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Association between sedentary time and cognitive function: A focus on different domains of sedentary behavior

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ABSTRACT

Studies which examined the association between sedentary behavior (SB) and cognitive function have presented equivocal findings. Mentally active/inactive sedentary domains may relate differently to cognitive function. We examined associations between SB and cognitive function, specifically focusing on different domains. Participants were recruited from the Nijmegen Exercise Study 2018 in the Netherlands. SB (h/day) was measured with the Sedentary Behavior Questionnaire. Cognitive function was assessed with a validated computer self-test (COST-A), and a z-score calculated for global cognitive function. Multivariate linear regression assessed associations between tertiles of sedentary time and cognitive function. Cognition tests were available from 2821 participants, complete data from 2237 participants (43% female), with a median age of 61 [IQR 52–67] and a mean sedentary time of 8.3 ± 3.2 h/day. In fully adjusted models, cognitive function was significantly better in participants with the highest total sedentary time (0.07 [95% CI 0.02–0.12], $P = 0.01$), work-related sedentary time (0.13 [95% CI 0.07–0.19], $P < 0.001$), and non-occupational computer time (0.07 [95% CI 0.02–0.12], $P = 0.01$), compared to the least sedentary. Leisure sedentary time and time spent sedentary in the domains TV, reading or creative time showed no association with cognitive function in final models (all $P > 0.05$). We found a strong, independent positive association between total SB and cognitive function in a heterogenous population. This relation was not consistent across different domains, with especially work- and computer-related SB being positively associated with cognitive function. This highlights the importance of assessing the various sedentary domains in understanding the relation between sedentary time and cognitive function.

1. Introduction

Sedentary behavior (SB) is increasingly recognized as a strong, independent risk factor for adverse health outcomes, including cardiovascular disease, type 2 diabetes and mortality (Patterson et al., 2018; Young et al., 2016). Accordingly, (inter)national guidelines on physical activity (PA) are aimed at preventing excessive amounts of SB (Australian Government Department of Health, 2019; Gezondheidsraad, 2017; UK Government, 2019). Evidence supporting the potential association between SB and cognitive function, however, is less clear. While some research suggests that SB is linked to poorer cognitive function (Falck et al., 2017), others report no such association (Maasakkers et al., 2020). Moreover, a recent study even reported better cognitive function with larger amounts of objectively measured SB (Ekblom et al., 2019). These opposing findings highlight the importance to better understand the link between SB and cognitive function.

Previous studies examined SB as the total amount of hours spent sedentary, which includes mentally 'inactive' domains (e.g. watching TV) and mentally 'active' domains of SB (e.g. reading, working, or playing a music instrument). These different domains of SB may differentially relate to cognitive function (Bakrania et al., 2018; Kesse-Guyot et al., 2012). While computer time has been positively related

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with cognitive function, a negative association has been found for TV time (Bakrania et al., 2018; Kesse-Guyot et al., 2012). In line with this, higher reading and computer times have been associated with a lower risk for cognitive decline, with TV time being associated with a higher risk (Bakrania et al., 2018; Nemoto et al., 2018). These potentially distinct associations between different domains of SB and cognitive function, highlight the potential limitation of assessing total SB alone or evaluating few (Bakrania et al., 2018; Kesse-Guyot et al., 2014, 2012; Nemoto et al., 2018) domains of SB only. Lack of insight into the domains of SB may explain some of the disparity between studies.

The aim of this study was to evaluate the association between SB and cognitive function, taking into account various domains of SB. We hypothesized that mentally active domains (reading, computer, work, creative time) are associated with better cognitive function, while mentally unchallenging domains (TV time) will be associated with lower cognitive function.

To this date, national guidelines on SB are constrained to the advice to limit or minimize sedentary time (Australian Government Department of Health, 2019; Gezondheidsraad, 2017; UK Government, 2019). A better understanding of the effects of different sedentary domains on cognitive function could help in (re-)defining and sharpening guidelines for SB.

2. Methods

2.1. Study design

Participants were recruited from the Nijmegen Exercise Study (NES), a prospective cohort study that started in 2011, including a yearly, rolling inclusion, with annual questionnaires about health and lifestyle habits. Participants provided informed consent and the study was approved by the local Medical Ethical Committee. Upon inclusion, participants filled in a questionnaire about demographics and current lifestyle habits. Lifestyle habits were re-assessed yearly. In 2018, participants were invited to take part in an online assessment of cognitive function and filled in a SB questionnaire. For this add-on study, 5028 individuals were invited. Cognition tests were available for 2821 (56%) participants. Individuals with dementia/Alzheimer's or Parkinson's disease ($n = 6$), and pregnant women ($n = 14$) were excluded. Complete, valid data were available for 2237 participants (Fig. 1).

2.2. Sedentary behavior

Total and domain specific SB (h/day) were assessed with the Sedentary Behavior Questionnaire (Rosenberg et al., 2010), which assesses sedentary time during TV time, non-occupational computer time, phone calls, work, reading, creative time (e.g. pottery, playing music instruments), transport, eating, and listening to music. Sedentary times from individual domains were combined to obtain total SB. Listening to music was excluded, as it is often done during other sedentary activities (e.g. driving, reading), and the data indeed showed overlap between music and other sedentary domains. Individual domains and total SB have moderate to excellent test-retest reliability (ICC range 0.51–0.93) (Rosenberg et al., 2010). Its validity compared to objective measures of SB is low, which is a general observation regarding SB questionnaires (Bakker et al., 2020). Participants with sedentary times > 24 h/day ($n = 6$) were excluded from analysis. Leisure SB was calculated by subtracting work-related sedentary time from the total sedentary time. The following domains were considered mentally active SB and analyzed individually: work-related SB, non-occupational computer time, reading, and SB during a creative hobby. TV time was considered mentally inactive, and also analyzed individually.

2.3. Cognitive function

Cognitive function was assessed with the validated Cognitive Online

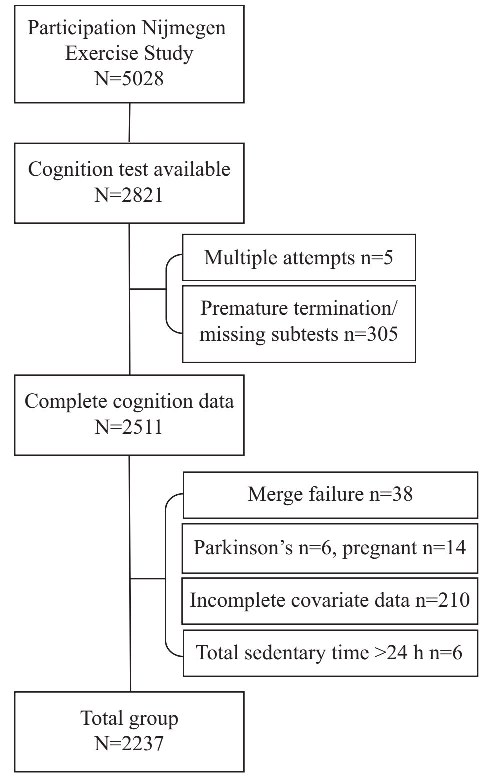

Fig. 1. Participant flow chart.

Self-Test Amsterdam (COST-A) (Van Mierlo et al., 2017), which consists of ten subtests, and can be completed in approximately 20 min. A detailed description is given by Van Mierlo et al., 2017. Subtests were scored by calculating the total number of correct answers for the following subtests: orientation (score 0–5), digit-sequence learning (score 0–3), immediate word recall (score 0–10), delayed word recall (score 0–10), delayed word recognition (score 0–20), word pairs immediate recall (score 0–20), word pairs recognition (score 0–10), semantic comprehension (score 0–6), trail making tests (A: connecting numbers, B: connecting letters and numbers; score 0–300: indicates time to complete). A mean z-score was calculated to indicate global cognitive function by averaging the z-scores for individual subtests. Trail making tests were reverse scored before calculating z-scores. The z-score has good convergent reliability with the Mini-Mental State Examination, as well as with global cognition, executive function, attention and memory domains of common neuropsychological assessments (Van Mierlo et al., 2017). With the COST-A, also a 5-item Geriatric Depression Scale (GDS) was administered (Hoyl et al., 1999; Rinaldi et al., 2003).

2.4. General characteristics

Education level upon inclusion was categorized as low (primary education or lower), middle (junior vocational training), and high (senior vocational or academic training). Smoking, working status, and habitual alcohol consumption were also assessed upon inclusion. During yearly follow-up questionnaires, participants were asked if their status had changed in the previous year. If the question was left open or the questionnaire not filled in, it was assumed unchanged. For working status, two additional assumptions were made: [A] people classified as not-working, who reported work-related SB > 0 h, were reclassified as working. [B] People classified as working, who reported 0 h of work-related SB and who were ≥ 65 years old (youngest retirement age in the Netherlands), were reclassified as not-working.

Smoking status was categorized as current-, past- and non-smoker; Alcohol consumption as high-consumption (men: > 14 drinks/week, women: > 7 drinks/week), moderate-consumption (men: > 3–14 drinks/week, woman: > 3–7 drinks/week), low-consumption (≤ 3 drinks/week) and no-consumption (National Institute on Alcohol Abuse and Alcoholism, 2006). Medication use and comorbidities were registered and added up to obtain a (modified) comorbidity-polypharmacy score (CPS) (Stawicki et al., 2011, 2015). The calculated score is slightly modified from the original CPS, as medication use was asked for categories (yes/no), rather than the absolute number of medications taken. Sleep disturbances (problems falling asleep, interrupted sleeping, waking up too early) were determined on a 4-point Likert scale, subsequently summed to obtain a total score. General health status was asked on a 5-point Likert scale. For Likert scales, higher scores indicated poorer sleep/health. PA levels were assessed with the Short Questionnaire to Assess Health-enhancing physical activity (SQUASH) (Wendel-Vos et al., 2003). To calculate total metabolic equivalent of Task (MET) minutes/week, MET-values were assigned using the Compendium of Physical Activities (Ainsworth et al., 2011).

2.5. Statistical analysis

SB was analyzed in tertiles (T1, low; T2, medium; T3, high sedentary time). For SB during creative hobbies, we divided participants into those without a creative hobby (73%), and those above or below the median (M1, low; M2, high sedentary time).

Associations between SB (i.e. in tertiles) and cognitive function were analyzed with (multivariate) linear regression analyses. Model 0 was unadjusted. We adjusted for known potential confounders in consecutive models, to obtain independent associations. Models were adjusted

Table 1
Participant characteristics of the total group and across tertiles of total sedentary time.

Characteristic	Total Group $N = 2237$	T1 Low sedentary time, $n = 746$	T2 Medium sedentary time, $n = 745$	T3 High sedentary time, n = 746	*P*-value
Age, years	61.0 [52.0–67.0]	65.0 [56.0–70.0]	61.0 [53.0–68.0]	57.0 [50.0–63.0]	**< 0.001**
BMI, kg/m^2	24.3 ± 3.6	24.3 ± 3.7	24.1 ± 3.4	24.5 ± 3.6	0.09
Sex, female	966 (43.2)	333 (44.6)	335 (45.0)	298 (39.9)	0.09
Education level[a]					**< 0.001**
Low	159 (7.1)	94 (12.6)	40 (5.4)	25 (3.4)	
Medium	845 (37.8)	333 (44.6)	267 (35.8)	245 (32.8)	
High	1233 (55.1)	319 (42.8)	438 (58.8)	476 (63.8)	
Smoking					**0.001**
Yes	79 (3.5)	23 (3.1)	29 (3.9)	27 (3.6)	
No, never	1177 (52.6)	361 (48.4)	380 (51.0)	436 (58.4)	
No, previously	981 (43.9)	362 (48.5)	336 (45.1)	283 (37.9)	
Alcohol consumption[b]					**0.002**
None	235 (10.5)	97 (13.0)	60 (8.1)	78 (10.5)	
Low	919 (41.1)	308 (41.3)	288 (38.7)	323 (43.3)	
Moderate	812 (36.3)	266 (35.7)	283 (38.0)	263 (35.3)	
High	271 (12.1)	75 (10.1)	114 (15.3)	82 (11.0)	
Working, yes	1662 (74.3)	443 (59.4)	540 (72.5)	679 (91.0)	**< 0.001**
Marital status					**< 0.001**
Single	280 (12.5)	82 (11.0)	89 (12.0)	109 (14.7)	
Married/partner	1562 (70.0)	538 (72.1)	525 (70.8)	499 (67.1)	
Divorced/separated	102 (4.6)	28 (3.8)	45 (6.1)	29 (3.9)	
Living together	238 (10.7)	64 (8.6)	78 (10.5)	96 (12.9)	
Widow	50 (2.2)	34 (4.6)	5 (0.7)	11 (1.5)	
Sleep disturbance score (1–12)	5.0 [4.0–7.0]	5.00 [4.0–7.0]	5.00 [4.00–6.00]	5.00 [4.0–7.0]	0.32
CPS (modified)	1.0 [0.0–3.0]	1.0 [0.0–3.0]	1.0 [0.0–3.0]	1.00 [0.0–3.0]	**0.003**
GDS (0–5)	0.0 [0.0–0.0]	0.0 [0.0–0.0]	0.0 [0.0–0.0]	0.00 [0.0–1.0]	**0.004**
General health score (1–5)	2.0 [2.0–2.0]	2.0 [2.0–2.0]	2.0 [2.0–2.0]	2.0 [2.0–2.0]	0.09
Physical activity (MET-min/week)	7362.0 [4422.0–9949.5]	6870.0 [4080.3–9996.0]	7224.0 [4496.0–9921.0]	7980.0 [4824.0–9999.0]	**0.02**
Sedentary time (h/day)					
Total	8.33 ± 3.16	5.23 [4.09–6.06]	8.20 [7.47–8.86]	11.32 [10.34–12.68]	**< 0.001**
Leisure	5.81 [4.44–7.41]	4.63 [3.59–5.60]	6.52 [4.66–7.72]	7.00 [5.62–9.38]	**< 0.001**
Work	1.00 [0.00–4.29]	0.08 [0.00–0.65]	1.43 [0.00–3.57]	5.00 [2.96–5.71]	**< 0.001**
TV	1.71 [1.00–2.29]	1.29 [0.75–2.00]	2.00 [1.00–2.29]	2.00 [1.29–2.86]	**< 0.001**
Computer	1.00 [0.55–1.71]	0.75 [0.37–1.00]	1.00 [0.71–2.00]	1.29 [0.82–2.00]	**< 0.001**
Reading	0.65 [0.30–1.11]	0.54 [0.30–1.00]	0.75 [0.37–1.29]	0.75 [0.37–1.29]	**< 0.001**
Creative	0.00 [0.00–0.08]	0.00 [0.00–0.03]	0.00 [0.00–0.12]	0.00 [0.00–0.08]	0.07
Z-score cognitive function	0.05 [−0.31–0.40]	−0.08 [−0.46–0.27]	0.08 [−0.29–0.40]	0.18 [−0.22–0.49]	**< 0.001**

Significant results (P-value < 0.05) were highlighted in bold.
Data are presented as mean ± SD or n (%), non-normal data as median [IQR]. T, tertile; BMI, body mass index; CPS, comorbidity-polypharmacy score; GDS, Geriatric Depression Scale; MET, Metabolic Equivalent of Task. GDS, CPS, general health score: a higher score indicates worse status.
[a] Low: primary education or lower; middle: junior vocational training; high: senior vocational or academic training.
[b] Low: ≤ 3 drinks/week and no-consumption; moderate: men: > 3–14 drinks/week, woman: > 3–7 drinks/week; high: men: > 14 drinks/week, women: > 7 drinks/week.

stepwise to show the potential impact of different confounders. Model 1 was adjusted for age, sex, and education level. Model 2 was adjusted additionally for BMI, general health status, comorbidities/polypharmacy (CPS), GDS, sleep disturbance, working status, smoking and alcohol habits. Model 3 was additionally adjusted for PA (MET-min/week). For the different sedentary domains, model 4 was additionally adjusted for the other sedentary domains. Leisure SB was adjusted for work-related SB in model 4. For analysis of work-related SB, non-workers were excluded from the analysis and models were not adjusted for working status. The association between sedentary domains and cognitive function was not different in men and women (no significant interaction) in any of the adjusted models, wherefore analyses were performed for the whole group. Fulfillment of model assumptions was inspected visually. Statistical analysis was performed with R studio version 3.6.2 (R Core Team, 2019). The tableone (Yoshida and Bartel, 2020) package was used for descriptives. Tertiles were made using the quantcut function of the gtools package (Warnes et al., 2020). Only complete cases were included for analysis (Fig. 1).

A sensitivity analysis was performed, excluding participants (≥ 65 year) who reported 0 h of SB at work and for whom it was not possible to confirm that they were currently working due to gaps in assessment (n = 96). This did not alter our findings substantially (Supplements, Table S1). In another sensitivity analysis we excluded participants younger than 50 years (Supplements, Table S2), as the COST-A has been validated in a population aged 50 years and older (Van Mierlo et al., 2017).

3. Results

In total, 2237 participants (43% female) were included for analysis (Fig. 1), with a median age of 61 y [IQR 52–67 y] and a mean BMI of 24.3 ± 3.6 kg/m^2. Participant characteristics for the total group and for tertile groups based on total sedentary time are shown in Table 1.

3.1. Total SB

Participants in the lowest tertile group had a daily median sedentary time of 5.23 h [IQR 4.09–6.06 h], in the medium group of 8.20 h [IQR 7.47–8.86 h] and in the highest group of 11.32 h [IQR 10.34–12.68 h]. Tertile groups differed significantly with regard to age, education level, smoking behavior, alcohol consumption, working status, marital status, modified CPS, GDS and PA (Table 1). Time spent sedentary during the domains work, leisure time, TV, computer, and reading was also significantly different between tertile groups of total SB (Table 1).

There was a positive association between total SB and cognitive function (Table 2). Participants with the highest SB consistently had a better cognitive function compared to those with the least SB. For participants with medium SB, this positive association reverted to a trend after adjustment for confounders. In the final model, cognitive function was significantly higher in the high SB tertile (0.07 [95% CI 0.02–0.12], P = 0.01), but not in the middle tertile (0.05 [95% CI −0.00–0.10], P = 0.05), compared to low SB (Fig. 2).

3.2. Work- versus leisure-related SB

Higher work-related SB was associated with better cognitive function in the unadjusted model, and remained significant across all adjusted models (Table 3, Fig. 2). In the univariate model, participants with the highest leisure SB had lower cognitive function compared to those in the lowest group (−0.09 [95% CI −0.15–(−0.04), P = 0.001]). However, this association disappeared after adjustment for confounders. In the final model, there was no association between leisure SB and cognitive function (Table 3, Fig. 2).

3.3. Domains of leisure-related SB

TV time was negatively associated with cognitive function (T3 vs T1: −0.08 [95% CI −0.13–(−0.02)], P = 0.01) in univariate analysis, whilst this association was not found in any of the adjusted models (Table 4). Non-occupational computer time was not associated with global cognitive function in univariate analysis, whilst a positive association was found in all adjusted models (Table 4). In the final model, participants with high non-occupational computer time had a significantly higher cognitive function compared to those with the least computer time (0.07 [95% CI 0.02–0.12], P = 0.01). Cognitive function in those with medium computer time was not different from those with the least computer time in the final model (0.04 [95% CI −0.00–0.09], P = 0.07). Reading time showed an inverse association with cognitive function in the unadjusted model, which reversed to a positive association in some adjusted models (model 1 and model 3, P < 0.05). In the fully adjusted model, a non-significant positive association was found (T3 vs T1 0.05 [95% CI −0.00–0.10], P = 0.06, Table 4). Creative time showed a positive relation with cognitive function in the unadjusted model (T2 vs T1 0.12 [95% CI 0.06–0.19], P < 0.001), which disappeared in the fully adjusted model (T2 vs T1 0.05 [95% CI −0.01–0.11], P = 0.08; T3 vs T1 0.05 [95% CI −0.00–0.11], P = 0.07; Table 4). Results of all final models are visualized in Fig. 2.

In a sensitivity analysis we excluded participants younger than 50 years. This resulted in a weaker positive association between SB at work and cognitive function (T3 vs T1 0.08 [95% CI 0.01–0.16], P = 0.03), but overall did not change our results substantially (Supplements, Table S2).

4. Discussion

The primary aim of the present study was to examine the relation between SB and cognitive function, specifically taking into account the various domains of SB. First, we reported a positive association between total SB and cognitive function. Second, and in line with our hypothesis, different domains of SB demonstrated distinct associations with

Table 2
Total sedentary behavior and global cognitive function.

		Sedentary time, h Median [IQR]	Model 0		Model 1		Model 2		Model 3	
			β [95% CI]	P-value	β [95% CI]	P-value	β [95% CI]	P-value	β [95% CI]	P-value
Total sedentary time	T1 n = 746	5.23 [4.09–6.06]	REF	–	REF	–	REF	–	REF	–
	T2 n = 745	8.20 [7.47–8.86]	0.16 [0.11–0.22]	**< 0.001**	0.05 [0.00–0.10]	**0.03**	0.05 [−0.00–0.10]	0.05	0.05 [−0.00–0.10]	0.05
	T3 n = 746	11.32 [10.34–12.68]	0.24 [0.18–0.29]	**< 0.001**	0.06 [0.01–0.11]	**0.02**	0.07 [0.02–0.12]	**0.01**	0.07 [0.02–0.12]	**0.01**

Significant results (P-value < 0.05) were highlighted in bold.
T, tertile. T1: low sedentary time; T2: medium sedentary time; T3: high sedentary time. Model 0: univariate analysis. Model 1: adjusted for age, sex, education level. Model 2: adjusted for age, sex, education level, BMI, working, smoking, alcohol consumption, health status, comorbidities/polypharmacy, sleep disturbances, Geriatric Depression Scale. Model 3: as model 2 + total MET-min/week.

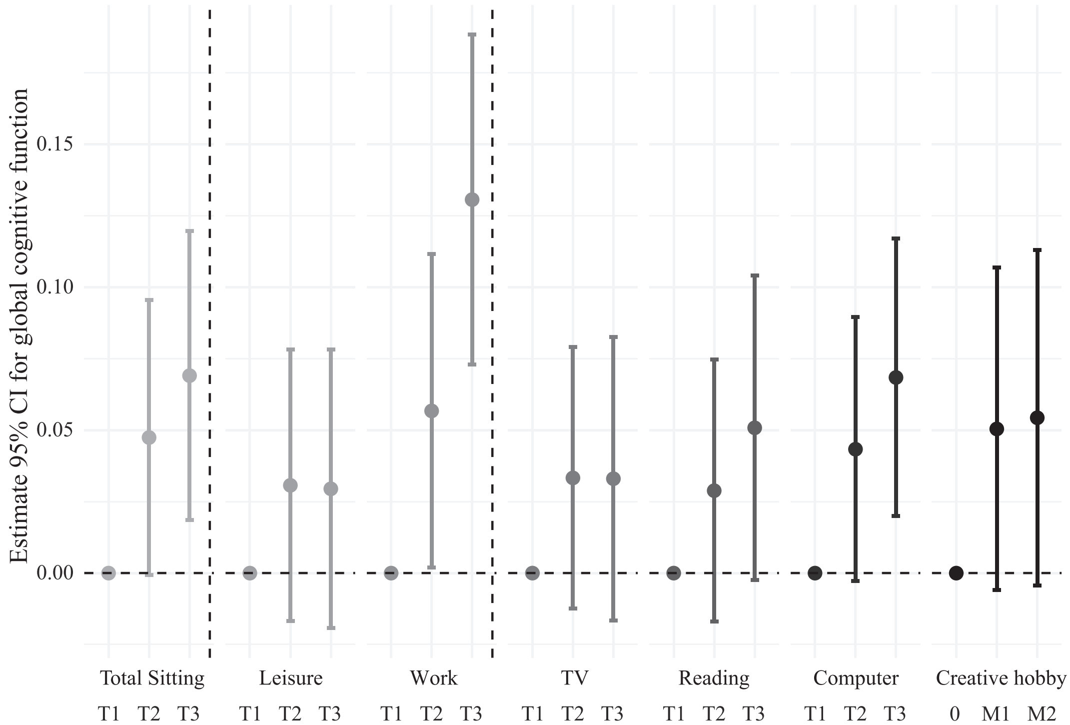

Fig. 2. Associations between total sedentary behavior (SB), leisure SB, different sedentary domains and global cognitive function. Model estimates of the fully adjusted models and 95% confidence intervals (CI) are shown. Model for total SB: adjusted for age, sex, education level, Body Mass Index, working status, smoking, alcohol consumption, health status, comorbidities/polypharmacy, sleep disturbances, Geriatric Depression Scale, MET-min/week. Leisure SB and other sedentary domains: additionally adjusted for the other sedentary domains. Estimates for work are based on working participants only ($n = 1662$), and therefore not adjusted for working status. T, tertile; M, median. T1: low sedentary time; T2: medium sedentary time; T3: high sedentary time. M1: low sedentary time; M2: high sedentary time.

cognitive function. Specifically, a positive association was found between the cognitively active domains work-related SB and non-occupational computer time. However, leisure sedentary time, reading time, TV time and creative time showed no association with cognitive function in the final models. These findings were independent of potential known confounders, including age, sex, education, BMI, general health, comorbidities/polypharmacy, depression, sleep disturbances, working status, smoking/alcohol habits and PA. Taken together, our study demonstrates the importance to critically evaluate the various domains of SB to understand the relation between SB and cognitive function in humans.

In our study population, we found an independent positive association between total SB and cognitive function. This finding supports observations from some previous work (Ekblom et al., 2019; Rosenberg et al., 2016; Vance et al., 2005), but not all (Falck et al., 2017; Maasakkers et al., 2020). Interestingly, in a systematic review, Falck et al. reported a negative association between SB and cognitive function (Falck et al., 2017). An important limitation of this review, however, is that half of the studies included used TV time as a proxy for SB (Hamer and Stamatakis, 2014; Kesse-Guyot et al., 2014, 2012; Lindstrom et al., 2005). Previous studies demonstrated that TV time is a poor measure of sedentary time and likely confounded by other factors, such as diet and socioeconomic status (Stamatakis et al., 2019). Other studies included in Falck's review found a positive, negative or no relation between SB and cognitive function (Rosenberg et al., 2016; Steinberg et al., 2015; Vance et al., 2005). Objectively measured SB has recently been positively associated with cognitive function (Ekblom et al., 2019), while a recent analysis across five population cohorts (with only one evaluating TV time) reported no association between cognitive function and global cognition (Maasakkers et al., 2020). This suggests that some of the disparity in the literature pertaining to the relation between SB and cognitive function may relate to the assessment of sedentary time, with TV time representing a poor measure of total SB.

Our study specifically examined different domains of SB, supported by previous work showing that certain sedentary domains may relate positively (e.g. computer time) and others negatively to cognitive function (e.g. TV time) (Bakrania et al., 2018; Kesse-Guyot et al., 2012; Nemoto et al., 2018). This concept is further supported by the results from our study, as we found a strong, independent positive relation between work-related SB, but also non-occupational computer time, and cognitive function. These seem to importantly contribute to the overall positive relation between total SB and cognitive function. Especially work-related SB seems to contribute, as leisure SB showed no association in the adjusted models. The domains computer and work-related SB represent approximately 40% of the total sedentary time, which can partly be explained by including a relatively high proportion of working population (i.e., 74%). This latter proportion contrasts with previous studies, where the working or non-retired group varied between 15 and 57% (Bakrania et al., 2018; Kesse-Guyot et al., 2012; Nemoto et al., 2018). The relatively high proportion of working population may, in part, explain the positive relation between SB and cognition. In addition, education level should also be considered. In line with previous work (Lakerveld et al., 2017), the highest tertile of total sedentary time was overrepresented by individuals working (90%) and highly educated (64%). Although we corrected for education level, we cannot rule out residual confounding.

Of the leisure-related SB, reading time was positively associated with cognitive function in some models, although the association disappeared after full adjustment for other sedentary domains, suggesting confounding by these. Whilst some others also did not find an association (Kesse-Guyot et al., 2012), Nemoto et al. reported that higher reading time related to a reduced risk for subjective cognitive decline (Nemoto et al., 2018). A potential limitation of our analysis is the small amount of reading time in our population (median 30 min/day) and, hence, the low power to detect statistically significant differences. Similarly, a positive association was found between creative time and cognitive function

Table 3
Leisure sedentary behavior, work-related sedentary behavior and global cognitive function.

Sedentary domain		Sedentary time, h Median [IQR]	Model 0		Model 1		Model 2		Model 3		Model 4	
			β [95% CI]	*P*-value	β [95% CI]	*P*-value	β [95% CI]	*P*-value	β [95% CI]	*P*-value	β [95% CI]	*P*-value
Leisure*	T1 n = 746	3.96 [3.18–4.44]	REF	–	REF	–	REF	–	REF	–	REF	–
	T2 n = 745	5.81 [5.40–6.27]	−0.01 [−0.07–0.04]	0.66	0.03 [−0.02–0.08]	0.24	0.04 [−0.01–0.08]	0.15	0.03 [−0.01–0.08]	0.15	0.03 [−0.02–0.08]	0.20
	T3 n = 746	8.23 [7.41– 9.51]	−0.09 [−0.15–(−0.04)]	**0.001**	0.01 [−0.03–0.06]	0.58	0.03 [−0.02–0.08]	0.22	0.03 [−0.02–0.08]	0.21	0.03 [−0.02–0.08]	0.24
Work**	T1 *n* = 605	0.54 [0.12–0.82]	REF	–	REF	–	REF	–	REF	–	REF	–
	T2 *n* = 539	3.14 [2.27–3.86]	0.21 [0.15–0.27]	**< 0.001**	0.07 [0.01–0.12]	**0.02**	0.06 [0.01–0.12]	**0.03**	0.06 [0.00–0.11]	**0.03**	0.06 [0.00–0.11]	**0.04**
	T3 *n* = 518	5.71 [5.00–5.93]	0.33 [0.27–0.39]	**< 0.001**	0.13 [0.07–0.19]	**< 0.001**	0.13 [0.08–0.19]	**< 0.001**	0.13 [0.07–0.19]	**< 0.001**	0.13 [0.07–0.19]	**< 0.001**

Significant results (P-value < 0.05) were highlighted in bold.
T, tertile. T1: low sedentary time; T2: medium sedentary time; T3: high sedentary time. Model 0: univariate analysis. Model 1: adjusted for age, sex, education level. Model 2: adjusted for age, sex, education level, BMI, working, smoking, alcohol consumption, health status, comorbidities/polypharmacy, sleep disturbances, Geriatric Depression Scale. Model 3: as model 2 + total MET-min/week. Model 4: as model 3 + other sedentary domains.

* Total sedentary time minus sedentary time at work.

** Excluded non-workers, total n = 1662, models for working are therefore not adjusted for working status.

Table 4
Different leisure-related sedentary domains and global cognitive function.

Sedentary domain		Sedentary time, h Median [IQR]	Model 0		Model 1		Model 2		Model 3		Model 4	
			β [95% CI]	*P*-value	β [95% CI]	*P*-value	β [95% CI]	*P*-value	β [95% CI]	*P*-value	β [95% CI]	*P*-value
TV	T1 *n* = 776	0.75 [0.30–1.00]	REF	–	REF	–	REF	–	REF	–	REF	–
	T2 *n* = 806	2.00 [1.29–2.00]	0.02 [−0.03–0.07]	0.46	0.03 [−0.02–0.08]	0.19	0.03 [−0.01–0.08]	0.16	0.03 [−0.01–0.08]	0.17	0.03 [−0.01–0.08]	0.15
	T3 *n* = 655	3.00 [2.29–3.29]	−0.08 [−0.13– (−0.02)]	**0.01**	0.02 [−0.03–0.07]	0.53	0.04 [−0.01–0.09]	0.15	0.03 [−0.02–0.08]	0.19	0.03 [−0.02–0.08]	0.19
Reading	**T1***n* = 757	0.19 [0.08–0.30]	REF	–	REF	–	REF	–	REF	–	REF	–
	T2 *n* = 902	0.75 [0.55–0.94]	−0.04 [−0.09–0.01]	0.16	0.03 [−0.01–0.08]	0.14	0.03 [−0.02–0.08]	0.20	0.03 [−0.01–0.08]	0.18	0.03 [−0.02–0.07]	0.22
	T3 *n* = 578	1.57 [1.29–2.00]	−0.07 [−0.13– (−0.01)]	**0.02**	0.05 [0.00–0.11]	**0.045**	0.05 [−0.00–0.11]	0.05	0.06 [0.00–0.11]	**0.04**	0.05 [−0.00–0.10]	0.06
Computer	T1 *n* = 808	0.37 [0.19–0.55]	REF	–	REF	–	REF	–	REF	–	REF	–
	T2 *n* = 755	1.00 [1.00–1.11]	0.05 [−0.00–0.11]	0.06	0.05 [0.00–0.10]	**0.03**	0.05 [0.01–0.10]	**0.02**	0.05 [0.01–0.10]	**0.03**	0.04 [−0.00–0.09]	0.07
	T3 *n* = 674	2.00 [2.00–2.71]	0.03 [−0.03–0.09]	0.28	0.06 [0.01–0.11]	**0.01**	0.08 [0.03–0.13]	**0.001**	0.08 [0.03–0.12]	**0.002**	0.07 [0.02–0.12]	**0.01**
Creative Hobby	0 n = 1626	0.00 [0.00–0.00]	REF	–	REF	–	REF	–	REF	–	REF	–
	M1 *n* = 323	0.12 [0.12–0.30]	0.12 [0.06–0.19]	**< 0.001**	0.04 [−0.01–0.10]	0.13	0.04 [−0.02–0.09]	0.20	0.04 [−0.02–0.09]	0.21	0.05 [−0.01–0.11]	0.08
	M2 *n* = 288	1.00 [0.71–1.43]	0.06 [−0.00–0.13]	0.07	0.05 [−0.01–0.11]	0.11	0.05 [−0.01–0.10]	0.13	0.05 [−0.01–0.11]	0.11	0.05 [−0.00–0.11]	0.07

Significant results (P-value < 0.05) were highlighted in bold.
T, tertile; M, median. T1: low sedentary time; T2: medium sedentary time; T3: high sedentary time. M1: low sedentary time; M2: high sedentary time. Model 0: univariate analysis. Model 1: adjusted for age, sex, education level. Model 2: adjusted for age, sex, education level, BMI, working, smoking, alcohol consumption, health status, comorbidities/polypharmacy, sleep disturbances, Geriatric Depression Scale. Model 3: as model 2 + total MET-min/week. Model 4: as model 3 + other sedentary domains.

using the unadjusted model, with the fully adjusted model reporting a trend for such a relation. Since the majority in our population ($n = 1626$) did not engage in a sedentary creative hobby, relatively low power was present to understand this relationship. Several previous studies report a negative association between TV time and cognitive function (Hamer and Stamatakis, 2014; Hoang et al., 2016; Kesse-Guyot et al., 2012; Lindstrom et al., 2005), which we were not able to confirm. However, some studies found that negative associations between TV time and cognitive health disappeared after adjustments for confounders (Kesse-Guyot et al., 2014; Maasakkers et al., 2020), which was also the case in our study.

At least, our findings provide support for the notion that SB within cognitively demanding domains may have a positive relationship with cognitive function. However, the strength of this association still varies between domains. Within this respect, the relative contribution of these domains to total sedentary time can vary between different populations, which might thereby contribute to different results regarding total SB. For instance, in a working population, work-related SB is likely to contribute strongly to total SB, while in a retired population a shift in the dominance of different sedentary domains can be expected (Touvier et al., 2010). Additionally, mental activity can also vary within a domain. For instance, non-occupational computer time can include unchallenging but also more challenging tasks. Similarly, the cognitive aspect of work-related SB depends strongly on the occupation, which could be valuable to explore further in future studies.

Related to cardiovascular and metabolic health, there is consensus that SB is detrimental (Lavie et al., 2019; Loh et al., 2020; Patterson et al., 2018; Saunders et al., 2018). In contrast, the domain of SB seems to importantly affect its relation with cognitive function, which may relate to the cognitive component of these activities (Ekblom et al., 2019; Nemoto et al., 2018). Mental activity immediately affects cerebral hemodynamics, with higher blood flow velocities and higher cerebral metabolism during cognitively demanding activities (Sorond et al., 2008; Stroobant and Vingerhoets, 2000). Repeated exposure to elevations in blood flow velocities and/or metabolism may ultimately contribute to improved cerebrovascular health, subsequently representing a mechanistic basis for positive association between cognitively demanding sedentary domains and cognitive function. Indeed, measures of cognitively inactive behaviors (i.e. TV) are associated with an increased risk for cognitive impairment (Wang et al., 2006) and development of Alzheimer's disease (Lindstrom et al., 2005), whilst intellectually stimulating activities seem protective (Lindstrom et al., 2005; Verghese et al., 2003; Wang et al., 2006). It is important to note that the latter studies did not assess the sedentary aspect of these activities, though most intellectually stimulating activities were likely performed sedentary (e.g. reading, making puzzles, writing, playing cards/board-games, knitting). Regarding cognitive function, this positive effect of mentally stimulating activities on brain health might counteract negative effects of SB on metabolic health.

Next to the intellectual aspect of a sedentary domain, also other factors such as the social setting may be of importance (Kelly et al., 2017; Shankar et al., 2013), with participation in social activities being linked to lower risk of developing Alzheimer's disease (Lindstrom et al., 2005). Objective evaluation of the domains, with context assessment (Giurgiu et al., 2020), seems a potential strategy to provide better insight into the specific domains of SB that are especially relevant in the preservation of cognitive function. For example, previous work found that reducing sitting at work did not change cognitive function (Magnon et al., 2018), while our analysis also suggests that benefits for cognitive function may not be expected from reducing SB at work. By investigating the impact of reducing SB in different domains, future intervention studies could shed more light into the relation between SB and cognitive function. Considering the limited validity of questionnaires to assess SB (Bakker et al., 2020) and increasing evidence for separate consideration of sedentary domains, objective assessment of domains could lead to great improvements in SB research. However, feasibility of accelerometer use in large studies is limited. At the very least, our results support a call for future studies to not only look at total SB but to include the various domains with regard to cognitive function.

Some limitations need to be acknowledged. First, we were not able to correct for diet, which might also affect cognitive function (Beilharz et al., 2015; Freeman et al., 2014). Secondly, our population reports relatively high levels of PA. However, since we were able to correct for PA, and results are therefore assumed to be independent of PA levels, it unlikely affected the main findings of our study. Thirdly, as the COST-A was computer-based, there might have been response bias. Considering the positive relation between computer time and cognitive function, our population might have had a higher overall cognitive function, although we believe that this does not impact the validity of our results. We did not observe a ceiling effect in the z-score distribution. Moreover, the COST-A was validated in a population aged 50 and older (Van Mierlo et al., 2017). Although the median age of our population was 61 years, 19% of the population was aged < 50 years. Nonetheless, our sensitivity analysis showed that excluding this younger subpopulation did not alter our main outcomes substantially. As the COST-A was developed to screen for mild cognitive impairment/dementia (Van Mierlo et al., 2017), it might have been less discriminative in our cognitively healthy population. However, the z-score was also shown to correlate with global cognitive function and cognitive domain scores (attention, memory, executive function) of neuropsychological assessments (Van Mierlo et al., 2017), wherefore we believe that its application in this study was suitable. Lastly, our study was not designed to examine causality or directionality of the association between SB and cognitive function.

5. Conclusion

We found a positive association between total SB and cognitive function which was not consistent across different domains of SB. Especially work- and non-occupational computer-related SB were positively associated with cognitive function, while TV time, reading time and creative time were not. Our results show that different sedentary domains can relate differently to cognitive function and underline the importance to evaluate these closely to understand the relation between cognitive function and SB.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2021.106731.

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