Associations between sedentary behaviours and cognitive function: cross-sectional and prospective findings from the UK Biobank

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ABSTRACT

We investigate the cross-sectional and prospective associations between different sedentary behaviours and cognitive function in a large sample of UK Biobank adults. Baseline data were available on 502,643 participants (years 2006-2010). Cognitive tests included prospective memory [n=171,585 (baseline only)], visual-spatial memory [round 1 (n=483,832); round 2 (n=482,762)], fluid intelligence [n=165,492], and short-term numeric memory [n=50,370]. After a mean period of 5.3-years, between 12,091 and 114,373 participants also provided follow-up cognitive data. Sedentary behaviours [Television (TV) viewing, driving, and non-occupational computer use time] were measured at baseline. At baseline, both TV viewing and driving time were inversely associated with cognitive function across all outcomes [e.g. for each additional hour spent watching TV, the total number of correct answers in the fluid intelligence test was 0.15 (99% confidence interval: 0.14, 0.16) lower].

Computer use time was positively associated with cognitive function across all outcomes. Both TV viewing and driving time at baseline were positively associated with the odds of having cognitive decline at follow-up across most outcomes. Conversely, computer use time at baseline was inversely associated with the odds of having cognitive decline at follow-up across most outcomes. This study supports health policies designed to reduce TV viewing and driving in adults.

Keywords: Cognitive decline; Cognitive function; Computer use; Driving; Epidemiology; Sedentary behaviour; Television (TV) viewing; United Kingdom Biobank

Currently, there are no effective long-term pharmacological therapies for the treatment or prevention of dementia. Therefore, identifying potentially modifiable risk factors of cognitive decline, a major characteristic of dementia, is a key priority. Engaging in healthy lifestyle practices, including physical activity, has been associated with a reduced risk of dementia and its symptoms, such as cognitive impairment (1, 2); suggesting a potential role for lifestyle therapies. Indeed, physical activity intervention studies have shown changes to the structure and function of the brain (3-7), supporting the observational associations.

Along with physical activity, engaging in sedentary behaviour, defined as sitting or reclining with low energy expenditure (8), could also be an important determinant of poor cognitive function. There is cumulative evidence indicating that sedentary time is associated with poor cardiometabolic health, chronic disease, and mortality (9-12).

A recent systematic review also suggested that sedentary behaviour is negatively associated with cognitive function; although the relationship between the two is complex, and recommend that future studies should focus on determining how different sedentary behaviours are associated with cognitive function (13). Limited observational research has indicated that television (TV) viewing is inversely associated with cognition (14-17). However, different sedentary behaviours may have different associations, with some evidence of computer/internet use linked to cognitive improvement (15-18). Furthermore, most of the existing data have emerged from relatively limited cross-sectional findings (16-18). Therefore, this warrants investigation in large-scale studies with prospective data.

The aim of this paper was to use the nationally representative UK Biobank cohort to examine the cross-sectional and prospective associations between domains of sedentary behaviour (TV viewing, driving, and computer use) and cognitive function (prospective memory, visual-spatial memory, fluid intelligence and short-term numeric memory).

METHODS

Design and population

The UK Biobank is a large prospective study of the middle-aged population (19-21). Approximately 500,000 adults (aged 37-73 years) were recruited between 2006-2010 via mailing out invitations to those registered with the National Health Service (NHS) and living within 25 miles of one of the 22 study assessment centres. Participants provided comprehensive baseline data on a broad range of biological,

cognition, demographic, health, lifestyle, mental, social, and well-being outcomes. Approximately 300,000 participants also provided an email address to allow for the remote follow-up of cognitive function in the future. From 2014 to 2015, around 125,000 participants provided some online follow-up cognitive function data. For the present study, baseline data were available on 502,643 individuals. Of these, depending on the cognitive test, between 50,370 and 483,832 participants provided baseline cognitive function data (see Web Figure 1). Of these, after a mean period of 5.3 years and depending on the cognitive test, between 12,091 and 114,373 participants also provided online follow-up cognitive function data (see Web Figure 2). All participants provided written informed consent and the study was approved by the NHS National Research Ethics Service (Ref: 11/NW/0382). Further details are available elsewhere (19-21).

Cognitive function tests

Questionnaires administered through a computerised touchscreen interface assessed cognitive function at baseline. Using the same methodology minus the touchscreen ability, follow-up measurements were obtained via online questionnaires that were completed remotely. To ensure effortless application on a large scale and wide response distributions, the cognitive function tests, which were refined over piloting, were designed comprehensively and specifically for UK Biobank. Prospective memory (available at baseline only), visual-spatial memory, fluid intelligence, and short-term numeric memory tests were included in this analysis. At baseline, there were variations between the numbers of individuals who completed each cognitive assessment due to tests being: abandoned or skipped by

participants, incorporated towards the end of recruitment (e.g. fluid intelligence), and/or phased out during the early stages of recruitment (e.g. short-term numeric memory). For more details on the cognitive function tests, see Web Appendix 1.

Sedentary behaviours

Data on sedentary behaviours were self-reported and collected at baseline using a computerised questionnaire. Domains of sedentary behaviour included: TV viewing time (<1, 1, 2, 3, ≥4 hours/day), driving time (<1, 1, 2, ≥3 hours/day), and non-occupational computer use time (<1, 1, 2, ≥3 hours/day). For more details, see Web Appendix 2.

Covariate data

Covariate data included: anthropometric (body mass index), demographic (age, sex, ethnicity, social deprivation index, employment status, education level), health (number of cancers, number of non-cancer illnesses, number of medications/treatments), and lifestyle (smoking status, alcohol drinking status, sleep duration, fruit and vegetable consumption, physical activity) variables. For more details, see Web Appendix 3.

Statistical analysis

Statistical analyses were executed using Stata/MP V14.0 (Stata Corporation, College Station, Texas, USA). Data were analysed in February 2017. With the

intention of maximising the use of the data, pairwise deletion was used to handle missing data (see Web Figure 1 and Web Figure 2). Participant characteristics were tabulated. Categorical variables were presented as numbers and proportions, whereas continuous variables were summarised as means and standard deviations (SD); and presented with their minimum and maximum values.

Cross-sectional analysis

Regression analysis was used to examine the cross-sectional associations between the three domains of sedentary behaviour and cognitive function at baseline. Multiple logistic regression models were fitted for each binary cognitive outcome variable (prospective memory, visual-spatial memory (round 1), and visual-spatial memory (round 2)). Multiple linear regression models were fitted for each continuous cognitive outcome variable (fluid intelligence and short-term numeric memory). For more details on the nature of the cognitive outcome variables used in the cross-sectional analysis, see Web Appendix 1. Model 1 was mutually adjusted for the other sedentary behaviours and for age and sex. Model 2 was further adjusted for body mass index, ethnicity, social deprivation index, employment status, education level, smoking status, alcohol drinking status, fruit and vegetable consumption, sleep duration, physical activity (frequency of ≥10 minutes of walking (days/week), frequency of ≥10 minutes of moderate physical activity (days/week), frequency of ≥10 minutes of vigorous physical activity (days/week)), number of cancers, number of non-cancer illnesses, and number of medications/treatments. For each sedentary behaviour, the '<1 hour/day' category was selected as the reference group. Linear trends (linear terms) across the categories of each sedentary behaviour were

reported. Interaction terms were separately added to the fully adjusted model (Model 2) to observe whether the associations between the sedentary behaviours and cognitive function were modified by age or sex. Significant results for age were stratified at 60 years.

Prospective analysis

Multiple logistic regression models investigated the prospective associations between the three domains of sedentary behaviour at baseline and cognitive function at follow-up. These models estimated the odds of having cognitive decline (i.e. a poor outcome) at follow-up. Cognitive outcomes included: visual-spatial memory (round 1), visual-spatial memory (round 2), fluid intelligence, and short-term numeric memory. For full details on the definitions and nature of the cognitive outcome variables used in the prospective analysis, see Web Appendix 1. As well as controlling for the baseline result/score of the cognitive test under consideration, models were adjusted for all the covariates mentioned previously (see list of confounders in Models 1 and 2 of the cross-sectional analyses). Linear trends across the categories of each sedentary behaviour were reported. Interactions by age and sex were also investigated.

Sensitivity analysis

To assess the generalizability of our findings, the cross-sectional and prospective analyses investigating the associations between sedentary behaviours and cognitive function (Model 1 and Model 2) were repeated across the sample of participants

without a medical history of cancer, cardiovascular disease, and/or cognitive/psychiatric illnesses as sensitivity analyses. For more details on the specific diseases/illnesses, see Web Appendix 4.

Statistical reporting

For each variable of interest (sedentary behaviours), the beta coefficient (linear regression) or odds ratio (logistic regression) with 99% confidence intervals (99% CIs) and p-values are reported. All analyses employed robust standard errors and all reported p-values are two-sided. To account for multiple comparisons, $p<0.01$ was considered to be statistically significant for the main analyses. For the interaction analyses, $p<0.05$ was considered to be statistically significant.

RESULTS

Cross-sectional findings

Table 1 presents the characteristics of the 502,643 participants with baseline data. The mean (SD) age of these individuals was 56.5 (8.1) years and 273,467 (54.4%) were female.

Table 2 presents the associations between the sedentary behaviours and cognitive function. In the fully adjusted models (Model 2), the cross-sectional data showed that TV viewing time was inversely associated with cognitive function across all outcomes apart from visual-spatial memory (round 2). For example, for each additional hour spent watching TV up to ≥4 hours/day, the fluid intelligence and short-term numeric

memory scores were 0.15 (99% CI: 0.14, 0.16) and 0.09 (0.07, 0.10) units lower, respectively. Correspondingly, the odds of a poor result in the prospective memory and visual-spatial memory (round 1) tests were 2% (0%, 3%) and 3% (2%, 4%) higher, respectively. Driving time was inversely associated with cognitive function across all outcomes. In contrast, computer use time was positively associated with cognitive function across all outcomes.

Interaction analyses showed that most findings were modified by age and sex ($p<0.05$). Stratification indicated that the associations were generally stronger in older adults (≥60 years) and in males (see Web Figure 3 (age) and Web Figure 4 (sex)).

Prospective findings

Table 3 presents the cognitive function data of the participants with cognitive data at both baseline and follow-up. Cognitive decline over time was apparent since participants performed better in each cognitive test at baseline than at follow-up. For example, the mean (SD) fluid intelligence score (n=46,704) at baseline and follow-up was 6.7 (2.1) and 5.5 (2.0), respectively; with 15,384 (32.9%) individuals reporting a good outcome at follow-up (baseline fluid intelligence score ≤ follow-up fluid intelligence score) and 31,320 (67.1) individuals reporting a poor outcome at follow-up (baseline fluid intelligence score > follow-up fluid intelligence score). The other tests followed a similar pattern.

Those with follow-up data had similar characteristics to the full UK Biobank cohort, although they were better educated and more likely to be employed (see Web Table 1).

Table 4 presents the associations between the sedentary behaviours at baseline and cognitive function at follow-up. In the fully adjusted models (Model 2), both TV viewing and driving time at baseline were positively associated with the odds of having cognitive decline at follow-up across most outcomes. For example, for each additional hour spent watching TV up to ≥4 hours/day at baseline, the odds of a lower fluid intelligence score at follow-up were 9% (6%, 11%) higher. Similarly, for each additional hour spent driving up to ≥3 hours/day at baseline, the odds of a lower fluid intelligence score at follow-up were 11% (7%, 15%) higher. In contrast, computer use time at baseline was inversely associated with the odds of having cognitive decline at follow-up across most outcomes. Interaction analyses showed that only the associations between TV viewing time and visual-spatial memory (round 2) were modified by age ($p<0.05$) (see Web Figure 5). Findings were not modified by sex.

Sensitivity analyses

The cross-sectional and prospective findings were generalizable across the sample of participants without cancer, cardiovascular disease, and/or cognitive/psychiatric illnesses (see Web Figure 6 (cross-sectional associations) and Web Figure 7 (prospective associations)).

DISCUSSION

Key findings

This is the first study to quantify the cross-sectional and prospective associations between domains of sedentary behaviour and cognitive function in a large cohort of UK adults. At baseline, both TV viewing and driving time were inversely associated with cognitive function. In contrast, computer use time was positively associated with cognitive function. Most findings were modified by age and sex, with stronger relationships generally observed in older adults and in males. These novel results suggest that the influence of sedentary behaviour on cognition is enhanced in older age and in men. Both TV viewing and driving time at baseline were positively associated with the odds of having cognitive decline at follow-up across most outcomes. In contrast, computer use time at baseline was inversely associated with the odds of having cognitive decline at follow-up across most outcomes. The cross-sectional and prospective findings were robust and generalizable across the sample of participants without cancer, cardiovascular disease, and/or cognitive/psychiatric illnesses.

Interpretations

To our knowledge, only a few number of studies have attempted to examine the prospective associations between the different types of sedentary behaviours and cognitive function (14-17, 22-26). However, these studies have all been limited by a small sample size (N ranging between 469 and 8,462), populations that only involved children or older adults, analyses that only considered one domain or test of

cognitive function, and/or cognitive data that were only collected at a single time point. Therefore, this novel study in a large sample of middle-aged adults representing the general population provides the most comprehensive observational analysis to date.

Our findings are consistent with the existing data in this research area. Observational studies have previously demonstrated an inverse association between TV viewing and cognition (14-17), and a positive association between computer/internet use and cognition (15-18). However, until this study, the interactions with age or the deleterious influence of driving on cognitive health were less clear. The inverse associations of TV viewing and driving time with cognitive function could be due to several factors. Cognition has previously been linked to cardiometabolic health (27, 28), and numerous studies have demonstrated inverse associations of TV viewing and driving time with cardiometabolic health (9-12, 29-31). Therefore, it is possible that the observed associations act via pathways linked to the risk of vascular dysfunction and chronic diseases. As vascular dysfunction and chronic diseases are linked to aging, this mechanism would also help explain the observed interactions with age. Other mediating factors could also explain the results for driving; it is known that driving is related to stress and fatigue (32), and with several studies previously showing the links between these factors and cognitive decline (33-35), it is plausible that the observed relationships are enhanced via this pathway. Furthermore, some types of sedentary behaviours, such as TV viewing and driving, could possibly segregate individuals from social networks and restrict external collaborations, factors which are known to affect cognition (36-38); this again could be particularly important in older adults. In contrast, the positive relationship shared between computer use and cognitive function coincides with previous work where

improved cognition or a lower risk of dementia were reported in those engaging in cognitively vitalising sedentary behaviours or leisure activities (15-18). Therefore, as computer use is likely to involve some level of cognitive challenge, stimulate social interactions and reduce solitariness, it may compensate for the associated sedentary behaviour in relation to cognitive health. Some of the mechanisms mentioned above are also linked to and vary by gender (39, 40); and therefore, they could help explain the observed interactions with sex.

The differences observed in cognitive function across the categories of sedentary behaviour in our analyses are likely to be clinically important beyond the risk of cognitive decline. For example, higher fluid intelligence scores have previously been shown to be strongly associated with a lower risk of all-cause mortality (41, 42). In a sample of 5,572 middle-aged British adults, Sabia and colleagues observed that a higher fluid intelligence score by 1 SD was associated with a 14% lower risk of all-cause mortality (41). Similarly, in a sample of 896 older Australian adults, Batterham and colleagues observed that a higher fluid intelligence score by 1 SD was associated with a 24% lower risk of all-cause mortality (42). In our analysis at baseline (Model 2), the SD of fluid intelligence score was 2.1. Regression analyses investigating the associations of sedentary behaviours with fluid intelligence demonstrated that TV viewing and driving time were linearly associated with lower fluid intelligence scores of 0.15 and 0.24 units, respectively. In contrast, computer use time was linearly associated with a higher fluid intelligence score of 0.12 units. Hence, using the data above, it can be estimated that lower fluid intelligence scores by 0.15 and 0.24 units would approximately equate to a 1.1%-3.2% higher risk of all-cause mortality. In contrast, a higher fluid intelligence score by 0.12 units would

approximately equate to a 0.9%-1.6% lower risk of all-cause mortality. For more details on these calculations, see Web Appendix 5.

Strengths and limitations

This study has several strengths and some limitations. Strengths include: exploitation of a large sample of adults representing the national population, follow-up cognitive function data allowing for prospective associations to be investigated, evaluation of dose-response and linear relationships between mutually adjusted and time quantified sedentary behaviours with a wide range of comprehensive cognitive outcomes, detailed covariate data enabling several important and relevant factors to be controlled for, interactions by age and sex, and robust sensitivity analyses investigating the associations in the healthy population. Although the UK Biobank is representative of the general population with respect to age, sex, ethnicity, and deprivation within the age range recruited, it may not be representative in other regards (43). While this limits the ability to generalize prevalence rates, estimates of the magnitude of associations in our study are unlikely to have been substantially affected by this due to the large and multifaceted base population (43, 44). Furthermore, the cognitive data from the UK Biobank cohort has recently been shown to be an important and valid resource for investigating predictors and modifiers of cognitive abilities and associated health outcomes in the general population (45).

The sedentary behaviour data used in this study have both strengths and limitations. Only three sedentary domains included; thus, the findings are restricted and cannot be generalized to other types of sedentary behaviour. Self-reported assessments of

sedentary behaviour are subjective and are influenced by recall and response issues (46, 47); hence, they tend to have low validity and increase the risk of regression dilution. However, although data that are more robust can be obtained using objective measurement tools (e.g. accelerometers) (46, 47), they would not provide information on the specific type of sedentary behaviour performed. Furthermore, since the reasons for using the computer outside work were unknown (e.g. utilised for activities such as: reading, watching videos, internet browsing, playing games, etc.), it is not possible to accurately classify or infer the type of computer use undertaken, and it may have involved crossover into cognitively inert tasks. Additionally, only those who provided an email address at baseline (~300,000) were contacted to participate in the online follow-up of cognitive function. Therefore, these participants all had computer access and presumably, some computer use experience. This may also have resulted in the small differences in characteristics (including level of education and employment status) in the follow-up sample (see Web Table 1). Consequently, the prospective analysis may be biased and lack generalizability. Moreover, at baseline, the cognitive function tests were implemented using questionnaires that were administered via a touchscreen interface. At follow-up, the measurements were obtained remotely via online questionnaires that were administered on a computer via a mouse interface. Therefore, this difference in the mode of administration could possibly account for some of the variability in cognitive performance and change over time. Nevertheless, the prospective analysis broadly supports and is consistent with the cross-sectional associations reported for the full cohort at baseline. Although we adjusted for a wide range of covariates, some unmeasured factors (e.g. type of employment/occupation) may have further confounded the reported associations. Our results may be subject to residual

confounding or reverse causality. For example, it is possible that the positive association observed between computer use and cognitive function was simply reflecting greater familiarity for interacting with a computer rather than better cognitive function as such. Correspondingly, individuals with better cognitive function are more likely to engage in healthy behaviours and abstain from unhealthy ones, a concept known as neuroselection (48, 49). Whilst we investigated interactions by age and sex in our study, it must be highlighted that similar differences observed in cognitive function across different groups (i.e. in younger adults vs. older adults, and females vs. males) may have different clinical meanings and should be interpreted with caution. For example, a unit difference in a cognitive function test score in a younger adult may not have the same result or significance on cognitive health as a unit difference in an older adult. Lastly, due to large variations between the numbers of individuals who completed each cognitive assessment at both baseline and follow-up, analyses were based on different sample sizes.

Conclusions

Our analysis, conducted in a large national sample of adults, demonstrates that some sedentary domains, but not all, are associated with poor cognition. Watching TV and driving are inversely associated with cognitive function, whereas computer use is positively associated with cognitive function. Of note, the associations were consistently stronger in older adults. Intervention studies are required to confirm these findings. Nevertheless, these results provide robust observational data supporting public health policies aimed at reducing TV viewing and driving time in adults.

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AUTHOR CONTRIBUTIONS

Thomas Yates and Kishan Bakrania had the original idea for the analysis, which was further developed and refined by Charlotte L. Edwardson, Kamlesh Khunti, Stephan Bandelow and Melanie J. Davies. Kishan Bakrania had full access to the data in the study and takes responsibility for the integrity of the data and the accuracy of the analysis. Kishan Bakrania wrote the first draft of the manuscript. Kishan Bakrania, Charlotte L. Edwardson, Kamlesh Khunti, Stephan Bandelow and Melanie J. Davies and Thomas Yates edited/reviewed the manuscript and approved the final version of the manuscript.

ETHICAL APPROVAL

The United Kingdom Biobank study received ethical approval from the NHS National Research Ethics Service (Ref: 11/NW/0382).

DATA SHARING

All the data reported in this study are fully available via application to the United Kingdom Biobank.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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TABLES

Table 1 - Baseline characteristics of the UK Biobank participants (n = 502,643; years 2006 to 2010)

Participant Characteristics	Number	%	Mean (SD)	Range
Anthropometrics				
Body mass index [a b]			27.4 (4.8)	12.1–74.7
Missing	3,105	0.6		
Demographics				
Age, years [b]			56.5 (8.1)	37.0–73.0
Missing	0	0.0		
Ethnicity [c]				
White British	442,699	88.1		
Other	57,166	11.4		
Missing	2,778	0.5		
Sex [c]				
Female	273,467	54.4		
Male	229,176	45.6		
Missing	0	0.0		
Social deprivation index [b]			-1.3 (3.1)	-6.3–11.0
Missing	627	0.1		
Employment status [c]				
In paid employment or self-employed	287,234	57.1		
Not in paid employment or self-employed	212,451	42.3		
Missing	2,958	0.6		
Education level [c]				
College or university degree	161,210	32.1		
No college or university degree	331,291	65.9		
Missing	10,142	2.0		
Lifestyle				
Smoking status [c]				
Never	273,603	54.4		
Previous	173,099	34.4		

Current	52,989	10.6		
Missing	2,952	0.6		
Alcohol drinking status [c]				
Never	22,547	4.5		
Previous	18,114	3.6		
Current	460,479	91.6		
Missing	1,503	0.3		
Fruit and vegetable consumption, portions/day [c]				
<5	300,352	59.8		
≥5	189,979	37.8		
Missing	12,132	2.4		
Sleep duration, hours/day [b]			7.2 (1.1)	1.0–23.0
Missing	4,218	0.8		
Frequency of ≥10 minutes of walking, days/week [c]				
0	12,455	2.5		
1	13,459	2.7		
2	29,991	6.0		
3	39,339	7.8		
4	40,036	8.0		
5	80,039	15.9		
6	50,082	9.9		
7	228,697	45.5		
Missing	8,545	1.7		
Frequency of ≥10 minutes of moderate physical activity, days/week [c]				
0	61,178	12.2		
1	38,290	7.6		
2	69,799	13.9		
3	71,507	14.2		
4	47,201	9.4		
5	71,441	14.2		
6	26,436	5.3		
7	89,506	17.8		

Missing	27,285	5.4		
Frequency of ≥10 minutes of vigorous physical activity, days/week [c]				
0	178,275	35.5		
1	66,853	13.3		
2	75,055	14.9		
3	65,276	13.0		
4	30,705	6.1		
5	32,452	6.5		
6	9,430	1.9		
7	17,005	3.4		
Missing	27,592	5.5		
Health				
Number of cancers [c]				
0	460,075	91.5		
≥1	41,706	8.3		
Missing	862	0.2		
Number of non-cancer illnesses [c]				
0	126,639	25.2		
1	134,113	26.7		
2	98,825	19.6		
3	62,828	12.5		
≥4	79,376	15.8		
Missing	862	0.2		
Number of medications/treatments [c]				
0	137,704	27.4		
1	94,776	18.8		
2	77,673	15.4		
3	57,819	11.5		
4	42,211	8.4		
5	29,937	6.0		
≥6	61,661	12.3		
Missing	862	0.2		

Medical history of cancer, cardiovascular disease, and/or cognitive/psychiatric illnesses [c]				
No	402,897	80.2		
Yes	99,746	19.8		
Missing	0	0.0		
Sedentary behaviours				
TV viewing time, hours/day [c]				
<1	39,456	7.8		
1	62,503	12.4		
2	132,780	26.4		
3	116,940	23.3		
≥4	145,546	29.0		
Missing	5,418	1.1		
Driving time, hours/day [c]				
<1	259,920	51.7		
1	140,144	27.9		
2	60,977	12.1		
≥3	31,663	6.3		
Missing	9,939	2.0		
Computer use time, hours/day [c]				
<1	240,648	47.9		
1	140,821	28.0		
2	62,859	12.5		
≥3	48,939	9.7		
Missing	9,376	1.9		
Cognitive function at baseline				
Prospective memory test [c d]				
Good result	130,910	26.0		
Poor result	40,675	8.1		
Missing	331,058	65.9		
Visual-spatial memory test (round 1) [c e]				
Good result	345,685	68.8		
Poor result	138,147	27.5		

Missing	18,811	3.7		
Visual-spatial memory test (round 2) [c f]				
Good result	82,130	16.3		
Poor result	400,632	79.7		
Missing	19,881	4.0		
Fluid intelligence test [b g]				
Total number of correct answers			6.0 (2.2)	0.0–13.0
Missing	337,151	67.1		
Short-term numeric memory test [b h]				
Maximum digits remembered correctly			6.7 (1.3)	2.0–12.0
Missing	452,273	90.0		

[a] Weight (kg)/height (m)^2.

[b] Continuous variable.

[c] Categorical variable.

[d] Prospective memory result: good result [correct recall on first attempt]; or poor result [incorrect recall on first attempt (i.e. correct recall on second attempt, instruction not recalled, skipped or incorrect)].

[e] Pairs matching result (round 1): good result [<1 incorrect matches]; or poor result [≥1 incorrect matches].

[f] Pairs matching result (round 2): good result [<2 incorrect matches]; or poor result [≥2 incorrect matches].

[g] Fluid intelligence score: total number of correct answers.

[h] Numeric memory score: maximum digits remembered correctly.

Table 2 - Cross-sectional associations at baseline between sedentary behaviours and cognitive function within the UK Biobank participants (n (range) = 44,097 to 471,474; years 2006 to 2010)

Cross-sectional Analysis: Sedentary Behaviours and Cognitive Function (Model 1 and Model 2) [a b]	Prospective Memory Test (Model 1: *n* = 166,401; Model 2: *n* = 148,327) [c]			Visual-Spatial Memory Test						Fluid Intelligence Test (Model 1: *n* = 161,348; Model 2: *n* = 145,124) [f]			Short-term Numeric Memory Test (Model 1: *n* = 49,035; Model 2: *n* = 44,097) [g]		
				Round 1 (Model 1: *n* = 471,474; Model 2: *n* = 422,731) [d]			Round 2 (Model 1: *n* = 470,433; Model 2: *n* = 421,851) [e]								
	OR	99% CI	P Value [h]	OR	99% CI	P Value [h]	OR	99% CI	P Value [h]	β	99% CI	P Value [h]	β	99% CI	P Value [h]
Model 1															
TV viewing time, hours/day [i]															
<1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	0.99	(0.93, 1.07)	p=0.838	1.05	(1.01, 1.09)	p=0.002	1.01	(0.96, 1.05)	p=0.712	-0.13	(-0.19, -0.07)	p<0.001	-0.15	(-0.22, -0.08)	p<0.001
2	0.94	(0.88, 1.00)	p=0.012	1.07	(1.03, 1.11)	p<0.001	1.02	(0.98, 1.06)	p=0.303	-0.30	(-0.36, -0.24)	p<0.001	-0.25	(-0.31, -0.19)	p<0.001
3	0.97	(0.91, 1.04)	p=0.303	1.14	(1.10, 1.18)	p<0.001	1.03	(0.99, 1.08)	p=0.036	-0.54	(-0.60, -0.49)	p<0.001	-0.35	(-0.41, -0.29)	p<0.001
≥4	1.23	(1.15, 1.30)	p<0.001	1.26	(1.22, 1.31)	p<0.001	1.08	(1.03, 1.12)	p<0.001	-0.99	(-1.04, -0.93)	p<0.001	-0.55	(-0.61, -0.48)	p<0.001
Linear trend	1.07	(1.05, 1.08)	p<0.001	1.06	(1.06, 1.07)	p<0.001	1.02	(1.01, 1.03)	p<0.001	-0.26	(-0.27, -0.25)	p<0.001	-0.13	(-0.15, -0.12)	p<0.001
Driving time, hours/day [i]															
<1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	1.05	(1.02, 1.09)	p<0.001	0.99	(0.97, 1.01)	p=0.270	1.01	(0.98, 1.03)	p=0.569	-0.19	(-0.22, -0.16)	p<0.001	-0.02	(-0.06, 0.01)	p=0.139
2	1.12	(1.07, 1.18)	p<0.001	1.05	(1.02, 1.08)	p<0.001	1.03	(1.00, 1.06)	p=0.024	-0.37	(-0.41, -0.33)	p<0.001	-0.13	(-0.18, -0.08)	p<0.001
≥3	1.50	(1.41, 1.60)	p<0.001	1.26	(1.22, 1.31)	p<0.001	1.12	(1.07, 1.17)	p<0.001	-0.88	(-0.94, -0.82)	p<0.001	-0.28	(-0.34, -0.21)	p<0.001

Linear trend	1.11	(1.09, 1.12)	p<0.001	1.05	(1.04, 1.06)	p<0.001	1.03	(1.01, 1.04)	p<0.001	-0.24	(-0.26, -0.23)	p<0.001	-0.08	(-0.09, -0.06)	p<0.001
Computer use time, hours/day [i]															
<1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	0.68	(0.66, 0.71)	p<0.001	0.79	(0.77, 0.80)	p<0.001	0.85	(0.83, 0.87)	p<0.001	0.52	(0.49, 0.55)	p<0.001	0.21	(0.17, 0.25)	p<0.001
2	0.69	(0.66, 0.72)	p<0.001	0.77	(0.75, 0.79)	p<0.001	0.80	(0.78, 0.83)	p<0.001	0.58	(0.53, 0.62)	p<0.001	0.21	(0.16, 0.26)	p<0.001
≥3	0.86	(0.82, 0.90)	p<0.001	0.81	(0.79, 0.84)	p<0.001	0.82	(0.79, 0.85)	p<0.001	0.40	(0.35, 0.44)	p<0.001	0.16	(0.11, 0.22)	p<0.001
Linear trend	0.91	(0.89, 0.92)	p<0.001	0.91	(0.90, 0.92)	p<0.001	0.92	(0.91, 0.93)	p<0.001	0.18	(0.17, 0.20)	p<0.001	0.07	(0.06, 0.09)	p<0.001
Model 2															
TV viewing time, hours/day [i]															
<1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	1.04	(0.96, 1.12)	p=0.232	1.07	(1.03, 1.12)	p<0.001	1.01	(0.97, 1.06)	p=0.403	-0.12	(-0.18, -0.06)	p<0.001	-0.13	(-0.20, -0.06)	p<0.001
2	0.96	(0.90, 1.03)	p=0.142	1.07	(1.03, 1.11)	p<0.001	1.02	(0.98, 1.07)	p=0.128	-0.21	(-0.27, -0.16)	p<0.001	-0.20	(-0.26, -0.13)	p<0.001
3	0.96	(0.89, 1.03)	p=0.159	1.09	(1.05, 1.14)	p<0.001	1.03	(0.98, 1.07)	p=0.136	-0.33	(-0.39, -0.28)	p<0.001	-0.25	(-0.32, -0.19)	p<0.001
≥4	1.09	(1.01, 1.17)	p=0.003	1.14	(1.10, 1.19)	p<0.001	1.03	(0.99, 1.08)	p=0.053	-0.58	(-0.64, -0.53)	p<0.001	-0.38	(-0.44, -0.31)	p<0.001
Linear trend	1.02	(1.00, 1.03)	p=0.001	1.03	(1.02, 1.04)	p<0.001	1.01	(1.00, 1.02)	p=0.057	-0.15	(-0.16, -0.14)	p<0.001	-0.09	(-0.10, -0.07)	p<0.001
Driving time, hours/day [i]															
<1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	1.21	(1.17, 1.27)	p<0.001	1.05	(1.03, 1.07)	p<0.001	1.04	(1.02, 1.07)	p<0.001	-0.28	(-0.31, -0.25)	p<0.001	-0.06	(-0.10, -0.03)	p<0.001
2	1.27	(1.20, 1.34)	p<0.001	1.10	(1.06, 1.13)	p<0.001	1.07	(1.03, 1.10)	p<0.001	-0.43	(-0.48, -0.39)	p<0.001	-0.18	(-0.23, -0.13)	p<0.001

≥3	1.54	(1.43, 1.66)	p<0.001	1.23	(1.19, 1.28)	p<0.001	1.11	(1.06, 1.16)	p<0.001	-0.73	(-0.79, -0.68)	p<0.001	-0.27	(-0.34, -0.19)	p<0.001
Linear trend	1.15	(1.13, 1.17)	p<0.001	1.06	(1.05, 1.07)	p<0.001	1.04	(1.02, 1.05)	p<0.001	-0.24	(-0.25, -0.22)	p<0.001	-0.09	(-0.11, -0.07)	p<0.001
Computer use time, hours/day [i]															
<1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	0.77	(0.74, 0.81)	p<0.001	0.85	(0.83, 0.87)	p<0.001	0.88	(0.86, 0.90)	p<0.001	0.32	(0.29, 0.35)	p<0.001	0.14	(0.10, 0.17)	p<0.001
2	0.74	(0.70, 0.78)	p<0.001	0.81	(0.79, 0.83)	p<0.001	0.83	(0.80, 0.86)	p<0.001	0.40	(0.36, 0.44)	p<0.001	0.15	(0.10, 0.20)	p<0.001
≥3	0.86	(0.81, 0.91)	p<0.001	0.84	(0.81, 0.86)	p<0.001	0.84	(0.81, 0.88)	p<0.001	0.26	(0.22, 0.31)	p<0.001	0.13	(0.07, 0.18)	p<0.001
Linear trend	0.92	(0.90, 0.94)	p<0.001	0.92	(0.91, 0.93)	p<0.001	0.93	(0.92, 0.94)	p<0.001	0.12	(0.11, 0.14)	p<0.001	0.06	(0.04, 0.07)	p<0.001

OR = odds ratio. 99% CI = 99% confidence interval. β = beta coefficient.

[a] Model 1 was mutually adjusted for the other sedentary behaviours and for age and sex.

[b] Model 2 was further adjusted for body mass index, ethnicity, social deprivation index, employment status, education level, smoking status, alcohol drinking status, fruit and vegetable consumption, sleep duration, frequency of ≥10 minutes of walking, frequency of ≥10 minutes of moderate physical activity, frequency of ≥10 minutes of vigorous physical activity, number of cancers, number of non-cancer illnesses, and number of medications/treatments.

[c] Prospective memory result: categorical: good result [(reference) correct recall on first attempt]; or poor result [incorrect recall on first attempt (i.e. correct recall on second attempt, instruction not recalled, skipped or incorrect)]. An odds ratio of less than 1 indicates lower odds of a poor result; and an odds ratio of greater than 1 indicates higher odds of a poor result.

[d] Pairs matching result (round 1): categorical: good result [(reference) <1 incorrect matches]; or poor result [≥1 incorrect matches]. An odds ratio of less than 1 indicates lower odds of a poor result; and an odds ratio of greater than 1 indicates higher odds of a poor result.

[e] Pairs matching result (round 2): categorical: good result [(reference) <2 incorrect matches]; or poor result [≥2 incorrect matches]. An odds ratio of less than 1 indicates lower odds of a poor result; and an odds ratio of greater than 1 indicates higher odds of a poor result.

[f] Fluid intelligence score: continuous: total number of correct answers. A beta coefficient of greater than 0 indicates a higher score; and a beta coefficient of less than 0 indicates a lower score.

[g] Numeric memory score: continuous: maximum digits remembered correctly. A beta coefficient of greater than 0 indicates a higher score; and a beta coefficient of less than 0 indicates a lower score.

[h] p<0.01 indicates statistical significance.

[i] <1 hour/day = reference.

Table 3 - Cognitive function data of the UK Biobank participants with cognitive data at both baseline and follow-up (n (range) = 12,091 to 114,373; mean follow-up period of 5.3 years)

Cognitive Function	Total Number	Baseline				Follow-up			
		Number	%	Mean (SD)	Range	Number	%	Mean (SD)	Range
Visual-spatial memory test (round 1) [a b]	114,373								
Good result		89,137	77.9			70,761	61.9		
Poor result		25,236	22.1			43,612	38.1		
Good outcome at follow-up						70,761	61.9		
Poor outcome at follow-up						43,612	38.1		
Visual-spatial memory test (round 2) [a c]	113,479								
Good result		23,262	20.5			14,886	13.1		
Poor result		90,217	79.5			98,593	86.9		
Good outcome at follow-up						14,886	13.1		
Poor outcome at follow-up						98,593	86.9		
Fluid intelligence test [d e]	46,704								
Total number of correct answers				6.7 (2.1)	0.0–13.0			5.5 (2.0)	0.0–13.0
Good outcome at follow-up						15,384	32.9		
Poor outcome at follow-up						31,320	67.1		

Short-term numeric memory test [d f]	12,091								
Maximum digits remembered correctly				7.0 (1.2)	2.0–12.0			6.9 (1.5)	2.0–11.0
Good outcome at follow-up						7,791	64.4		
Poor outcome at follow-up						4,300	35.6		

[a] Categorical variable.

[b] Pairs matching result (round 1): good result [<1 incorrect matches]; or poor result [≥1 incorrect matches]. Good outcome at follow-up [<1 incorrect matches at follow-up]; or poor outcome at follow-up [≥1 incorrect matches at follow-up].

[c] Pairs matching result (round 2): good result [<2 incorrect matches]; or poor result [≥2 incorrect matches]. Good outcome at follow-up [<2 incorrect matches at follow-up]; or poor outcome at follow-up [≥2 incorrect matches at follow-up].

[d] Continuous variable.

[e] Fluid intelligence score: total number of correct answers. Good outcome at follow-up [baseline fluid intelligence score ≤ follow-up fluid intelligence score]; or poor outcome at follow-up [baseline fluid intelligence score > follow-up fluid intelligence score].

[f] Numeric memory score: Maximum digits remembered correctly. Good outcome at follow-up [baseline numeric memory score ≤ follow-up numeric memory score]; or poor outcome at follow-up [baseline numeric memory score > follow-up numeric memory score].

Table 4 - Prospective associations between sedentary behaviours at baseline and cognitive function at follow-up within the UK Biobank participants (N (range) = 11,299 to 113,129; mean follow-up period of 5.3 years)

Prospective Analysis: Sedentary Behaviours and Cognitive Function (Model 1 and Model 2) [a b]	**Visual-Spatial Memory Test**						**Fluid Intelligence Test (Model 1: *n* = 46,158; Model 2: *n* = 43,350) [e]**			**Short-term Numeric Memory Test (Model 1: *n* = 11,957; Model 2: *n* = 11,299) [f]**		
	Round 1 (Model 1: *n* = 113,129; Model 2: *n* = 106,665) [c]			**Round 2 (Model 1: *n* = 112,252; Model 2: *n* = 105,861) [d]**								
	OR	**99% CI**	**P Value [g]**	**OR**	**99% CI**	**P Value [g]**	**OR**	**99% CI**	**P Value [g]**	**OR**	**99% CI**	**P Value [g]**
Model 1												
TV viewing time, hours/day [h]												
<1	-	-	-	-	-	-	-	-	-	-	-	-

1	1.04	(0.97, 1.11)	p=0.154	1.02	(0.93, 1.11)	p=0.623	1.15	(1.02, 1.28)	p=0.002	1.05	(0.85, 1.31)	p=0.557
2	1.09	(1.03, 1.15)	p<0.001	1.00	(0.92, 1.08)	p=0.961	1.24	(1.12, 1.37)	p<0.001	1.13	(0.93, 1.37)	p=0.112
3	1.13	(1.07, 1.20)	p<0.001	1.03	(0.94, 1.12)	p=0.439	1.37	(1.24, 1.52)	p<0.001	1.26	(1.03, 1.55)	p=0.003
≥4	1.17	(1.10, 1.25)	p<0.001	1.01	(0.93, 1.10)	p=0.672	1.66	(1.50, 1.84)	p<0.001	1.43	(1.17, 1.76)	p<0.001
Linear trend	1.04	(1.03, 1.06)	p<0.001	1.00	(0.99, 1.02)	p=0.612	1.13	(1.10, 1.15)	p<0.001	1.10	(1.05, 1.15)	p<0.001
Driving time, hours/day [h]												
<1	-	-	-	-	-	-	-	-	-	-	-	-
1	1.06	(1.02, 1.10)	p<0.001	1.01	(0.96, 1.07)	p=0.480	1.15	(1.08, 1.22)	p<0.001	1.05	(0.93, 1.18)	p=0.319
2	1.07	(1.01, 1.12)	p=0.002	1.00	(0.93, 1.08)	p=0.903	1.10	(1.00, 1.21)	p=0.008	1.09	(0.92, 1.30)	p=0.193
≥3	1.18	(1.09, 1.28)	p<0.001	1.01	(0.90, 1.13)	p=0.831	1.44	(1.25, 1.66)	p<0.001	1.11	(0.85, 1.44)	p=0.318
Linear trend	1.05	(1.03, 1.07)	p<0.001	1.00	(0.98, 1.03)	p=0.709	1.10	(1.06, 1.14)	p<0.001	1.04	(0.98, 1.11)	p=0.108
Computer use time, hours/day [h]												
<1	-	-	-	-	-	-	-	-	-	-	-	-
1	0.96	(0.93, 1.00)	p=0.013	0.96	(0.91, 1.02)	p=0.068	0.93	(0.87, 1.00)	p=0.006	0.90	(0.79, 1.02)	p=0.034
2	0.90	(0.86, 0.94)	p<0.001	0.87	(0.81, 0.93)	p<0.001	0.94	(0.86, 1.02)	p=0.041	0.77	(0.65, 0.90)	p<0.001
≥3	0.91	(0.86, 0.96)	p<0.001	0.89	(0.83, 0.96)	p<0.001	0.96	(0.88, 1.05)	p=0.293	0.86	(0.72, 1.03)	p=0.035
Linear trend	0.96	(0.95, 0.98)	p<0.001	0.95	(0.93, 0.97)	p<0.001	0.98	(0.96, 1.01)	p=0.150	0.93	(0.88, 0.98)	p=0.001
Model 2												
TV viewing time, hours/day [h]												

<1	-	-	-	-	-	-	-	-	-	-	-	-
1	1.02	(0.96, 1.09)	p=0.348	1.03	(0.94, 1.12)	p=0.470	1.16	(1.03, 1.30)	p=0.001	1.02	(0.82, 1.28)	p=0.817
2	1.07	(1.00, 1.13)	p=0.006	1.01	(0.93, 1.09)	p=0.815	1.21	(1.09, 1.35)	p<0.001	1.08	(0.88, 1.33)	p=0.310
3	1.08	(1.02, 1.15)	p=0.001	1.03	(0.94, 1.12)	p=0.416	1.29	(1.15, 1.44)	p<0.001	1.16	(0.94, 1.44)	p=0.066
≥4	1.09	(1.02, 1.17)	p=0.001	1.00	(0.91, 1.10)	p=0.993	1.45	(1.29, 1.62)	p<0.001	1.29	(1.04, 1.61)	p=0.003
Linear trend	1.02	(1.01, 1.04)	p<0.001	1.00	(0.98, 1.02)	p=0.955	1.09	(1.06, 1.11)	p<0.001	1.07	(1.02, 1.12)	p<0.001
Driving time, hours/day [h]												
<1	-	-	-	-	-	-	-	-	-	-	-	-
1	1.07	(1.03, 1.12)	p<0.001	1.02	(0.97, 1.08)	p=0.294	1.19	(1.11, 1.27)	p<0.001	1.05	(0.92, 1.19)	p=0.363
2	1.08	(1.02, 1.14)	p=0.001	1.01	(0.94, 1.10)	p=0.624	1.15	(1.04, 1.27)	p<0.001	1.05	(0.88, 1.27)	p=0.466
≥3	1.16	(1.06, 1.26)	p<0.001	1.01	(0.90, 1.13)	p=0.895	1.43	(1.24, 1.66)	p<0.001	1.05	(0.80, 1.39)	p=0.650
Linear trend	1.05	(1.03, 1.07)	p<0.001	1.01	(0.98, 1.04)	p=0.552	1.11	(1.07, 1.15)	p<0.001	1.02	(0.96, 1.10)	p=0.363
Computer use time, hours/day [h]												
<1	-	-	-	-	-	-	-	-	-	-	-	-
1	0.97	(0.93, 1.01)	p=0.053	0.97	(0.92, 1.03)	p=0.250	0.94	(0.87, 1.01)	p=0.020	0.92	(0.80, 1.05)	p=0.090
2	0.91	(0.86, 0.95)	p<0.001	0.88	(0.82, 0.94)	p<0.001	0.94	(0.86, 1.03)	p=0.073	0.76	(0.64, 0.90)	p<0.001
≥3	0.90	(0.85, 0.96)	p<0.001	0.90	(0.83, 0.98)	p=0.001	0.97	(0.88, 1.06)	p=0.359	0.84	(0.69, 1.01)	p=0.016
Linear trend	0.96	(0.95, 0.98)	p<0.001	0.96	(0.93, 0.98)	p<0.001	0.99	(0.96, 1.02)	p=0.207	0.92	(0.87, 0.98)	p<0.001
OR = odds ratio. 99% CI = 99% confidence interval.												

[a] Model 1 was mutually adjusted for the other sedentary behaviours and for age, sex and the baseline result/score of the cognitive test under consideration.
[b] Model 2 was further adjusted for body mass index, ethnicity, social deprivation index, employment status, education level, smoking status, alcohol drinking status, fruit and vegetable consumption, sleep duration, frequency of ≥10 minutes of walking, frequency of ≥10 minutes of moderate physical activity, frequency of ≥10 minutes of vigorous physical activity, number of cancers, number of non-cancer illnesses, and number of medications/treatments.
[c] Pairs matching result (round 1): categorical: good outcome at follow-up [<1 incorrect matches at follow-up]; or poor outcome at follow-up [≥1 incorrect matches at follow-up]. An odds ratio of less than 1 indicates lower odds of having cognitive decline at follow-up (i.e. a good outcome at follow-up); and an odds ratio of greater than 1 indicates higher odds of having cognitive decline at follow-up (i.e. a poor outcome at follow-up).
[d] Pairs matching result (round 2): categorical: good outcome at follow-up [<2 incorrect matches at follow-up]; or poor outcome at follow-up [≥2 incorrect matches at follow-up]. An odds ratio of less than 1 indicates lower odds of having cognitive decline at follow-up (i.e. a good outcome at follow-up); and an odds ratio of greater than 1 indicates higher odds of having cognitive decline at follow-up (i.e. a poor outcome at follow-up).
[e] Fluid intelligence score: categorical: good outcome at follow-up [baseline fluid intelligence score ≤ follow-up fluid intelligence score]; or poor outcome at follow-up [baseline fluid intelligence score > follow-up fluid intelligence score]. An odds ratio of less than 1 indicates lower odds of having cognitive decline at follow-up (i.e. a good outcome at follow-up); and an odds ratio of greater than 1 indicates higher odds of having cognitive decline at follow-up (i.e. a poor outcome at follow-up).
[f] Numeric memory score: categorical: good outcome at follow-up [baseline numeric memory score ≤ follow-up numeric memory score]; or poor outcome at follow-up [baseline numeric memory score > follow-up numeric memory score]. An odds ratio of less than 1 indicates lower odds of having cognitive decline at follow-up (i.e. a good outcome at follow-up); and an odds ratio of greater than 1 indicates higher odds of having cognitive decline at follow-up (i.e. a poor outcome at follow-up).
[g] $p<0.01$ indicates statistical significance.
[h] <1 hour/day = reference.