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CHAPTER 2

EPISODIC MEMORY FUNCTION IS AFFECTED BY LIFESTYLE FACTORS: A 14-YEAR FOLLOW-UP STUDY IN AN ELDERLY POPULATION

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ABSTRACT

Understanding the relationship between memory function and lifestyle offers great opportunities for promoting beneficial lifestyle choices to foster healthy cognitive aging and for the development of intervention programs for older adults. We studied a cohort of older adults (age 65 and older) enrolled in the Longitudinal Aging Study Amsterdam (LASA), an ongoing prospective population-based research project. A total of 1,966 men and women participated in an episodic memory test every three years over a period of 14 years. Lifestyle habits were repeatedly assessed using self-report measures. Physical activity, light to moderate alcohol consumption, difficulties staying asleep, and social engagement were associated with better memory function over the course of 14 years. In contrast, smoking and long sleep duration were associated with worse memory function. These findings suggest that certain lifestyle factors can have long-term protective or harmful effects on memory function in aging individuals.

Key words: Episodic memory, aging, lifestyle factors, longitudinal study,
neuropsychological assessment

INTRODUCTION

Cognitive decline is, to some degree, an inevitable consequence of aging. However, the rate of decline differs substantially between individuals. Episodic memory function, which refers to encoding and retrieval of information in the context of time and place, is crucial to carry out daily living tasks and to engage in meaningful social interactions. It is also particularly vulnerable to age-related decline (Lezak, Howieson, & Loring, 2004). There is a growing body of evidence suggesting that some potentially modifiable lifestyle habits can influence the rate of memory decline in late life.

Physical activity, smoking tobacco, sleep habits, alcohol consumption, and social engagement are modifiable lifestyle factors that can play a crucial role in addressing the burden of cognitive decline. In particular, some studies have reported that higher levels of physical activity are linked to better cognitive function and less cognitive decline (Ku et al., 2012). On the other hand, smoking tobacco (Anstey, von Sanden, Salim & O'Kearney, 2007) and poor quality of sleep (Scullin & Bliwise, 2015) have been associated with an increased risk of dementia and cognitive decline. Study findings regarding which aspects of sleep (i.e. duration, difficulties falling asleep or staying asleep, time spent in different sleep stages etc.) contribute to impaired cognition in aging adults have been inconsistent thus far (Scullin & Bliwise, 2015). Moreover, there are only few longitudinal studies about the effect of poor sleep on cognitive aging and studies often did not control for comorbidities like depression (Scullin & Bliwise, 2015).

Research on the effect of alcohol consumption on cognitive health shows a rather complex picture. When compared to alcohol abstinence, light to moderate alcohol consumption (generally defined as up to 2 drinks per day for men and up to one drink per day for women; Falk, Yi, & Hiller-Sturmhofel, 2006) in older adults is associated with a number of benefits including a slower rate of cognitive decline (Ganguli, Vander Bilt, Saxton, Shen, & Dodge, 2005). Heavy alcohol consumption (generally defined as more than 14 drinks per week for men and more than seven drinks per week for women; Falk et al., 2006), on the other hand, has been linked to Korsakoff's syndrome (Lezak et al., 2004), premature death (O'Keefe, Bhatti, Bajwa, DiNicolantonio, & Lavie, 2014), and to an increased risk of dementia (Deng et al., 2006). Alcohol abstinence may be due to health-related reasons, which may also cause poor cognitive functioning. It is therefore important to control for potential confounders such as chronic diseases or depression and to use light/moderate alcohol consumption as a reference group when exploring the effects of drinking on cognitive aging.

Similar to alcohol consumption, studies on the influence of social activities on cognitive aging are inconclusive thus far (Brown et al., 2012; James, Wilson, Barnes, & Bennett, 2011). According to Rowe and Kahn's model of successful aging (Rowe & Kahn, 1997), successful aging is determined by low disability and disease, high cognitive and physical functioning, and the ability to actively engage in life. Part of this network is engagement and integration in a social network, including both the feeling of being emotionally connected and actively contributing to a community (Rowe & Kahn, 1997). Social engagement is a complex construct that is defined by the frequency and diversity of social interactions (educational, leisure, social, cultural) as well as level of active attendance. These aspects are often overlooked and should be taken into account when examining the effect of social engagement on cognitive health.

Despite a large body of research, results are mixed and there is still a significant gap in understanding the effects of lifestyle habits on cognition in old age. Inconsistencies between studies are likely due to methodological differences. For instance, the use of subjective versus objective measurements likely yields different results. However, validated assessment tools for lifestyle factors are often not available. In addition, potentially confounding factors such as socioeconomic variables, gender, or health status are frequently not taken into account and need to be controlled for. Many studies are cross-sectional, have relatively short follow-up intervals or use brief neuropsychological assessment instruments. There is a need for longitudinal studies with a large sample size and well-characterized cohorts to examine the effects of lifestyle factors on cognitive aging while taking into account potential confounders.

This study investigates the effects of a number of modifiable lifestyle factors on episodic memory function over a period of 14 years in a large cohort of older men and women. The goal of the study is to test the hypotheses that physical activity, moderate levels of alcohol consumption, and social engagement have beneficial effects on episodic memory function, and that poor sleep quality and smoking have harmful effects, while addressing the above discussed methodological concerns.

METHODS

Data was used from the Longitudinal Aging Study Amsterdam (LASA), an ongoing prospective population-based study conducted in three geographic regions in the Netherlands. The design of the study is in detail described in Huisman et al., 2011. In short, the study cohort was recruited from municipal registries in 1992, and included a larger number of older adults and men. There were no exclusion criteria. The cooperation rate for the baseline interview was 62% (Huisman et al., 2011).

The first measurement cycle took place in 1992 with a total of 3,107 participants. To date, there have been six measurement cycles; the latest retained a total of 985 participants of the original sample. The main reason for attrition was mortality. Participants also dropped from the study because they were too frail, decided to discontinue, or could not be reached for follow-up, all of which are commonly encountered in longitudinal aging studies (Huisman et al., 2011).

Practice effects are likely to occur in longitudinal studies due to habituation to the testing format. In order to minimize the influence of potential practice effects between the first and the second time point, the first assessment cycle was excluded from analyses. The second assessment cycle (wave C) took place in 1995; only participants aged 65 years

Table 1. Follow-up interval and sample size of study cohort

	Year	Total N	Mean age (SD)
Wave C	1995-1996	1,966	76.18 (6.83)
Wave D	1998-1999	1,538	78.29 (6.65)
Wave E	2001-2002	1,190	80.22 (6.36)
Wave F	2005-2006	819	82.58 (5.65)
Wave G	2008-2009	601	84.52 (5.14)

Notes: SD = Standard deviation

and older at this time were included in the present research since memory tests were only administered to this age cohort (N=1,966; **Table 1**). A total of five time points (waves C through G), measured every three years between 1995 and 2009, were included in the analyses. All variables with the exception of verbal intelligence, which is not expected to change over time, were repeatedly assessed over the five time points. In order to explore the effects of lifestyle factors on healthy and pathological aging, subjects were not excluded based on dementia.

Outcome Variables

Episodic memory function was assessed with an adapted version of the Rey Auditory Verbal Learning Test (AVLR; Rey, 1964) using three instead of five learning trials (Deelman, Brouwer, van Zomeren, & Saan, 1980) in order to reduce administration time and subject burden (Lezak et al., 2004). During three consecutive learning trials, a list of 15 words was verbally presented to the participant. After each trial and after a delay of 20 minutes, participants were asked to recall as many words as possible. The highest score on the three trials was used as a measure of learning. The number of words recalled after the delay period was used as a measure of storage. The retention score (measure of forgetting) was calculated by dividing the delayed recall score by the highest learning score of the three trials. In order to minimize practice effects, two alternative word lists were used for repeated assessments. Raw memory scores were used for the analyses.

Lifestyle factors

Current physical activity was assessed using the LASA physical activity questionnaire (LAPAQ; Stel et al., 2004), a self-rating survey. Participants were asked how often and for how long in the previous two weeks they had participated in the following activities: outdoors walking, bicycling, light household, heavy household, and two additional sport activities as open questions. A total physical activity score (minutes per day) was computed.

During the interview, participants' current smoking status and alcohol consumption were assessed. Alcohol consumption was categorized into abstainers, light/moderate drinkers (1-14 drinks/week for men and 1-7 drinks/week for women), and heavy drinkers (more than 15 drinks/week for men and more than 8 drinks/week for women; Falk et al., 2006).

Sleep habits and problems were assessed with a self-rating questionnaire. In addition to the number of hours of sleep in 24 hours, participants were asked to indicate how often they experienced problems falling asleep, waking up during the night, and waking up too early in the morning. Frequencies of sleep problems were subsequently dichotomized into "good sleep quality" ("almost never" and "some of the time") and "bad sleep quality" ("often" and "most of the time"). Sleep duration was categorized as short (5 hrs/day of sleep or less), normal (6-8 hrs), and long (9 hrs or longer) because non-linear relationships between this variable and the outcome variables were expected.

Social engagement was defined as participation in recreational and social activities that involve interaction with other individuals. Participants were asked to indicate whether or not they were a member of an organization, to specify the number of memberships, the number of social activities they were attending and the frequency of attendance. Frequency of attendance was dichotomized into "sometimes" (once a month or less) and "often" (at least two times a month). Amongst others, activities included neighborhood organizations, professional clubs, sports clubs, religious organizations, political party, and organizations for singing, music, or theatre.

Covariates

Several covariates were included in the analyses to control for the potential influence of these variables on the association between dependent and independent variables. Sex, age, and time of the assessments were included as demographic variables. Time (i.e. number of years between measurement cycles) was included as a covariate in order to study the effect of time on memory. Income was used as a measure of socioeconomic status (SES). Depressive symptom severity, functional limitations, and chronic diseases were included as health factors. All covariates, except for sex, were included in the analyses as continuous measures. Covariates correlated significantly with at least one of the outcome measures.

Depressive symptoms were measured with the Center for Epidemiologic Studies Depression Scale (CES-D; Radloff, 1977). In order to assess functional limitations, participants were asked to indicate whether or not they experienced difficulties with six daily living tasks (Deeg et al., 2012). The total number of tasks that the participant reported difficulty with (ranging from zero to six) was included in the analyses. The number of chronic diseases was based on the chronic disease questionnaire of Statistics Netherlands (Central Bureau of Statistics, 1989). In addition, since verbal functioning has been linked to performance on the AVLT, verbal intelligence was included as a covariate (Bolla-Wilson & Bleeker, 1986). Verbal intelligence, a measure of crystallized and premorbid intelligence, was assessed by means of a subtest of the Groninger Intelligence Test (GIT; Luteijn & van der Ploeg, 1983).

Statistical Analyses

A linear mixed model (LMM) analysis was applied to explore the associations between lifestyle factors and memory function (outcome) over fourteen years split into five separate time points. LMM, a regression analysis of longitudinal data, was chosen because it controls for the dependency between repeated measurements of the same participants and for missing values. Analyses were performed using IBM SPSS Statistics 21 software.

Associations between predictor variables (lifestyle factors) and outcome measures (learning, delayed recall, retention) were analyzed in three different models that controlled for the influence of potential confounders in a stepwise manner. Analyses included intercept as a random effect. Age, time, sex, independent variables and covariates were included as fixed effects. Model 1 was adjusted for age, time, and sex. Model 2 was additionally adjusted for SES and crystallized intelligence, and model 3 was additionally adjusted for depression, chronic diseases, and functional limitations. Over-fitting of the model was controlled for by using the Akaike Information Criterion (AIC).

In addition to main effects, which measure cross-sectional correlations over time, interaction effects with time were explored in order to measure the rate of change over time. Non-linear terms were explored for all continuous independent variables (physical activity, number of memberships, number of social activities attended) by including the quadratic terms in the fully adjusted model 3. P values smaller than .05 were considered statistically significant.

RESULTS

At wave C, the study cohort consisted of a total of 1,966 participants (Table 1). Table 2 shows descriptive statistics of the cohort. Analyses controlled for the influence of potential confounders in three adjusted models; the AIC decreased for all variables as more covariates were included in each model, indicating that the fully adjusted models (model 3) were the best fit to explain the data. Tables 3 to 5 present associations between lifestyle factors and memory scores (main effects).

Lifestyle factors

Physical activity

A positive association between physical activity and all three memory measures was found indicating that more physical activity predicted better memory function (Tables 3-5). This effect remained significant after correcting for covariates. For all three memory measures, no interaction effects were found between physical activity and time, suggesting that the rate of decline in memory was not dependent on physical activity.

The quadratic term of physical activity was significant for learning (*p* = .05), delayed recall (*p* = .003), and retention (*p* = .033) suggesting non-linear associations. While this finding is unexpected and the statistical model not including the quadratic term of physical activity showed a smaller AIC indicating a better fit, we categorized physical activity into

Table 2. Descriptive statistics of the study cohort at wave C in mean (SD) or n (%)

	Wave C	N
Demographics		
Age in years, M (SD)	76.18 (6.83)	1,966
Female, n (%)/ Male, n (%)	1058 (53.8)/908 (46.2)	1,058/908
Education in years, M (SD)	8.68 (3.28)	1,964
Cognitive functioning		
Memory learning score, M (SD)	7.93 (2.64)	1,464
Memory delayed recall score, M (SD)	5.51 (3.04)	1,463
Memory retention score, M (SD)	66.17 (26.96)	1,460
Lifestyle factors		
Physical activity min per day, M (SD)	140.16 (97.82)	1,666
Does not drink alcohol, n (%)	388 (28.7)	388
Light/moderate alcohol consumption, n (%)	885 (65.5)	885
Heavy alcohol consumption, n (%)	79 (5.8)	79
Current smoker n (%)	288 (19.1)	1,507
Sleep		
Hours of sleep, M (SD)	7.56 (1.44)	1,500
Problems falling asleep often, n (%)*	262 (17.3)	1,518
Waking up during the night often, n (%)*	370 (24.4)	1,515
Waking up too early often, n (%)*	437 (28.8)	1,520
Social engagement		
Member Y, n (%)	1276 (75.7)	1,685
Number memberships, M (SD)	1.66 (1.53)	1,759
Attending activities, M (SD)	1.10 (1.32)	1,682
Frequency attendance often, n (%)**	628 (37.9)	1,655

Notes: * Sometimes= almost never, some of the time; Often= often, most of the time. ** Sometimes= never, almost never, few times a year, every month; Often= few times a month, every week, few times a week, every day.

the following three groups to further explore this result: low physical activity (0-90 min/day), moderate physical activity (91-180 min/day), and high physical activity (181 min/day and above).

Stratified analyses showed that compared to the low physical activity group, moderate physical activity was associated with better learning (*B* = .241; 95% CI: .081 to .401; *p* = .003), better delayed recall (*B* = .276; 95% CI: .100 to .451; *p* = .002), and better retention (*B* = .324; 95% CI: 4.083 to 5.848; *p* = .022). Likewise, compared to the low physical activity group, high physical activity was associated with better learning (*B* = .244; 95% CI: .053 to .435; *p* = .012), better delayed recall (*B* = .348; 95% CI: .138 to .559; *p* = .001), and better retention (*B* = 3.621; 95% CI: 1.393 to 5.848; *p* = .001). No significant associations were found when comparing the moderate physical activity group with the high physical activity group.

Table 3. Association between lifestyle factors and learning score (Linear Mixed Model)

	Model 1		Model 2		Model 3	
	B	95% CI	B	95% CI	B	95% CI
Physical activity	.001	.001 to .002***	.001	.001 to .002***	.001	.000 to .002*
Alcohol consumption						
Abstinent	-.540	-.738 to -.343***	-.216	-.422 to -.010*	-.175	-.384 to .033
Heavy consumption	.048	-.348 to .445	.017	-.389 to .424	-.002	-.412 to .407
Tobacco use	-.415	-.653 to -.177**	-.413	-.651 to -.175**	-.421	-.660 to -.181**
Sleep						
Hours of sleep						
Sleep duration short	.026	-.240 to .292	.097	-.181 to .375	.167	-.113 to .447
Sleep duration long	-.427	-.621 to -.233***	-.244	-.444 to -.045*	-.194	-.396 to .007
Problems falling asleep	-.078	-.271 to .115	-.035	-.236 to .166	.036	-.171 to .242
Waking during night	.158	-.011 to .326	.157	-.018 to .332	.198	.020 to .377*
Waking too early	-.023	-.187 to .141	.015	-.155 to .185	.058	-.116 to .231
Social engagement						
Member Y/N	-.363	-.533 to -.194***	-.300	-.473 to -.125**	-.280	-.455 to -.103**
Number memberships	.149	.100 to .200***	.101	.049 to .153***	.091	.038 to .143**
Attending activities	.144	.085 to .203***	.106	.045 to .166**	.088	.026 to .150**
Frequency attendance	.244	.102 to .386**	.177	.030 to .325*	.136	-.013 to .285

Notes: CI = confidence interval. Model 1 = adjusted for age, time and sex. Model 2 = model 1 additionally adjusted for SES and crystallized intelligence. Model 3 = model 2 additionally adjusted for depression, chronic diseases, functional limitations. Reference groups: alcohol=light/moderate consumption; tobacco=not smoking; hours of sleep=normal; problems falling asleep, waking during night, waking too early=good sleep quality; membership=yes; frequency of attendance=sometimes. *$p<.05$; **$p<.01$; ***$p<.001$

Table 4. Association between lifestyle factors and delayed recall score (Linear Mixed Model)

	Model 1		Model 2		Model 3	
	B	95% CI	*B*	95% CI	*B*	95% CI
Physical activity	.002	.001 to .003***	.002	.001 to .003***	.002	.001 to .002***
Alcohol consumption						
Abstinent	-.618	-.837 to -.398***	-.384	-.618 to -.149**	-.364	-.602 to -.127**
Heavy consumption	-.326	-.756 to .134	-.282	-.730 to .166	-.293	-.146 to .161
Tobacco use	-.184	-.450 to .082	-.107	-.379 to .165	-.127	-.401 to .146
Sleep						
Hours of sleep						
Sleep duration short	-.036	-.330 to .258	.023	-.288 to .334	.143	-.349 to .635
Sleep duration long	-.369	-.583 to -.154**	-.250	-.473 to -.026*	-.466	-.791 to -.138**
Problems falling asleep	-.010	-.224 to .203	-.020	-.247 to .206	.046	-.187 to .279
Waking during night	.107	-.079 to .294	.101	-.095 to .297	.132	-.068 to .332
Waking too early	.037	-.145 to .219	.064	-.126 to .255	.096	-.098 to .291
Social engagement						
Member Y/N	-.132	-.318 to .055	-.119	-.312 to .074	-.094	-.290 to .102
Number memberships	.094	.039 to .149**	.044	-.015 to .102	.033	-.026 to .092
Attending activities	.102	.037 to .167**	.066	-.002 to .133	.048	-.021 to .117
Frequency attendance	.178	.024 to .332*	.128	-.034 to .290	.103	-.062 to .267

Notes: CI= confidence interval. Model 1= adjusted for age, time and sex. Model 2= model 1 additionally adjusted for SES and crystallized intelligence. Model 3= model 2 additionally adjusted for depression, chronic diseases, functional limitations. Reference groups: alcohol=light/moderate consumption; tobacco=not smoking; hours of sleep=normal; problems falling asleep, waking during night, waking too early=good sleep quality; membership=yes; frequency of attendance=sometimes. *p<.05; **p<.01; ***p<.001

Table 5. Association between lifestyle factors and retention score (Linear Mixed Model)

	Model 1		Model 2		Model 3	
	B	95% CI	*B*	95% CI	*B*	95% CI
Physical activity	.024	.015 to .032***	.020	.011 to .029***	.019	.010 to .028***
Alcohol consumption						
Abstinent	-5.368	-7.591 to -3.144***	-3.782	-6.122 to -1.441**	-3.810	-6.177 to -1.443**
Heavy consumption	-3.937	-8.533 to .659	-3.146	-7.830 to 1.539	-2.860	-7.583 to 1.862
Tobacco use	-.236	-2.871 to 2.399	.993	-1.661 to 3.646	1.004	-1.659 to 3.666
Sleep						
Hours of sleep						
Sleep duration short	-.477	-3.450 to 2.544	.275	-2.852 to 3.401	1.477	-3.572 to 6.526
Sleep duration long	-3.19	-5.391 to -.982**	-2.384	-4.639 to 1.129*	-5.860	-9.205 to 2.514**
Problems falling asleep	.982	-1.210 to 3.175	.393	-1.871 to 2.657	.736	-1.596 to 3.067
Waking during night	.982	-.942 to 2.907	.662	-1.319 to 2.644	.918	-1.109 to 2.945
Waking too early	1.725	-.142 to 3.591	1.488	-.424 to 3.401	1.727	-.232 to 3.685
Social engagement						
Member Y/N	.098	- 1.858 to 2.055	.123	-1.883 to 2.130	.283	-1.747 to 2.314
Number memberships	.460	-.115 to 1.035	-.043	-.639 to .553	-.147	-.748 to .454
Attending activities	.459	-.218 to 1.136	.133	-.557 to .822	.028	-.670 to .727
Frequency attendance	1.316	-.349 to 2.982	.635	-1.072 to 2.343	.638	-1.087 to 2.364

Notes: CI= confidence interval. Model 1= adjusted for age, time and sex. Model 2= model 1 additionally adjusted for SES and crystallized intelligence. Model 3= model 2 additionally adjusted for depression, chronic diseases, functional limitations.

Reference groups: alcohol=light/moderate consumption; tobacco=not smoking; hours of sleep=normal; problems falling asleep, waking during night, waking too early=good sleep quality; membership=yes; frequency of attendance=sometimes.

**p*<.05; ***p*<.01; ****p*<.001

Alcohol consumption

Participants reported drinking an average of 7.5 alcoholic beverages per week. With light/moderate alcohol consumption as the reference group, alcohol abstinence was associated with worse learning, delayed recall, and retention. Associations with delayed recall and retention remained significant after controlling for confounders. Compared to light/moderate alcohol consumption, no associations were found between heavy alcohol consumption and memory function. No interaction between alcohol consumption and time were found for memory function.

Tobacco use

Compared to non-smokers, smokers showed worse learning, indicating that smoking predicts poorer memory function. The strength of this association did not change after adjusting for potential confounders. No main effects were found for the influence of tobacco on delayed recall and retention. In addition, no significant interactions were found between smoking and time for the memory measures.

Sleep

Compared with normal sleep duration, long sleep duration was associated with worse learning, delayed recall, and retention. After controlling for the influence of potential confounders, associations remained significant for delayed recall and retention. No significant associations were found between short sleep duration and memory function when compared to normal sleep duration.

With normal sleep duration as the reference group, for long sleep duration an interaction effect with time was found for delayed recall (B = .058; 95% CI: .003 - .113; p = .039) and for retention (B = .891; 95% CI: .302 – 1.479; p = .003). Post hoc data analysis of this interaction effect showed that while individuals who reported long sleep durations performed worse on the memory tasks than individuals who reported normal sleep durations, long sleep duration was also associated with an increase in memory function over time while normal sleep duration was associated with a slight decrease in memory function.

Analyses showed no significant correlation between problems falling asleep and memory measures. In addition, no interaction effects with time were found.

Waking up during the night was positively associated with learning after adjusting for covariates, suggesting that frequent waking predicted better learning. No significant correlations were found between waking up during the night and delayed recall and retention, respectively. Moreover, no interaction effects between time and waking up during the night were found for the memory measures.

No correlations were found between waking up too early and memory function. In addition, no interaction effects between waking up too early and time were found for the memory measures.

Social engagement

Membership of an organization, the number of memberships, and attending activities were positively associated with learning over time. These associations remained significant after controlling for potential confounders. The quadratic terms of number of memberships and attending activities were not significant suggesting linear associations. A positive correlation between frequency of engaging in social activities and learning did not remain significant in the fully adjusted model.

For delayed recall, no significant correlation with being a member of an organization was found. The number of memberships, attending activities, and the frequency of attending meetings were positively correlated with delayed recall. However, after adjusting for the influence of confounders, these associations were no longer significant. No significant associations between social engagement and retention scores were found. For all three memory measures, analyses showed no interaction effects between time and social engagement.

DISCUSSION

Healthy cognitive aging is the result of a complex interplay between various lifestyle factors. Understanding these relationships and identifying predictors of cognitive decline offers the potential to promote healthy cognitive aging in order to improve the quality of life in the elderly population, and to reduce the burden on the caregiver generation. The present study confirmed our hypotheses that physical activity, light/moderate alcohol consumption and social engagement are associated with better memory function, and that smoking and excessive sleep have detrimental effects on cognition. We found no associations with the rate of memory decline for any of these factors with the exception of sleep duration.

With regard to sleep, our findings were partly unexpected as difficulties staying asleep predicted better learning over time. However, this association has been reported previously and has been proposed to be due to hyperarousal or increased efforts to compensate for sleep deprivation (Scullin & Bliwise, 2015). In addition, since sleep becomes more fragmented with older age, frequent waking during the night might simply reflect a normal aging pattern rather than an indication for accelerated cognitive decline. Long sleep duration (9 hrs/day or more) was associated with poorer memory function than normal sleep duration (6-8 hrs/day). These findings were expected since long sleep duration has been linked to underlying health conditions such as an increased risk of cardiovascular diseases and stroke (Cappuccio, Cooper, D'Elia, Strazzullo, & Miller, 2011), which in turn are predictors for cognitive decline (American Heart Association/American Stroke Association, 2011). Nevertheless, since the present study controlled for the influence of underlying health conditions, additional mechanisms likely account for this association. For instance, long sleep duration may be an indicator for poor sleep quality as individuals may report needing more sleep in order to feel rested (Gildner, Liebert, Kowal, Chatterji, & Snodgrass, 2014). Other measures of sleep quality were not linked to impaired cognition.

The mechanisms behind the protective effects of physical activity and alcohol and the harmful effects of smoking on cognitive function are likely explained by their effects on the cardiovascular system and consequently brain health (Cotman et al., 2007; Deng et al., 2006; Meyer et al., 1999). Physical activity has been linked to neurogenesis and increased synaptic plasticity explaining better cognitive functioning in active older adults (Cotman, Berchtold, & Christie, 2007). Zlatar et al. (2015) highlight the importance of assessing physical activity objectively and the need of a validated measurement tool. While both aerobic fitness and self-reported physical activity were associated with gray matter density in several brain regions, only aerobic fitness was found to combat age-related loss of gray matter density (Zlatar et al., 2015).

It is less clear how much exercise is needed and what sort of physical activity is required to benefit from its health effects. While intensity of physical activity was not assessed, the present study included walking in the overall measurement of physical activity suggesting that even mild exercise has beneficial effects on cognition. However, it would be useful for future studies to assess the relative influence of both frequency and intensity of physical activity on cognitive health. No differences were found between moderate and high levels of physical activity in terms of frequency, stressing the importance of staying physically active for healthy aging in general.

Light to moderate alcohol intake has beneficial effects on cardiovascular health, such as reduced risks of stroke and congestive heart failure (O'Keefe et al., 2014), promoting brain health (Deng et al., 2006). In the present study, light to moderate alcohol consumption was linked to better memory function than alcohol abstinence. However, it is important to keep in mind that the alcohol abstinent group likely represented a cohort with poorer overall health. Heavy drinking was not found to be associated with poorer memory function than light/moderate drinking. These findings are in line with a recent study (Horvat et al., 2015). Smoking tobacco, on the other hand, causes inflammation and oxidative stress (Bruno & Traber, 2006), and has been linked to accelerated brain atrophy and decline in cerebral gray and white matter densities (Meyer et al., 1999).

This study found that social engagement was associated with better learning over time but not memory storage and retrieval. Different aspects of social engagement were taken into consideration in order to assess their individual contribution to memory function. Being a member of an organization, a higher number of memberships, and attending activities were associated with better memory function. The frequency of attendance, however, was not predictive of better cognition. These findings raise the question what the mechanisms are behind these relationships. Social activities require complex cognitive processes such as attention, working memory, task switching, and memory. It is therefore plausible that social engagement serves as a type of "brain training", which stimulates and helps preserve neural networks and consequently acts as a type of buffer against age-related cognitive decline (James et al., 2011; Stern, 2002). In addition, social interactions may indirectly foster individuals to take care of their own health and manage chronic conditions. This study did not assess the influence of social integration and social support systems such as relationships, presence of a spouse, children, or other caregivers. Including these types of social interaction would have provided a more comprehensive analysis of the influence of social engagement on memory function in older adults.

The implications of these findings are important for the development of clinical intervention programs to delay or prevent cognitive decline. While interventional programs are gaining increasing popularity, there is a need for more scientific evidence about which lifestyle factors can impact cognitive health in a meaningful way. In addition to educating older adults about the beneficial and harmful effects of certain lifestyle choices, interventional programs should focus on teaching older adults targeted activities, which they can integrate into their daily lives. For instance, it would be valuable to teach physical activities that can be done by even fragile older adults and to offer guidance in reducing concerns about incurring injuries during exercise. Likewise, engaging older adults in programs that connect them with other people with similar interests or to provide a platform to teach skills or knowledge to younger adults or children could have tremendous benefits. These programs could be advocated by general practitioners, assisted living or retirement facilities, community centers, and caregivers. Intervention programs engaging older adults in social activities have been found to be successful in the past but more research is needed to substantiate their efficiency and applicability to everyday life.

Lifestyle factors affected the three memory measures differently, which could be explained by the circumstance that learning, storage, and retrieval of information depend on distinct regions of the brain. Learning primarily involves the medial temporal lobes, including the hippocampus, while free recall primarily involves prefrontal structures. It seems therefore plausible that the hippocampus, which is most vulnerable to age-related structural changes, is also most susceptible to the beneficial or harmful effects of lifestyle factors. Retention, which measures the rate of forgetting of previously learned information, could be an indicator for dementia. Since the study sample was heterogeneous, i.e. subjects showing symptoms of dementia at baseline or throughout the study were not excluded, the rate of cognitive decline could indicate pathological aging. However, since we did not find an increased rate of decline, it is not likely that our findings point to early stage dementia.

This study has some methodological strengths and weaknesses. All lifestyle factors were based on self-report measures, which may be influenced by response biases such as giving socially desirable answers or over- or underreporting. In addition, cognitively impaired older adults may have experienced difficulties accurately recalling information relative to their lifestyle and social habits. The use of objective instead of subjective measurements could have reduced these limitations. In addition, while participants were not explicitly asked whether or not they had any sleep disorders, such as sleep apnea, they were asked to list chronic diseases. Analyses controlled for the potential effect of chronic diseases. Another limitation is that regular light drinkers and occasional binge-drinkers were included in the same category. Assessing for binge-drinking and alcohol dependence would have added valuable information. The underlying causes or mechanisms for the above-discussed associations cannot be determined based on the present findings and need to be further explored.

We performed multiple comparisons between memory functions and lifestyle factors, which might have introduced a type I error. Controlling for multiple comparisons and the likelihood of chance findings by applying a Bonferroni correction, however, would have increased the chances of a type II error and falsely rejecting associations between variables (Perneger et al., 1998). We therefore chose not to apply conservative Bonferroni corrections but to include significance levels and confidence intervals in this article.

A key strength of the present research is that it is based on a large community-dwelling cohort of older men and women who were followed over a period of 14 years. Longitudinal studies exploring effects of lifestyle factors on cognitive decline are sparse and often limited by relatively short follow-up periods. However, longitudinal studies are particularly valuable in determining cognitive decline in the same individual over time. Another strength of this study is that memory function was well-characterized. Memory was used as the outcome measure because memory is particularly vulnerable to the consequences of aging. Many studies measure general cognitive function by means of short screening tests like the Mini Mental State Exam. More comprehensive neuropsychological testing is necessary to reveal subtle and specific changes in cognition and to provide a better understanding of the relationship between lifestyle and cognition.

In conclusion, the present study provides compelling data that memory function in aging adults can be positively influenced on a long-term basis by physical activity, moderate levels of alcohol consumption, and social engagement. Smoking and long sleep durations can harm memory function in this population. Several questions emerge for future research. The cause-effect relationship between these factors is not clear, i.e. does cognitive impairment cause older adults to engage in less social and physical activities or to experience poorer sleep quality or vice versa? Furthermore, the present study measured late life lifestyle factors, which raises the question whether these factors need to be maintained during a lifetime or whether initiating lifestyle choices in late adulthood is sufficient to combat age-related cognitive decline. Along those lines, a potential future direction of research is to explore how change in lifestyle over time relates to change in episodic memory function. Lastly, it is important to link the findings from this study to structural changes or individual differences in the brain.

The interplay between different lifestyle factors is rather complex; it would be valuable to investigate how different factors influence each other and what the relative impact of each factor and their interaction is on cognitive function. For instance, does increased physical activity improve quality of sleep and consequently slow down cognitive decline or does alcohol consumption disturb restorative sleep and subsequently cause cognitive impairments in older adults? In addition, future studies should focus on the neurological mechanisms that underlie the links between lifestyle factors and cognitive decline. Nevertheless, the findings of the present study provide compelling data to identify older adults who are at risk for memory impairment. In addition, our data offer great potential to promote healthy aging and to support the development of clinical intervention programs in order to help older adults retain optimal cognitive capacity.

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