Joint associations of physical activity and sleep duration with cognitive ageing: longitudinal analysis of an English cohort study

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Summary

Background Physical activity and sleep duration are key factors associated with cognitive function and dementia risk. How physical activity and sleep interact to influence cognitive ageing is not well explored. We aimed to examine the associations of combinations of physical activity and sleep duration with 10-year cognitive trajectories.

Methods In this longitudinal study, we analysed data from the English Longitudinal Study of Ageing collected between Jan 1, 2008, and July 31, 2019, with follow-up interviews every 2 years. Participants were cognitively healthy adults aged at least 50 years at baseline. Participants were asked about physical activity and nightly sleep duration at baseline. At each interview, episodic memory was assessed using immediate and delayed recall tasks and verbal fluency using an animal naming task; scores were standardised and averaged to produce a composite cognitive score. We used linear mixed models to examine independent and joint associations of physical activity (lower physical activity or higher physical activity, based on a score taking into account frequency and intensity of physical activity) and sleep duration (short [<6 h], optimal [6–8 h], or long [>8 h]) with cognitive performance at baseline, after 10 years of follow-up, and the rate of cognitive decline.

Findings We included 8958 respondents aged 50–95 years at baseline (median follow-up 10 years [IQR 2–10]). Lower physical activity and suboptimal sleep were independently associated with worse cognitive performance; short sleep was also associated with faster cognitive decline. At baseline, participants with higher physical activity and optimal sleep had higher cognitive scores than all combinations of lower physical activity and sleep categories (eg, difference between those with higher physical activity and optimal sleep *vs* those with lower physical activity and short sleep at baseline age 50 years was 0·14 SDs [95% CI 0·05–0·24]). We found no difference in baseline cognitive performance between sleep categories within the higher physical activity category. Those with higher physical activity and short sleep had faster rates of cognitive decline than those with higher physical activity and optimal sleep, such that their scores at 10 years were commensurate with those who reported low physical activity, regardless of sleep duration (eg, difference in cognitive performance after 10 years of follow-up between those with higher physical and optimal sleep and those with lower physical activity and short sleep was 0·20 SDs [0·08–0·33]; difference between those with higher physical activity and optimal sleep and those with lower physical activity and short sleep was 0·22 SDs [0·11–0·34]).

Interpretation The baseline cognitive benefit associated with more frequent, higher intensity physical activity was insufficient to ameliorate the more rapid cognitive decline associated with short sleep. Physical activity interventions should also consider sleep habits to maximise benefis of physical activity for long-term cognitive health.

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Introduction

Alzheimer's disease and related dementias are leading causes of cognitive dysfunction and disability in older adults, and a pressing public health concern given global population ageing. Multiple lifestyle factors might contribute to poor cognitive function in individuals aged 65 years and older, including physical activity and sleep, whereby less physical activity and poor sleep—characterised by features such as sleep duration outside 6–8 h, difficulty sleeping or waking, or frequent disturbances—are associated with worse cognitive performance.[1] Sleep disturbances might also be caused by cognitive dysfunction.[1] As associations between cognitive performance and dementia risk are well established,[2] physical activity and sleep are two factors thought to contribute to dementia risk. Indeed, more physical activity has been associated with less accumulation of Alzheimer's disease biomarkers[3] and decreased risk of dementia,[4] and poor sleep has been associated with greater accumulation of Alzheimer's disease biomarkers and increased risk of dementia.[1,5] As such, physical activity is identified in WHO guidelines as a target to improve cognitive health.[6]

Research in context

Evidence before this study
We searched PubMed for publications from database inception until Feb 20, 2023, using the search terms "sleep", "physical activity", "cognition", "cognitive aging", "cognitive function", and "cogniti*", without language restrictions. Lack of physical activity and nightly sleep duration outside 6–8 h are key lifestyle factors that might contribute to poor cognitive function and risk of Alzheimer's disease and related dementias. Despite their interrelated nature whereby physical activity might influence sleep and vice versa, how physical activity and sleep duration combine to influence trajectories of cognitive ageing is not well explored. Cross-sectional evidence suggests the poorer cognitive performance observed in those with suboptimal compared with optimal sleep duration might be ameliorated by sufficient physical activity, or vice versa.

Added value of this study
Because no effective treatment for Alzheimer's disease exists, it is important to investigate modifiable risk factors for poor cognitive performance from midlife onwards to delay onset of clinical symptoms. Alzheimer's disease has a lengthy preclinical period characterised by cognitive decline and behaviour changes years before onset of clinical symptoms, so it is not possible to assess whether the associations observed in previous cross-sectional studies examining physical activity, sleep duration, and cognitive function are due to effects of preclinical Alzheimer's symptoms on physical activity and sleep. The present study contributes longitudinal data to the body of evidence. To reduce the influence of preclinical Alzheimer's symptoms on physical activity and sleep, we excluded those with a dementia diagnosis or cognitive scores that suggested cognitive impairment.
We found that more frequent, higher intensity physical activity and 6–8 h of sleep per night were both associated with better cognitive scores at baseline; however, we also found that the cognitive benefit afforded by physical activity was insufficient to consistently reduce the more rapid cognitive decline associated with short sleep (<6 h). Our results suggest the importance of considering physical activity and sleep together, as these factors might combine in complex ways to influence cognitive trajectories from age 50 years onwards.

Implications of all the available evidence
Physical activity and sleep duration are both important interrelated contributors to cognitive health. Although WHO already identify physical activity as a key target for interventions to maintain cognitive function, effective physical activity interventions should also consider sleep habits to maximise long-term benefits for cognitive health and potentially delay onset of dementia.

Physical activity and sleep are interrelated, with more physical activity of moderate and vigorous intensity associated with better sleep quality,[7] although physical activity and sleep might also influence cognitive function through distinct mechanisms.[1] Even so, little research exists examining joint associations of physical activity and sleep with cognitive function. A review[1] identified seven studies that examined interactions between physical activity and sleep characteristics and their associations with cognitive performance, suggesting sufficient physical activity might reduce the effect of suboptimal sleep on cognitive function or vice versa. However, these studies were small (n<1000)[8–12] and cross-sectional,[13,14] and the review highlighted the need to undertake large-scale, longitudinal studies to better understand how these factors influence cognitive ageing. As no effective treatment exists for Alzheimer's disease, it is particularly important to identify modifiable risk factors for poor cognitive function from midlife onwards to delay onset of clinical symptoms.

To examine independent associations of physical activity and sleep duration with cognitive function, as well as how these factors interact to play a role in cognitive ageing, we used longitudinal data on cognitively healthy adults from the English Longitudinal Study of Ageing (ELSA) to compare 10-year cognitive trajectories between physical activity and sleep duration groups.

Methods

Study design and participants

ELSA is a nationally representative cohort study of the English population aged 50 years or older.[15] Data collection began in 2002–03, with follow-up every 2 years. Details of survey design are available elsewhere.[15]

Participants were asked about sleep duration starting in the 2008–09 wave (wave 4). Physical activity and episodic memory were assessed in all waves; verbal fluency was left out of wave 6. Therefore, we used waves 4–5 and 7–9 in this study (Jan 1, 2008, to July 31, 2019). Respondents aged 50 years or older participating in wave 4 with at least one round of cognitive testing were eligible for this analysis.

ELSA wave 9 received ethics approval from the South Central–Berkshire Research Ethics Committee on May 10, 2018 (17/SC/0588). ELSA wave 8 received ethics approval from the South Central–Berkshire Research Ethics Committee on Sept 23, 2015 (15/SC/0526). ELSA wave 7 received ethics approval from the National Research Ethics Service Committee South Central–Berkshire on Nov 28, 2013 (13/SC/0532). ELSA wave 5 received ethics approval from the Berkshire Research Ethics Committee on Dec 21, 2009 (09/H0505/124). ELSA wave 4 received ethics approval from the National Hospital for Neurology and Neurosurgery & Institute of Neurology Joint Research Ethics Committee on Oct 12, 2007 (07/H0716/48). No further ethics approval was required for the present study.

Physical activity and sleep duration

Physical activity and sleep duration were ascertained by self-report at baseline (wave 4). Participants were asked how many hours they slept on an average weeknight; sleep was categorised as short (<6 h), optimal (6–8 h), or long (>8 h) on the basis of previous evidence of a quadratic association between sleep duration and cognitive performance.[1]

To assess physical activity, participants were asked about frequency of participation in light, moderate, and vigorous physical activity and could answer "more than weekly", "weekly", "1–3 times monthly", or "rarely/never". Participants were given examples of activities in each intensity category. To derive a physical activity measure that considered both the frequency and intensity of activities, we expanded on methods used in another ELSA study[17] examining physical activity and cognitive performance (appendix p 2). We translated physical activity frequency into "bouts per month" in each intensity category, assuming 4·3 weeks per month. "More than weekly" corresponded to 8·6 bouts per month, "weekly" to 4·3 bouts per month, "1–3 times monthly" to 2·0 bouts per month, and "rarely/never" to 0 bouts per month. We multiplied each of these bouts by a previously derived estimate for the average metabolic equivalent of task for each intensity category (appendix p 3).[17] We then summed the scores from each intensity category to give an overall physical activity score. This calculation required the assumption that bouts were of equal length; to reduce misclassification, we categorised physical activity scores into tertiles. Examination of physical activity characteristics in the tertiles led us to combine the bottom two tertiles of physical activity scores (lower physical activity), and compare with the top tertile (higher physical activity) to facilitate presentation of the results, where respondents in the lower physical activity group reported less frequent and less intense physical activity than those in the higher physical activity group did.

Covariates

Sociodemographic covariates included age at baseline (years), sex (male *vs* female), and marital status (married or partnered *vs* not). Socioeconomic covariates included education (less than secondary, secondary, and above secondary) and wealth. Degree level was not included because 83% of participants were educated to secondary level or lower. Included indicators of health behaviour were current smoking status, weekly alcohol use, and BMI (kg/m²). Participants were also asked whether they had been diagnosed with high blood pressure, diabetes, cancer, lung disease, cardiovascular conditions, arthritis, or high cholesterol. Depressive symptoms were included using scores on the 8-item Center for Epidemiologic Studies Depression Scale (CES-D),[18] with higher scores corresponding to worse depressive symptoms. Finally, we included practice effect—referring to the tendency of participants' cognitive scores to improve with successive rounds of testing because of familiarity with testing protocol[19]—as an indicator showing what round of cognitive testing it was for each participant. All covariates except age, sex, and education were time-varying.

Cognitive function

Episodic memory was assessed at each interview using the Consortium to Establish a Registry for Alzheimer's Disease immediate and delayed recall tasks.[20] Participants were given a ten-word list and asked to recall the list immediately and after a delay; scores on these tests were summed. Verbal fluency was assessed at each interview using the animal naming task.[21] Participants were required to name as many animals as possible within 1 min. Scores on the memory and fluency tasks were standardised to the cohort and averaged to yield a standardised composite cognitive score, after preliminary analyses showed results were similar in each cognitive domain (appendix pp 4–7).

See Online for appendix

To reduce the influence of preclinical or clinical dementia symptoms on physical activity and sleep, we excluded participants reporting dementia diagnoses during the follow-up period. We also excluded participants scoring 1·5 SDs or more below the mean for their 10-year age and education group in either cognitive domain for at least two waves (or one wave if the respondent participated in one wave), a cutoff which has been used to identify cognitive impairment.[22]

Statistical analysis

We examined associations between baseline characteristics, sleep, and physical activity using Pearson's χ^2 test for categorical and independent *t* test for continuous variables. The assumptions required for all statistical methods that we used were appropriately assessed.

To examine associations of physical activity and sleep with 10-year cognitive trajectories (the median follow-up duration), we used linear mixed models with years since baseline as the timescale and a random intercept and slope at the individual level (unstructured correlation matrix, multivariate normal joint distribution). In these models, continuous variables were centred at the cohort median (age 65 years) or mean (BMI 28·3 kg/m² or depressive symptom score 1·31), or were standardised (wealth).

The basic model included physical activity, sleep, time in years since baseline (denoted time), interactions between physical activity and time, and interactions between sleep and time, to report average cognitive performance at baseline in each physical activity and sleep category for the cohort. We then added practice effects and the minimally sufficient set of confounders based on previous evidence of their associations with physical activity, sleep, and cognitive performance: age at baseline, sex, education, wealth, smoking status, alcohol use, BMI, chronic conditions, and CES-D score. We examined interactions of all included variables with age and time (for non-time-varying covariates only), retaining higher-order interactions if p<0·05 on the basis of the Wald test. We used this model to examine independent associations of physical activity and sleep with cognitive performance at baseline and cognitive decline.

To examine joint associations of physical activity and sleep with cognitive trajectories, we added interactions between physical activity and sleep, and physical activity, sleep, and time to the model. We considered there to be a joint association of physical activity and sleep with cognitive trajectory if the physical activity and sleep interaction terms were significant (p<0·05) based on the Wald test. Finally, we used this model to predict cognitive trajectories over 10 years from baseline ages 50, 60, and 70 years. We reported differences in cognitive performance at baseline, 10-year follow-up, and 10-year cognitive decline between a reference category (higher physical activity with optimal sleep) and other physical activity and sleep categories. We did all analyses in StataMP (version 17.0) with a two-sided p<0·05 considered significant.

While examination of interaction terms between sex, physical activity, and sleep duration suggested results were similar for men and women, given cross-sectional evidence of sex differences in associations of physical activity and sleep with cognitive performance,[23] we reran analyses stratified by sex. We also reran analyses using non-standardised scores to examine the effects of our choice of population for standardisation.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

Of 10 734 ELSA participants aged at least 50 years participating in wave 4, 444 (4·1%) were missing sleep data, two (<0·1%) were missing physical activity, and 62 (0·6%) were missing cognitive scores at all waves (appendix p 16). 516 (4·8%) participants were missing covariates and 752 (7·0%) reported dementia diagnosis or had cognitive scores suggesting cognitive impairment, leading to an analytic sample of 8958 participants (appendix p 16).

In the higher physical activity category (n=3069), the largest proportion of respondents (1525 [50·0%]) reported participating in light, moderate, and vigorous physical activity more than weekly; the next most common (1161 [37·8%]) combination of responses was more than weekly light and moderate, and monthly or weekly vigorous physical activity (appendix p 8). In the lower physical activity category (n=5889), the largest proportion (2384 [40·5%]) reported no vigorous physical activity, but more than weekly light and moderate physical activity, and 1511 (25·7%) respondents reported more than weekly light physical activity, no vigorous physical activity, and moderate physical activity weekly or less (appendix p 9).

The higher physical activity group were more likely to sleep 6–8 h per night, be younger at baseline, male, married or partnered, with higher education and wealth than those in the lower physical activity group (p<0·0001 for all; table 1). The higher physical activity group were more likely not to smoke, to use alcohol weekly, had lower BMIs, fewer diagnoses of all chronic conditions, and fewer depressive symptoms compared with those in the lower physical activity group (p<0·0001 for all, except for cancer p=0·0007; table 1). Median follow-up time was similar between physical activity and sleep categories: 8 years (IQR 2–10) for lower physical activity and short sleep or long sleep, 9 years (2–10) for lower physical activity and optimal sleep, and 10 years (6–10) for all higher physical activity categories.

Average baseline cognitive performance was –0·11 SDs (95% CI –0·13 to –0·09) in the lower physical activity group and 0·22 (0·19 to 0·25) in the higher physical activity group. The average baseline cognitive performance was 0·08 (0·05–0·10) for optimal sleepers, –0·10 (–0·14 to –0·06) for short sleepers, and –0·05 (–0·08 to –0·02) for long sleepers. After adjustment for all covariates, higher physical activity was independently associated with a baseline cognitive benefit that increased with age. The higher physical activity group had cognitive scores 0·07 (0·01 to 0·12; age 50 years), 0·10 (0·07 to 0·13; age 60 years), or 0·13 (0·10 to 0·17; age 70 years) higher than those in the lower physical activity group. Compared with short or long sleep, optimal sleep was also independently associated with a baseline cognitive benefit for all ages. Optimal sleepers had higher cognitive performance compared with short sleepers at ages 50 years (0·08 [0·00 to 0·16]), 60 years (0·07 [0·02 to 0·12]), and 70 years (0·06 [0·01 to 0·10]). The difference in baseline cognitive performance between optimal and long sleepers increased with age; optimal sleepers performed better than long sleepers at ages 50 years (0·03 [–0·03 to 0·09]), 60 years (0·05 [0·02 to 0·09]), and 70 years (0·08 [0·04 to 0·11]).

After adjustment for all covariates, we found negligible differences in 10-year cognitive decline between physical activity categories (difference higher *vs* lower 0·00 SDs [95% CI –0·04 to 0·03]). By contrast, short sleepers declined 0·11 SDs (0·01 to 0·21) more over 10 years than optimal sleepers at baseline age 50 years; differences in decline between optimal and short sleepers were minor at baseline ages 60 years (difference –0·03 [–0·02 to 0·09]) and 70 years (0·04 [–0·11 to 0·03]), as were differences in 10-year decline between optimal and long sleepers (age 50 years difference –0·02 [–0·10 to 0·06], age 60 years difference –0·02 [–0·06 to 0·02], and age 70 years difference –0·02 [–0·07 to 0·03]).

After including physical activity and sleep interaction terms in the model, we found evidence of a joint association of physical activity and sleep with cognitive trajectory (p=0·032; figure 1). At age 50 years, those with higher physical activity and optimal sleep performed 0·14 SDs (95% CI 0·05 to 0·24) better than those with lower physical activity and short sleep, 0·05 SDs (0·00 to 0·11) better than those with lower physical activity and optimal sleep, and 0·11 SDs (0·03 to 0·19) better than those with lower physical activity and long sleep at baseline (table 2; figure 2A). We found smaller or negligible differences between those with higher physical activity and optimal sleep and both those with higher physical activity and short sleep (difference 0·06

	Lower physical activity (n=5889)	Higher physical activity (n=3069)	p value
Baseline standardised cognitive performance	−0·11 (0·83)	0·21 (0·81)	<0·0001
Sleep duration			
Short (<6 h)	943 (16·0%)	328 (0·7%)	..
Optimal (6–8 h)	3208 (54·5%)	1845 (60·1%)	<0·0001
Long (>8 h)	1738 (29·5%)	896 (29·2%)	..
Age at baseline in years	65 (58–73)	62 (57–68)	<0·0001
Sex			
Male	2464 (41·8%)	1527 (49·8%)	<0·0001
Female	3425 (58·2%)	1542 (50·2%)	..
Race or ethnicity			
White	5757 (97·7%)	3015 (98·2%)	0·12
Non-White	133 (2·3%)	54 (1·8%)	..
Married or partnered	3900 (66·2%)	2268 (73·9%)	<0·0001
Education			
Less than secondary	2501 (42·5%)	771 (25·1%)	..
Secondary	2632 (44·7%)	1505 (49·0%)	<0·0001
Above secondary	756 (12·8%)	793 (25·8%)	..
Non-housing wealth tertile			
First (lowest wealth)	2235 (38·0%)	721 (23·5%)	..
Second (intermediate wealth)	1964 (33·3%)	1048 (34·1%)	<0·0001
Third (highest wealth)	1690 (28·7%)	1300 (42·4%)	..
Current smoker	954 (16·2%)	264 (8·6%)	<0·0001
Reports weekly alcohol consumption	3256 (55·3%)	2245 (73·2%)	<0·0001
BMI, kg/m²	28 (25–31·2)	26·7 (24·3–29·7)	<0·0001
Comorbidities			
High blood pressure	2582 (43·8%)	943 (30·7%)	<0·0001
Diabetes	616 (10·5%)	141 (4·6%)	<0·0001
Cancer	513 (8·7%)	204 (6·6%)	0·0007
Lung disease	1055 (17·9%)	376 (12·3%)	<0·0001
Cardiovascular condition	1185 (20·1%)	386 (12·6%)	<0·0001
Arthritis	2280 (38·7%)	766 (25·0%)	<0·0001
High cholesterol	1952 (33·1%)	772 (25·2%)	<0·0001
CESD score	1 (0–2)	1 (0–1)	<0·0001

Data are n (%), mean SD, or median (IQR), unless otherwise indicated. CESD=Center for Epidemiologic Studies Depression Scale. ELSA=English Longitudinal Study of Ageing.

Table 1: **Characteristics of the analytic sample**

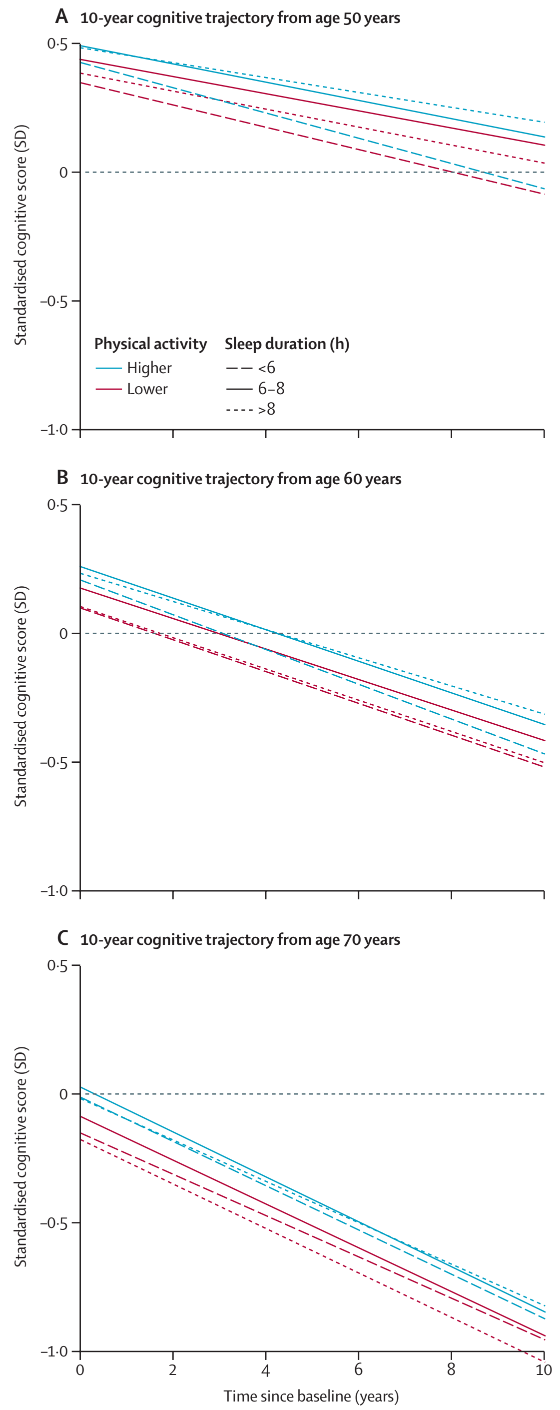

Figure 1: **10-year cognitive trajectories from ages 50, 60, and 70 years in each combination of physical activity and sleep duration category**
10-year cognitive trajectory from age 50 years (A) and from age 60 years (B), and from age 70 years (C). Results were based on models adjusted for practice effect, sociodemographic and socioeconomic characteristics, health behaviours, chronic conditions, and depressive symptoms. Data are plotted for reference values of covariates (male, first round of cognitive testing, married or partnered, secondary education, non-smoker, weekly alcohol consumption, or no chronic conditions) or for mean value in cohort (wealth, BMI, or depressive symptoms).

	At baseline			After 10 years of follow-up		
	Aged 50 years at baseline	Aged 60 years at baseline	Aged 70 years at baseline	Aged 50 years at baseline	Aged 60 years at baseline	Aged 70 years at baseline
Higher physical activity with short sleep	0·07 (–0·03 to 0·16)	0·05 (–0·03 to 0·13)	0·04 (–0·04 to 0·12)	0·20 (0·08 to 0·33)	0·11 (0·02 to 0·21)	0·03 (–0·08 to 0·13)
Higher physical activity with optimal sleep (ref)	Ref	Ref	Ref	Ref	Ref	Ref
Higher physical activity with long sleep	0·01 (–0·06 to 0·08)	0·03 (–0·03 to 0·08)	0·04 (–0·01 to 0·10)	–0·06 (–0·15 to 0·03)	–0·04 (–0·11 to 0·02)	–0·02 (–0·10 to 0·05)
Lower physical activity with short sleep	0·14 (0·05 to 0·24)	0·16 (0·10 to 0·22)	0·18 (0·12 to 0·24)	0·22 (0·11 to 0·34)	0·17 (0·09 to 0·24)	0·11 (0·03 to 0·19)
Lower physical activity with optimal sleep	0·05 (0·00 to 0·11)	0·08 (0·04 to 0·12)	0·11 (0·07 to 0·16)	0·03 (–0·03 to 0·10)	0·06 (0·01 to 0·11)	0·09 (0·04 to 0·14)
Lower physical activity with long sleep	0·11 (0·03 to 0·19)	0·16 (0·11 to 0·20)	0·20 (0·15 to 0·26)	0·10 (0·00 to 0·20)	0·15 (0·09 to 0·21)	0·20 (0·13 to 0·26)

Positive value indicates cognitive performance is higher in the reference category. Cognitive performance refers to mean of standardised memory and fluency scores. Results are based on models adjusted for practice effect, sociodemographic and socioeconomic characteristics, health behaviours, chronic conditions, and depressive symptoms.

Table 2: Difference in composite cognitive score between those with higher physical activity and optimal sleep and other combinations of physical activity and sleep categories

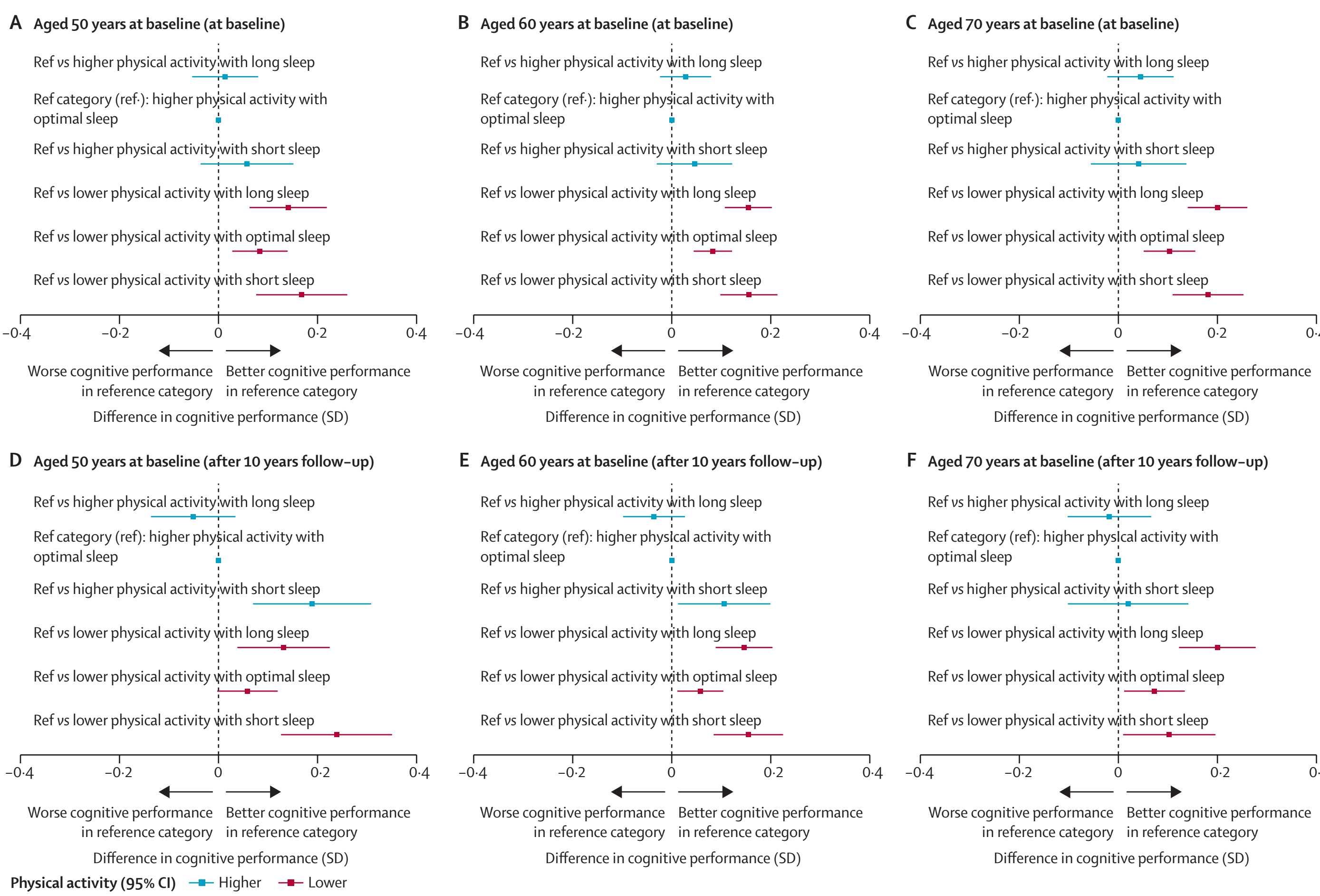

Figure 2: **Difference in standardised cognitive performance between reference and other physical activity plus sleep duration categories at baseline and 10-year follow-up for baseline ages 50, 60, and 70 years**
Reference category was higher physical activity with optimal sleep. 95% CIs that do not intersect 0 line indicate statistically significant difference between given physical activity plus sleep category and higher physical activity with optimal sleep (=0·05). Panels A–C show differences at baseline. Panels D–F show differences after 10 years of follow up. All results were based on models adjusted for practice effect, sociodemographic and socioeconomic characteristics, health behaviours, chronic conditions, and depressive symptoms.

[–0·03 to 0·16]) and those with higher physical activity and long sleep (0·01 [–0·06 to 0·08]). Results were similar for ages 60 years and 70 years (table 2; figures 2B, C).

Cognitive decline also differed between categories of physical activity and sleep duration (table 3). First, participants with higher physical activity and long sleep

	Aged 50 years at baseline	Aged 60 years at baseline	Aged 70 years at baseline
Higher physical activity with short sleep	0·14 (0·01 to 0·26)	0·06 (–0·04 to 0·16)	–0·01 (–0·12 to 0·09)
Higher physical activity with optimal sleep (ref)	Ref	Ref	Ref
Higher physical activity with long sleep	–0·07 (–0·16 to 0·03)	–0·07 (–0·13 to 0·00)	–0·07 (–0·14 to 0·01)
Lower physical activity with short sleep	0·08 (–0·03 to 0·19)	0·00 (–0·07 to 0·08)	–0·07 (–0·15 to 0·01)
Lower physical activity with optimal sleep	–0·02 (–0·07 to 0·03)	–0·02 (–0·07 to 0·03)	–0·02 (–0·07 to 0·03)
Lower physical activity with long sleep	–0·01 (–0·09 to 0·08)	–0·01 (–0·07 to 0·05)	–0·01 (–0·07 to 0·06)

Positive value indicates slower cognitive decline in those with higher physical activity with optimal sleep. 10-year cognitive decline refers to the difference in predicted cognitive score at 10 years follow-up compared with baseline. Results are based on models adjusted for practice effect, sociodemographic and socioeconomic characteristics, health behaviours, chronic conditions, and depressive symptoms.

Table 3: **Difference in 10-year cognitive decline between higher physical activity with optimal sleep and other combinations of physical activity and sleep categories**

declined less rapidly than those with higher physical activity and optimal sleep (difference in 10-year decline [reference *vs* higher physical activity with long sleep] age 50 years –0·07 [95% CI –0·16 to 0·03]; age 60 years –0·07 [–0·13 to 0·00], and age 70 years –0·07 [–0·14 to 0·01]; table 3). Second, from baseline age 50 years, although those with higher physical activity and short sleep started out performing similarly to those with higher physical activity and optimal sleep at baseline, those with higher physical activity and short sleep declined more rapidly (difference in 10-year decline [reference *vs* higher physical activity with short sleep] 0·14 [0·01 to 0·26]; table 3). Results were similar for baseline age 60 years (table 3). As a result, after 10 years of follow-up, those with higher physical activity and short sleep had cognitive scores similar to those with lower physical activity and short sleep from baseline ages 50 and 60 years (table 2; figure 2D, E), but not 70 years (table 2; figure 2F).

Results for men and women separately were similar to those of the main analysis, with the exception of long sleep, which was associated with a more favourable cognitive trajectory for men only (appendix pp 10–13). Results were substantively unchanged when non-standardised scores were used (appendix pp 14–15).

Discussion

This analysis of 10-year cognitive trajectories in middle-aged and older adults has two key findings. First, more frequent, higher intensity physical activity and optimal sleep duration were independently associated with baseline cognitive performance, and short sleep was also associated with a faster rate of cognitive decline. Second, both physical activity and sleep duration at baseline were associated with cognitive performance after 10 years of follow-up, with evidence of a joint association of physical activity and sleep duration with cognitive trajectory, suggesting combinations of physical activity and sleep duration interact to influence cognitive scores up to 10 years later: the higher physical activity group generally had the highest baseline cognitive scores regardless of sleep duration; however, for ages 50 and 60 years, those with higher physical activity and short sleep declined more rapidly such that after 10 years of follow-up, they had cognitive scores similar to those in the lower physical activity groups. Taken together, these results point to an important combined role of physical activity and sleep duration in shaping cognitive trajectories from age 50 years onwards.

Our findings are consistent with cross-sectional studies,[9,13] human sleep-deprivation studies,[24] and isotemporal substitution studies[11] that suggest physical activity might partly attenuate the effect of poor sleep on cognitive function, or vice versa.[1] Our analysis expands on these studies by also examining longitudinal associations between combinations of physical activity and sleep categories with cognitive performance in a considerably larger cohort. We reiterated the U-shaped association between sleep duration and cognitive performance, in which participants reporting 6–8 h of sleep generally had more favourable cognitive trajectories than those reporting longer or shorter sleep, and the association between more frequent, more intense physical activity and better cognitive performance. However, we also showed that physical activity and sleep duration interact in nuanced ways: for baseline ages 50 and 60 years, higher physical activity was insufficient to ameliorate the rapid cognitive decline associated with short sleep; by age 70 years, the cognitive benefit associated with higher physical activity was maintained over the 10-year follow-up period. Although long sleep was independently associated with a cognitive deficit, the cognitive trajectory over 10 years for those with higher physical activity and long sleep was slightly better than for those with higher physical activity and optimal sleep. Furthermore, the sex-stratified results suggested that the cognitive benefits associated with higher physical activity combined with long sleep occurred for men only, indicating that determinants of long sleep might differ between men and women and warranting further research.

These complex associations of physical activity and sleep probably reflect independent and joint mechanisms through which these factors are thought to influence cognitive function. Physical activity might act through neurotransmitters such as insulin-like growth factor or brain-derived neurotrophic factor to increase plasticity in the hippocampus, improving memory performance,[25] whereas sleep might influence cognitive function through its effects on acetylcholine concentrations and memory consolidation.[1] However, physical activity might also influence sleep and vice versa. These interacting mechanisms highlight the importance of examining physical activity and sleep together.

A major strength of the present analysis is our use of up to 11 years of longitudinal data in a large-scale nationally representative cohort. Previous examinations of interactions between physical activity and sleep and their associations with cognitive performance have been cross-sectional, preventing examination of cognitive decline. Our study also improves on previous cross-sectional studies because the results are less likely to be influenced by reverse causation; we excluded individuals with cognitive impairment or self-reported dementia diagnosis, as Alzheimer's disease has a decade-long preclinical period characterised by progressive cognitive decline that might lead to behavioural changes years before onset of clinical disease.[26] The large sample size allowed sufficient power to examine interactions between physical activity and sleep to show that combinations of physical activity and sleep duration were associated with 10-year cognitive trajectories, beyond simple additive independent associations of physical activity and sleep.

There are limitations to this study. First, 75% of ELSA respondents reported physical activity consistent with guidelines of 150 min/week of moderate or 75 min/week of vigorous physical activity, compared with less than 60% of UK adults.[27] Overestimation of physical activity might have led to an underestimation of the relationship between physical activity and cognitive performance if those with less physical activity were also more likely to over-report; otherwise, if over-reporting was systematic, there would be no effect on the results. Because we used a dichotomised physical activity measure, our assumption that bouts of physical activity were of equal length is also less likely to have influenced the results. Shorter follow-up durations in the lower physical activity and suboptimal sleep groups might have led to an underestimation of the cognitive deficit associated with lower physical activity and suboptimal sleep; however, overall differences in follow-up duration between individuals reporting different combinations of physical activity and sleep duration were minor. Self-reported physical activity and sleep duration might not be consistent with objectively assessed measures; however, evidence suggests that accuracy of self-reported sleep is not related to age or cognitive performance,[28] making this possibility less likely to have affected the results. Also, self-reported physical activity was correlated with accelerometer-accessed physical activity in a subsample of 116 ELSA participants.[16] Furthermore, self-reported sleep measures have been associated with multiple health outcomes, suggesting that these measures have clinical importance.[1] Some participants with transient cognitive impairment might have been excluded from the sample. Residual confounding due to confounders such as use of sleep medication, sleep disorders, or traumatic brain injury might limit causal inference. Residual confounding from measurement error and the potential for time-varying confounders to be influenced by sleep and physical activity might have also introduced bias to the results; reproducing results using G methods to handle time-varying confounding is an important next step. We were also not able to adjust for changes in physical activity and sleep during follow-up because of lack of sleep data; however, evidence suggests that physical activity levels decreased over time in ELSA,[29] whereas sleep quality and duration decrease with age,[30] meaning our estimates might underestimate cognitive deficits in lower physical activity and suboptimal sleep groups. Finally, whether results can be generalised to other study populations remains to be seen. Repeating results in more diverse study populations, with more cognitive domains examined separately without composite cognitive scores, other domains of sleep quality, and using objective measures such as accelerometery would further elucidate relationships between physical activity, sleep, and cognitive ageing.

Lifestyle factors that contribute to better midlife cognitive function and slower cognitive decline might delay the age at which poor cognitive function limits quality of life or functional capacity, prolonging cognitively healthy years and potentially delaying dementia diagnosis. The results of this analysis suggest that combinations of physical activity and sleep habits might influence cognitive function up to 10 years later, and that frequent, high intensity physical activity might lessen some detrimental cognitive effects of suboptimal sleep duration for adults aged 70 years and older. This finding points to the importance of regular participation in moderate and vigorous-intensity physical activity for older adults. However, for adults in middle-age and early old age, frequent participation in high intensity physical activity was insufficient to protect against the faster cognitive decline observed in short sleepers, suggesting that both physical activity and sleep habits should be addressed to maintain cognitive function from midlife onwards.

Physical activity is already identified by WHO guidelines as an important target for interventions to maintain cognitive health,[6] and growing evidence supports a link between sleep duration and cognitive function.[1] Our findings highlight the importance of understanding not only these independent associations of physical activity and sleep with cognitive function, but also how they interact to inform cognitive ageing trajectories. Effective physical activity interventions should also consider sleep habits to maximise long-term benefits of physical activity on cognitive health, improve cognitive ageing outcomes, and potentially delay onset of dementia.

Contributors

MB, LB, and AS contributed to study conceptualisation, investigation, formal analysis, data curation, writing of the original draft, and data visualisation. LB and AS validated the data. AS supervised the study and acquired funding. All authors contributed to developing the methods used in this study and manuscript review and editing. All authors had access to all the included data. MB and LB accessed and verified the data. MB had the final responsibility to submit for publication.

Declaration of interests

We declare no competing interests.

Data sharing

ELSA data are available to researchers after registration with the UK data service at https://beta.ukdataservice.ac.uk/datacatalogue/series/series?id=200011.

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