, Gill, Jonathan Huntley, Andrew Sommerlad, David Ames, Clive Ballard, Sube Banerjee, Carol Brayne, et al. 2020. “Dementia Prevention, Intervention, and Care: 2020 Report of the

Lancet Commission.” *The Lancet* 396 (10248): 413–46. https://doi.org/10.1016/S0140-6736(20)30367-6.

Livingston, Gill, Andrew Sommerlad, Vasiliki Orgeta, Sergi G Costafreda, Jonathan Huntley, David Ames, Clive Ballard, et al. 2017. “Dementia Prevention, Intervention, and Care.” *The Lancet* 390 (10113): 2673–2734. https://doi.org/10.1016/S0140-6736(17)31363-6.

Lobo, Antonio. 2000. “Prevalence of Dementia and Major Subtypes in Europe: A Collaborative Study of Population-Based Cohorts. Neurologic Diseases in the Elderly Research Group.”

Migueles, Jairo H., Cristina Cadenas-Sanchez, Ulf Ekelund, Christine Delisle Nyström, Jose Mora-Gonzalez, Marie Löf, Idoia Labayen, Jonatan R. Ruiz, and Francisco B. Ortega. 2017. “Accelerometer Data Collection and Processing Criteria to Assess Physical Activity and Other Outcomes: A Systematic Review and Practical Considerations.” *Sports Medicine* 47 (9): 1821–45. https://doi.org/10.1007/s40279-017-0716-0.

“Muistisairaudet: Käypä Hoito -Suositus.” 2023. *Muistisairaudet. Käypä Hoito -Suositus. Suomalaisen Lääkäriseuran Duodecimin, Societas Gerontologica Fennican, Suomen Geriatrit -Yhdistyksen, Suomen Neurologisen Yhdistyksen, Suomen Psykogeriatrisen Yhdistyksen Ja Suomen Yleislääketieteen Yhdistyksen Asettama Työryhmä. Helsinki: Suomalainen Lääkäriseura Duodecim, 2023*.

Norton, Sam, Fiona E Matthews, Deborah E Barnes, Kristine Yaffe, and Carol Brayne. 2014. “Potential for Primary Prevention of Alzheimer’s Disease: An Analysis of Population-Based Data.” *The Lancet Neurology* 13 (8): 788–94. https://doi.org/10.1016/S1474-4422(14)70136-X.

Oliveira, José Jonas De, Anna Gabriela Silva Vilela Ribeiro, Jasiele Aparecida De Oliveira Silva, Carolina Gabriela Reis Barbosa, Alexandre De Souza E Silva, Giovanna Melissa Dos Santos, Rozangela Verlengia, and Adriana Pertille. 2023. “Association between Physical Activity Measured by Accelerometry and Cognitive Function in Older Adults: A Systematic Review.” *Aging & Mental Health* 27 (11): 2089–2101. https://doi.org/10.1080/13607863.2023.2248477.

Orgeta, V., N. Mukadam, A. Sommerlad, and G. Livingston. 2019. “The Lancet Commission on Dementia Prevention, Intervention, and Care: A Call for Action.” *Irish Journal of Psychological Medicine* 36 (2): 85–88. https://doi.org/10.1017/ipm.2018.4.

Phillips, Christine B., Jerri D. Edwards, Ross Andel, and Marcus Kilpatrick. 2016. “Daily Physical Activity and Cognitive Function Variability in Older Adults.” *Journal of Aging and Physical Activity* 24 (2): 256–67. https://doi.org/10.1123/japa.2014-0222.

Pulakka, Anna, Tuija Leskinen, Annemarie Koster, Jaana Pentti, Jussi Vahtera, and Sari Stenholm. 2019. “Daily Physical Activity Patterns among Aging Workers: The Finnish Retirement and Aging Study (FIREA).” *Occupational and Environmental Medicine* 76 (1): 33–39. https://doi.org/10.1136/oemed-2018-105266.

Pulakka, Anna, Tuija Leskinen, Kristin Suorsa, Jaana Pentti, Jaana I. Halonen, Jussi Vahtera, and Sari Stenholm. 2020. “Physical Activity across Retirement Transition by Occupation and Mode of

Commute." *Medicine & Science in Sports & Exercise* 52 (9): 1900–1907. https://doi.org/10.1249/MSS.0000000000002326.

Roitto, Hanna-Maria, Elsi Lindell, Seppo Koskinen, and Kati Sarnola. 2016. "Diagnosoitujen muistisairauksien ilmaantuvuus ja esiintyvyys Suomessa vuosina 2016–202," no. 85.

Rovio, Suvi P., Katja Pahkala, Jaakko Nevalainen, Markus Juonala, Pia Salo, Mika Kähönen, Nina Hutri-Kähönen, et al. 2016. "Cognitive Performance in Young Adulthood and Midlife: Relations with Age, Sex, and Education—The Cardiovascular Risk in Young Finns Study." *Neuropsychology* 30 (5): 532–42. https://doi.org/10.1037/neu0000239.

Salthouse, T.A. 2004. "Localizing Age-Related Individual Differences in a Hierarchical Structure."

Sewell, Kelsey R., Stephanie R. Rainey-Smith, Jeremiah Peiffer, Hamid R. Sohrabi, Kevin Taddei, David Ames, Paul Maruff, et al. 2023. "The Relationship between Objective Physical Activity and Change in Cognitive Function." *Alzheimer's & Dementia* 19 (7): 2984–93. https://doi.org/10.1002/alz.12950.

Sofi, F., D. Valecchi, D. Bacci, R. Abbate, G. F. Gensini, A. Casini, and C. Macchi. 2011. "Physical Activity and Risk of Cognitive Decline: A Meta-Analysis of Prospective Studies: Physical Activity and Risk of Cognitive Decline." *Journal of Internal Medicine* 269 (1): 107–17. https://doi.org/10.1111/j.1365-2796.2010.02281.x.

Stenholm, Sari, Anna Pulakka, Tuija Leskinen, Jaana Pentti, Olli J Heinonen, Annemarie Koster, and Jussi Vahtera. 2021. "Daily Physical Activity Patterns and Their Association With Health-Related Physical Fitness Among Aging Workers—The Finnish Retirement and Aging Study." Edited by Anne B Newman. *The Journals of Gerontology: Series A* 76 (7): 1242–50. https://doi.org/10.1093/gerona/glaa193.

Stenholm, Sari, Kristin Suorsa, Tuija Leskinen, Saana Myllyntausta, Anna Pulakka, Jaana Pentti, and Jussi Vahtera. 2023. "Finnish Retirement and Aging Study: A Prospective Cohort Study." *BMJ Open* 13 (12): e076976. https://doi.org/10.1136/bmjopen-2023-076976.

Teräs, Tea, Suvi Rovio, Adam P. Spira, Saana Myllyntausta, Anna Pulakka, Jussi Vahtera, and Sari Stenholm. 2020. "Associations of Accelerometer-Based Sleep Duration and Self-Reported Sleep Difficulties with Cognitive Function in Late Mid-Life: The Finnish Retirement and Aging Study." *Sleep Medicine* 68 (April): 42–49. https://doi.org/10.1016/j.sleep.2019.08.024.

Troiano, Richard P., David Berrigan, Kevin W. Dodd, Louise C. Mâsse, Timothy Tilert, and Margaret Mcdowell. 2008. "Physical Activity in the United States Measured by Accelerometer." *Medicine & Science in Sports & Exercise* 40 (1): 181–88. https://doi.org/10.1249/mss.0b013e31815a51b3.

Tucker-Drob, Elliot M., Andreas M. Brandmaier, and Ulman Lindenberger. 2019. "Coupled Cognitive Changes in Adulthood: A Meta-Analysis." *Psychological Bulletin* 145 (3): 273–301. https://doi.org/10.1037/bul0000179.

United Nations. 2019. *World Population Prospects 2019*. United Nations.

Vuoksimaa, Eero. 2019. “Kognitiivisten toimintojen muutokset – mikä on ikääntymistä, mikä sairautta?”

Waller, Katja Linda, Erik Lykke Mortensen, Kirsten Avlund, Merete Osler, Birgitte Fagerlund, Martin Lauritzen, and Poul Jennum. 2016. “Subjective Sleep Quality and Daytime Sleepiness in Late Midlife and Their Association with Age-Related Changes in Cognition.” *Sleep Medicine* 17 (January): 165–73. https://doi.org/10.1016/j.sleep.2015.01.004.

“World Alzheimer Report 2018 - The State of the Art of Dementia Research: New Frontiers.” n.d. *NEW FRONTIERS*.

Wu, Zhi-jian, Zhu-ying Wang, Bing-qian Hu, Xu-hui Zhang, Fan Zhang, Hou-lei Wang, and Fang-hui Li. 2020. “Relationships of Accelerometer-Based Measured Objective Physical Activity and Sedentary Behaviour with Cognitive Function: A Comparative Cross-Sectional Study of China’s Elderly Population.” *BMC Geriatrics* 20 (1): 149. https://doi.org/10.1186/s12877-020-01521-y.

Zhu, Wenfei, Virginia J. Howard, Virginia G. Wadley, Brent Hutto, Steven N. Blair, John E. Vena, Natalie Colabianchi, David Rhodes, and Steven P. Hooker. 2015. “Association Between Objectively Measured Physical Activity and Cognitive Function in Older Adults—The Reasons for Geographic and Racial Differences in Stroke Study.” *Journal of the American Geriatrics Society* 63 (12): 2447–54. https://doi.org/10.1111/jgs.13829.

Zhu, Wenfei, Virginia G. Wadley, Virginia J. Howard, Brent Hutto, Steven N. Blair, and Steven P. Hooker. 2017. “Objectively Measured Physical Activity and Cognitive Function in Older Adults.” *Medicine & Science in Sports & Exercise* 49 (1): 47–53. https://doi.org/10.1249/MSS.0000000000001079.

Zlatar, Zvinka Z., Chelsea C. Hays, Zoe Mestre, Laura M. Campbell, M.J. Meloy, Katherine J. Bangen, Thomas T. Liu, Jacqueline Kerr, and Christina E. Wierenga. 2019. “Dose-Dependent Association of Accelerometer-Measured Physical Activity and Sedentary Time with Brain Perfusion in Aging.” *Experimental Gerontology* 125 (October): 110679. https://doi.org/10.1016/j.exger.2019.110679.