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ORIGINAL ARTICLE

Eating and healthy ageing: a longitudinal study on the association between food consumption, memory loss and its comorbidities

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Abstract

Objectives To explore the longitudinal association between food groups and memory loss and comorbid heart disease and diabetes (both Type 1 and 2) for people living in New South Wales, Australia.

Methods We assessed 139,096 adults (aged 45 years and over) from the 45 and Up Study who completed both baseline (2006–2009) and follow-up (2012–2015) surveys. Mixed linear and generalized estimating equation models were used to examine the longitudinal associations.

Results High consumption of fruit, vegetable and protein-rich food associated with lower odds of memory loss. High consumption of fruit and vegetables also associated with lower odds of comorbid heart disease ($p \leq 0.001$). People who aged $\geq$ 80 years with low consumption of cereals had the highest odds of memory loss and comorbid heart disease than people in other age groups ($p < 0.01$).

Conclusions The results highlighted the longitudinal association of fruit and vegetable in relation to memory loss and comorbid heart disease. Age effects on cereals consumption which have an influence on memory loss and comorbid heart disease.

Keywords Food groups · Memory loss · Comorbidities · Heart disease · Longitudinal study

Introduction

Memory loss is one of the main early symptoms for people with dementia (National Institute on Aging 2017). Dementia is the second leading cause of death of Australians, contributing to 5.4% of all deaths in males and 10.6% of all deaths in females each year (Australian Bureau of Statistics 2018a). People living with dementia have on average 2–8 comorbidities, which may accelerate the state of cognitive and functional impairment (Poblador-Plou et al. 2014). The common comorbidities in dementia include cardiovascular diseases, diabetes and hypertension (Doraiswamy et al. 2002; Poblador-Plou et al. 2014). A cross-sectional study of 72,815 people diagnosed with dementia demonstrates that 69.6% of people had at least two comorbidities and 48.1% had at least three comorbidities (Poblador-Plou et al. 2014). People with comorbidities are more likely to use health services, have higher healthcare costs and rate of mortality for hospitalized patients (Poblador-Plou et al. 2014). This intensifies the strain put on the healthcare system, caregivers and their families (Kuo et al. 2015; Schulz and Martire 2004).

Eating a healthy diet can be considered a modifiable risk factor to prevent memory loss, dementia and chronic diseases (Katz et al. 2018). The link between single nutrient (or food) and memory loss, cognitive function or dementia has been proposed, with the mechanism of certain nutrient or food lowering oxidative stress, reducing inflammation, preventing vascular comorbidity and protection against cerebrovascular diseases (Frisardi et al. 2010). For example, vitamin C and E are related to decreased risk of vascular dementia, and better cognitive function (Scarmeas et al. 2006a). Fish can potentially improve brain function, including memory loss and cognitive function (Dangour et al. 2009). The previous studies also examine the specific

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dietary pattern in relation to health outcomes. For example, it has been reported that a Mediterranean diet, which includes high consumption of olive oil, legumes, unrefined cereals, fruits and vegetables, can potentially corresponds to lowered vascular risk, reducing the risk for diabetes, hypertension, dyslipidaemia (Scarmeas et al. 2006b) and dementia (Scarmeas et al. 2006a). Our previous study results show the protein-rich dietary pattern positively associated with cognitive function in older people (Xu et al. 2018).

While there is literature to indicate the benefits of single food or nutrient in memory loss, cognitive function and dementia, many epidemiologic evidence of investigating this association is limited by cross-sectional design (van de Rest et al. 2015), and the results from longitudinal studies were mixed (Fischer et al. 2018; van de Rest et al. 2015). Also, little is known about the association between food and comorbidities in people with memory loss or dementia. Therefore, the aim of the present study is to (1) examine the longitudinal association between food groups and memory loss, and (2) examine the longitudinal association between foods and comorbid heart disease and diabetes in people with memory loss.

Methods

Study design and participants

We conducted longitudinal analysis of data from the 45 and Up Study, which is one of the largest ongoing studies, designed to understand how Australians are ageing (Sax Institute 2017). Participants are randomly sampled from the Department of Human Services (formerly Medicare Australia) enrolment database. A total of 267,153 men and women aged 45 and over across New South Wales, Australia, were recruited and surveyed in 2006–2009 representing about 10% of this age group. Upon recruitment, participants provided consent for future follow-up. The first follow-up survey data were collected between 2012 and 2015. At both time points, socio-economic, health behaviour and health-related information were collected via a comprehensive questionnaire (Banks et al. 2007). Detailed 45 and Up Study sampling process is described elsewhere (Banks et al. 2007).

There were 142,503 participants who completed both baseline and follow-up survey. A total of 139,096 participants, who completed both baseline and follow-up questionnaires, and completed the disease condition questions (memory status, heart disease and diabetes) were included in the analysis.

Measures

Dietary consumption

In the 45 and Up questionnaire, dietary consumption was assessed by a short food frequency questions (Sax Institute, 2008). Participants were asked the frequency and amount of fruit and vegetable (FV) consumption by asking the question "about how many serves of FV (vegetables include potatoes, fruit does not include fruit juice) do you usually eat each day?" The frequency of red meat, chicken, processed meat, fish or seafood, cereal and cheese consumption was asked the question "about how many times each weeks do you eat…"; The frequency of milk consumption was not been asked in the questionnaire but ascertained by asking the question "which type of milk do you mostly have?" We further categorized the variable of milk (including whole, soy, skim, reduced fat and others) as Yes/No for analysis. These short food frequency questions from 45 and Up Study have been used in the previous publications (Mihrshahi et al. 2017; Xu et al. 2019), and each of these questions on diet were previously validated in the Million Women Study (Astell-Burt et al. 2013).

The Australian Dietary Guideline (ADG) was developed to assist Australians to achieve a healthy diet. In brief, the ADG includes 11 components, including five core food groups, i.e. (1) vegetables, (2) fruit, (3) grain (cereals), (4) lean meat and protein food alternatives and (5) milk and milk alternatives. The ADG encourages people to eat a wide variety of foods from each of the five food groups, in the amounts recommended (Roy et al. 2016).

The five key food groups from ADG were harmonized with participants' response of the food frequency questions in the 45 and Up Study for analysis. The frequency of food groups for (1) vegetables, (2) fruit, (3) grain (cereals), (4) lean meat and protein food alternatives (including beef, lamb, pork, chicken, turkey, duck, fish and seafood) was divided into three quantiles, indicating consumption from low to high. The food group of milk and milk alternatives (cheese) was categorized as Yes/No.

Outcome variables

Memory status was collected using five-point Likert scale of memory function from participants by answering "In general, how would you rate your memory?" with choices as excellent, very good, good, fair and poor. We further classified participants' memory as good (excellent/very good/good) and memory loss (fair/poor) for analysis. This cut-off is consistent with the previous study by using the 45 and Up Study (Paradise et al. 2011). Heart disease and diabetes as reported on each survey in response to the question “has a doctor ever told you that you have…”.

Covariates

Socio-demographic and health behaviour factors were significantly associated with prevalence and incidence of diseases in the previous studies (Allen et al. 2017); therefore, we included them as covariates in the analysis. Socio-demographic factors included age, sex, marital status, education and socioeconomic levels. Education levels were divided into three categories, i.e. Low: no school certificate or other qualification, and school or intermediate certificate; Medium: high school or leaving certificate; and trade or apprenticeship; and High: certificate or diploma, and university degree or higher. Socioeconomic levels were assessed by Socio-Economic Indexes For Areas (SEIFA), which is based on three quantiles (low, medium, high) of Index of Relative Socio-economic Advantage and Disadvantage (Australian Bureau of Statistics 2018b).

Health behaviour factors included smoking, drinking and physical activity levels. Smokers were identified based on the question “are you a regular smoker now?”. Alcohol consumption was allocated to two categories (Yes/No), with the question “about how many alcoholic drinks do you have each week?”. Physical activity level was allocated to two categories (inadequate and adequate) based on the Australia’s Physical Activity and Sedentary Behaviour Guidelines. People who spent 150 min of moderate intensity physical activity or 75 min of vigorous intensity physical activity per week were considered as having adequate physical activity (The Department of Health 2017). BMI was calculated based on the formula of weight in kilograms (kg) over height in metres (m) squared (kg/m^2), and used Australian Institute of Health and Welfare cut-points that BMI between 25.0 and 30.0 kg/m^2 considered as overweight and greater than 30.0 kg/m^2 considered as obesity (AIHW 2019).

Analysis

N (%) was used to present the participants’ characteristics by memory status at baseline. Chi-square test was used to examine the differences between memory status and socio-demographic, as well as health behaviour factors. Median and interquartile range (IQR) were used to describe each food group consumption at baseline, and follow-up given in the data of each food consumption was not normally distributed. Mixed linear models were used to examine the longitudinal association between each food group and survey year. Coefficients (β) with 95% confidence intervals (CIs) were reported. Generalized estimating equation (GEE) models were used to examine the longitudinal association between milk consumption and survey year. GEE models were also used to test the association between each food group and memory loss, and the association between each food group and comorbid heart disease, as well as comorbid diabetes in people with memory loss. Odds ratios (ORs) with 95% CIs in crude model and adjusted model (adjustment of socio-demographic and health behaviour factors) were reported. Marginal plots were used to present the interaction between cereals and age groups in relation to memory loss and comorbidities in people with memory loss.

Post hoc supplementary analysis was conducted to examine the associations between food group and incidence of memory loss and comorbid heart diseases and diabetes in people with memory loss by using GEE models. In the post hoc analysis, we excluded people in three groups separately: (1) those had memory loss at baseline, (2) those had comorbid heart disease in people with memory loss at baseline, and (3) those had comorbid diabetes in people with memory loss at baseline. ORs with 95% CIs were reported in crude and adjusted models. All analyses were conducted in STATA/SE 14 (StataCorp, USA).

Results

Participants’ characteristics

A total of 139,096 participants, who completed both baseline and follow-up questionnaires and the disease condition questions (memory status, heart disease and diabetes), were included in the analysis. Table 1 shows participants’ characteristics by memory status at baseline. Participants in the older age group, male, widowed, with low education level and low socioeconomic area reported significantly higher percentage of memory loss compared to their counterparts ($p < 0.001$). Participants who were underweight, smoked, had inadequate physical activity reported significantly higher percentage of memory loss, while participants who did not drink alcohol reported higher percentage of memory loss than their counterparts ($p < 0.001$). Participants with heart disease reported significantly higher percentage of memory loss than those with no heart disease. Similarly, participants with diabetes reported significantly higher percentage of memory loss than those with no diabetes ($p < 0.001$).

Supplementary Fig. 1 shows the percentage of memory loss, and comorbid heart disease and diabetes in people with memory loss at baseline and follow-up. People in the older age had higher percentage of memory loss, and comorbid heart disease and diabetes than people in the younger age ($p < 0.001$). There was higher percentage of

Table 1 Participant's characteristics by memory status at baseline (2006–2009) in New South Wales, Australia

Variables	Memory status (N = 139,096)		p value*
	Good memory Good/very good/excellent	Memory loss Fair/poor	
Age groups (N = 139,092)	N (%)		
45–64 years	83,664 (87.6)	11,845 (12.4)	< 0.001
65–79 years	30,747 (82.9)	6360 (17.1)	
80 years or above	5041 (77.8)	1435 (22.2)	
Gender (N = 139,096)			
Male	52,696 (84.4)	9780 (15.7)	< 0.001
Female	66,760 (87.1)	9860 (12.9)	
Marital status (N = 138,355)			
Married/partner	94,635 (86.6)	14,641 (13.4)	< 0.001
Single/divorce/separated	17,522 (83.7)	3407 (16.3)	
Widowed	6671 (81.9)	1479 (18.2)	
Education (N = 137,773)			
Low	31,914 (81.4)	7273 (18.6)	< 0.001
Medium	50,217 (85.4)	8557 (14.6)	
High	36,267 (91.1)	3545 (8.9)	
SEIFA[a] (N = 135,141)			
Low	33,533 (82.6)	7055 (17.4)	< 0.001
Medium	39,021 (85.3)	6723 (14.7)	
High	43,466 (89.1)	5343 (11.0)	
BMI[b] (N = 139,096)			
Underweight	1149 (82.5)	244 (17.5)	< 0.001
Normal	42,050 (86.5)	6586 (13.5)	
Overweight	45,249 (86.3)	7207 (13.7)	
Obesity	31,008 (84.7)	5603 (15.3)	
Current smoking (N = 138,545)			
No	112,624 (86.1)	18,145 (13.9)	< 0.001
Yes	6383 (82.1)	1393 (17.9)	
Alcohol drinking (N = 137,431)			
No	33,747 (83.9)	6467 (16.1)	< 0.001
Yes	84,413 (86.8)	12,804 (13.2)	
Physical activity** (N = 137,989)			
Inadequate	110,342 (85.8)	18,335 (14.3)	< 0.001
Adequate	8189 (87.9)	1123 (12.1)	
Heart disease (N = 139,096)			
No	108,445 (86.5)	16,921 (13.5)	< 0.001
Yes	11,011 (80.2)	2719 (19.8)	
Diabetes (N = 139,096)			
No	111,617 (86.3)	17,678 (13.7)	< 0.001
Yes	7839 (80.0)	1962 (20.0)	

*Chi-square test was used to examine the difference between self-rated memory and categorical measurements

**People who spent 150 min of moderate intensity physical activity or 75 min of vigorous intensity physical activity per week were considered as having adequate physical activity

[a]*SEIFA* socio-economic indexes for areas

[b]Underweight: < 18.5 kg m^{-2}; normal: 18.5 to less than 25 kg m^{-2}; overweight: 25 to less than 30 kg m^{-2}; general obesity: $\geq$ 30 kg m^{-2}

comorbid heart disease in people with memory loss than comorbid diabetes in people with memory loss ($p < 0.001$).

The changes of food consumption over time

As age increases, older people consumed 0.05 serve more fruit ($p < 0.001$) and 0.16 serve more vegetable ($p < 0.001$) per day. Older people consumed 0.41 times more meat and protein food alternatives ($p < 0.001$) but 0.18 times less cereals ($p < 0.001$) per week. As age increases, people have 0.88 lower odds of consuming milk and milk alternatives ($p < 0.001$) (Table 2).

The longitudinal associations

Table 3 shows the longitudinal association between consumption of each food group and memory loss, and comorbid heart disease and diabetes in people with memory loss. We included all participants with memory loss and comorbid diseases in the analysis. After adjustment of socioeconomic and health behaviour factors, compared to people who had no fruit consumption, people who consumed the highest level of fruit had an odds of memory loss of 0.72 (95% CI 0.68; 0.76); compared with people who had no vegetable consumption, people who consumed the highest level of vegetables had an odds of 0.69 of memory loss (95% CI 0.64; 0.74); compared with people who had no meat and protein food alternatives consumption, people who consumed the highest level of meat and protein food alternatives had an odds of 0.82 of memory loss (95% CI 0.76; 0.89); compared to people who did not have milk and milk alternatives, people who had milk and milk alternatives had an odds of 0.84 of memory loss (95% CI 0.77; 0.91). There was the interaction between age groups and cereals in relation to peoples' memory. People who aged 80 years or over with highest level of cereals consumption had highest odds of memory loss than other age groups (p for trend < 0.001, Supplementary Fig. 2). The interaction was also found between fruit and gender in terms of

Table 2 Changes of each food consumption across two survey points (2006–2009 and 2012–2015, $N = 139{,}096$) in New South Wales, Australia

Food groups[a]	Frequency		Coefficient (95% CI)	p for trend*
	Mean (SD)			
	Baseline	Follow-up		
Fruit				
Low	1.00 (0.02)	1.00 (0.01)	0.05 (0.04; 0.06)	< 0.001
Median	1.99 (0.06)	2.00 (0.01)		
High	3.69 (1.43)	3.86 (1.74)		
Vegetable				
Low	1.74 (0.45)	1.74 (0.44)	0.16 (0.14; 0.18)	< 0.001
Median	3.89 (0.78)	3.89 (0.78)		
High	7.83 (2.60)	8.09 (2.94)		
Cereals				
Low	3.44 (1.42)	3.38 (1.42)	− 0.18 (− 0.19; − 0.17)	< 0.001
Median	6.86 (0.35)	6.86 (0.34)		
High	11.3 (3.91)	11.2 (3.92)		
Meat and protein food alternatives				
Low	4.19 (1.80)	4.89 (1.25)	0.41 (0.39; 0.43)	< 0.001
Median	7.37 (0.48)	7.38 (1.25)		
High	11.5 (3.94)	11.4 (3.64)		
Milk and milk alternatives**	N (%)		Odds Ratio (95% CI)	
No	3079 (2.2)	3506 (2.5)	0.88 (0.84; 0.92)	< 0.001
Yes	139,424 (97.8)	138,997 (97.5)		

*Mixed linear model was used to examine the longitudinal association between each food group and survey year

**Generalized estimating equation (GEE) was used to examine the longitudinal association between milk (and milk alternatives) and survey year

[a]Fruit and vegetable consumption were based on the number of serves per day. Cereals, meat and protein food alternatives consumption were based on the number of serves per week. Milk and milk alternatives consumption were categorized into yes and no

Table 3 Longitudinal association between each food group consumption and memory loss, and comorbid heart disease and diabetes in people with memory loss across two survey points (2006–2009 and 2012–2015) in New South Wales, Australia

Food groups	Memory loss (N = 29,493)				p for trend
	Odds ratio (95% CI)				
	No consumption	Low	Medium	High	
Fruit					
Crude model	1.00	0.83 (0.80; 0.87)	0.73 (0.70; 0.77)	0.71 (0.68; 0.74)	< 0.001
Adjusted model*	1.00	0.85 (0.81; 0.89)	0.75 (0.71; 0.79)	0.72 (0.68; 0.76)	< 0.001
Vegetable					
Crude model	1.00	0.76 (0.72; 0.81)	0.64 (0.60; 0.68)	0.63 (0.59; 0.67)	< 0.001
Adjusted model*	1.00	0.84 (0.79; 0.90)	0.75 (0.70; 0.80)	0.69 (0.64; 0.74)	< 0.001
Cereals					
Crude model	1.00	0.97 (0.94; 1.00)	1.07 (104; 1.10)	1.28 (1.15; 1.43)	< 0.001
Adjusted model*	1.00	0.99 (0.95; 1.02)	0.96 (0.93; 1.00)	1.22 (1.08; 1.39)	0.15
Meat and protein food alternatives					
Crude model	1.00	0.83 (0.78; 0.88)	0.79 (0.74; 0.84)	0.81 (0.76; 0.87)	< 0.001
Adjusted model*	1.00	0.85 (0.79; 0.91)	0.80 (0.74; 0.86)	0.82 (0.76; 0.89)	< 0.001
Milk and milk alternatives					
Crude model	1.00	–	–	0.78 (0.72; 0.83)	< 0.001
Adjusted model*	1.00	–	–	0.84 (0.77; 0.91)	< 0.001
Comorbid heart disease in people with memory loss (N = 4016)					
Fruit					
Crude model	1.00	0.94 (0.85; 1.03)	0.84 (0.76; 0.93)	0.81 (0.73; 0.89)	< 0.001
Adjusted model*	1.00	0.87 (0.78; 0.98)	0.83 (0.74; 0.93)	0.79 (0.70; 0.89)	< 0.001
Vegetable					
Crude model	1.00	0.65 (0.57; 0.73)	0.51 (0.45; 0.57)	0.58 (0.51; 0.65)	< 0.001
Adjusted model*	1.00	0.87 (0.76; 1.01)	0.80 (0.70; 0.92)	0.83 (0.72; 0.96)	0.01
Cereals					
Crude model	1.00	1.03 (0.95; 1.11)	1.41 (1.31; 1.52)	1.42 (1.11; 1.82)	< 0.001
Adjusted model*	1.00	1.03 (0.94; 1.12)	0.97 (0.90; 1.06)	1.14 (0.85; 1.52)	0.40
Meat and protein food alternatives					
Crude model	1.00	0.86 (0.75; 0.99)	0.90 (0.78; 1.05)	0.91 (0.79; 1.05)	0.19
Adjusted model*	1.00	0.99 (0.83; 1.18)	1.04 (0.87; 1.23)	1.03 (0.87; 1.23)	0.17
Milk and milk alternatives					
Crude model	1.00	–	–	0.70 (0.60; 0.82)	< 0.001
Adjusted model*	1.00	–	–	0.96 (0.80; 1.16)	0.69
Comorbid diabetes in people with memory loss (N = 2419)					
Fruit					
Crude model	1.00	0.94 (0.83; 1.06)	0.92 (0.81; 1.04)	0.93 (0.82; 1.06)	0.45
Adjusted model*	1.00	1.02 (0.89; 1.18)	1.03 (0.89; 1.20)	1.04 (0.88; 1.20)	0.70
Vegetable					
Crude model	1.00	0.66 (0.57; 0.76)	0.57 (0.49; 0.66)	0.65 (0.56; 0.75)	< 0.001
Adjusted model*	1.00	0.76 (0.64; 0.90)	0.73 (0.62; 0.87)	0.76 (0.64; 0.90)	0.09
Cereals					
Crude model	1.00	0.96 (0.88; 1.05)	1.12 (1.03; 1.22)	1.14 (0.84; 1.57)	< 0.001
Adjusted model*	1.00	0.89 (0.80; 0.99)	0.94 (0.84; 1.03)	1.06 (0.74; 1.52)	0.52
Meat and protein food alternatives					
Crude model	1.00	0.80 (0.67; 0.95)	0.74 (0.63; 0.88)	0.84 (0.71; 1.00)	0.93
Adjusted model*	1.00	0.86 (0.70; 1.06)	0.80 (0.65; 0.99)	0.89 (0.72; 1.10)	0.82

Table 3 (continued)

Food groups	Memory loss (N = 29,493)				p for trend
	Odds ratio (95% CI)				
	No consumption	Low	Medium	High	
Milk and milk alternatives					
Crude model	1.00	–	–	0.74 (0.61; 0.89)	0.002
Adjusted model*	1.00	–	–	0.86 (0.69; 1.09)	0.22

*Adjusted model was after adjustment of age, sex, marital status, education level, *SEIFA* (socio-economic indexes for areas), alcohol drinking, smoking, *BMI* (body mass index) and physical activity levels

memory loss. Compared with men with no fruit consumption, women with highest level of fruit consumption had an odd of 0.81 of memory loss (95% CI 0.73; 0.90).

High consumption of fruits and vegetables was significantly negatively associated with the comorbid heart disease in people with memory loss (Table 3). After adjustment of socio-economic and health behaviour factors, compared to people who had no fruit consumption, people who consumed the highest level of fruit had an odds of 0.79 of comorbid heart disease in people with memory loss (95% CI 0.70; 0.89); compared with people who had no vegetable consumption, people who consumed the highest level of vegetables had an odds of 0.83 of comorbid heart disease in people with memory loss (95% CI 0.72; 0.96). In the adjusted model, no associations were found between other food groups and comorbid heart disease in people with memory loss ($p > 0.05$). There was the interaction between age groups and cereals in relation to heart disease in people with memory loss. People who aged 80 years and over with low consumption of cereals had the highest odds of comorbid heart disease in people with memory loss than people in other age groups (p for trend < 0.01, Supplementary Fig. 3). The interaction was also found between FV and gender in terms of comorbid heart disease in people with memory loss. Compared with men with no fruit consumption, women with highest level of fruit consumption had an odd of 0.72 of comorbid heart disease in people with memory loss (95% CI 0.56; 0.93). Compared with men with no vegetable consumption, women with highest level of vegetable consumption had an odd of 0.59 of comorbid heart disease in people with memory loss (95% CI 0.43; 0.80).

High consumption of vegetable was negatively associated with comorbid diabetes in people with memory loss in both unadjusted and adjusted model (Table 3). In adjusted model, compared with people who had no vegetable consumption, people who consumed the highest level of vegetables had an odd of 0.76 of comorbid diabetes in people with memory loss (95% CI 0.64; 0.90). There were no interactions found between food groups and age in relation to diabetes in people with memory loss ($p > 0.05$).

Post hoc supplementary analysis

Table 4 shows the longitudinal association between food groups and incidence of memory loss, and comorbid heart disease and diabetes in people with memory loss. We excluded participants with memory loss and comorbid diseases at baseline in the analysis. The results were similar to the previous analysis.

The number of incident new cases of memory loss, and of comorbid heart disease and diabetes in people with memory loss was 9853, 1297, and 457, respectively. Across two survey points, the incident risk of self-reported memory loss increased by 50%; the incident risk of self-reported comorbid heart disease in people with memory loss increased by 48%, and the incident risk of self-reported diabetes in people with memory loss increased by 23%. After adjustment of socio-economic and health behaviour factors, higher consumption of vegetables was significantly associated with lower odds of memory loss (p for trend < 0.001); higher consumption of fruit was associated with lower odds of memory loss (p for trend < 0.001), but no significant association were found between fruit and incidence of comorbid heart disease in people with memory loss ($p > 0.05$). No significant associations were found between food groups of cereals, milk and incidence of memory loss; and no significant associations were found between food groups of cereals, milk and the incidence of comorbid heart disease and diabetes in people with memory loss ($p > 0.05$).

Discussion

By using longitudinal 45 and Up Study datasets, our results show the percentage of memory status differs by socio-economic status and health behaviour factors. Our results also show the changes of dietary consumption over years, and highlight higher vegetable consumption associated with lower odds of memory loss, and comorbid heart disease in people with memory loss. However, no association

Table 4 Longitudinal association between each food group consumption and incidence of memory loss, and comorbid heart disease and diabetes in people with memory loss across two survey points (2006–2009 and 2012–2015) in New South Wales, Australia

Food groups	Incidence of memory loss (*N* = 9853)				*p* for trend
	Odds ratio (95% CI)				
	No consumption	Low	Medium	High	
Fruit					
Crude model	1.00	0.87 (0.82; 0.93)	0.76 (0.71; 0.81)	0.76 (0.71; 0.81)	< 0.001
Adjusted model*	1.00	0.86 (0.80; 0.92)	0.77 (0.71; 0.82)	0.73 (0.68; 0.79)	< 0.001
Vegetable					
Crude model	1.00	0.73 (0.67; 0.80)	0.59 (0.54; 0.64)	0.59 (0.53; 0.64)	< 0.001
Adjusted model*	1.00	0.87 (0.79; 0.97)	0.77 (0.70; 0.86)	0.72 (0.64; 0.80)	< 0.001
Cereals					
Crude model	1.00	0.94 (0.89; 0.98)	1.19 (1.14; 1.24)	1.42 (1.21; 1.66)	< 0.001
Adjusted model*	1.00	0.97 (0.92; 1.02)	1.01 (0.96; 1.06)	1.31 (1.09; 1.57)	0.12
Meat and protein food alternatives					
Crude model	1.00	0.76 (0.69; 0.83)	0.70 (0.64; 0.76)	0.75 (0.68; 0.82)	< 0.001
Adjusted model*	1.00	0.74 (0.67; 0.82)	0.69 (0.62; 0.76)	0.72 (0.65; 0.80)	< 0.001
Milk and milk alternatives					
Crude model	1.00	–	–	0.79 (0.71; 0.89)	< 0.001
Adjusted model*	1.00	–	–	0.91 (0.80; 1.04)	0.16
Incidence of comorbid heart disease in people with memory loss (*N* = 1297)					
Fruit					
Crude model	1.00	0.85 (0.72; 1.01)	0.85 (0.71; 1.01)	0.83 (0.70; 0.99)	0.19
Adjusted model*	1.00	0.81 (0.67; 0.99)	0.83 (0.69; 1.01)	0.80 (0.66; 0.98)	0.24
Vegetable					
Crude model	1.00	0.73 (0.58; 0.92)	0.55 (0.44; 0.69)	0.59 (0.46; 0.75)	< 0.001
Adjusted model*	1.00	1.20 (0.90; 1.60)	1.06 (0.79; 1.41)	1.04 (0.77; 1.40)	0.04
Cereals					
Crude model	1.00	0.97 (0.85; 1.11)	1.52 (1.35; 1.71)	1.81 (1.21; 2.71)	< 0.001
Adjusted model*	1.00	1.01 (0.86; 1.17)	1.07 (0.93; 1.22)	1.19 (0.72; 1.97)	0.22
Meat and protein food alternatives					
Crude model	1.00	0.87 (0.68; 1.11)	0.78 (0.61; 1.00)	0.82 (0.64; 1.06)	0.07
Adjusted model*	1.00	0.87 (0.66; 1.15)	0.74 (0.56; 0.99)	0.76 (0.57; 1.02)	< 0.01
Milk and milk alternatives					
Crude model	1.00	–	–	1.10 (0.78; 1.56)	0.58
Adjusted model*	1.00	–	–	1.35 (0.90; 2.02)	0.14
Incidence of comorbid diabetes in people with memory loss (*N* = 457)					
Fruit					
Crude model	1.00	0.68 (0.52; 0.88)	0.58 (0.45; 0.76)	0.68 (0.52; 0.89)	0.05
Adjusted model*	1.00	0.72 (0.54; 0.95)	0.65 (0.49; 0.87)	0.76 (0.56; 1.01)	0.34
Vegetable					
Crude model	1.00	0.68 (0.47; 0.98)	0.48 (0.33; 0.70)	0.51 (0.38; 0.75)	< 0.001
Adjusted model*	1.00	0.94 (0.62; 1.44)	0.83 (0.55; 1.27)	0.79 (0.51; 1.22)	0.05
Cereals					
Crude model	1.00	0.79 (0.65; 0.97)	0.95 (0.79; 1.14)	0.73 (0.30; 1.79)	0.84
Adjusted model*	1.00	0.91 (0.73; 1.14)	0.83 (0.67; 1.03)	0.51 (0.16; 1.60)	0.06
Meat and protein food alternatives					
Crude model	1.00	0.76 (0.51; 1.12)	0.66 (0.44; 0.98)	0.79 (0.53; 1.17)	0.66
Adjusted model*	1.00	0.70 (0.45; 1.09)	0.60 (0.39; 0.94)	0.64 (0.41; 0.99)	0.07

Table 4 (continued)

Food groups	Incidence of memory loss (N = 9853)				p for trend
	Odds ratio (95% CI)				
	No consumption	Low	Medium	High	
Milk and milk alternatives					
Crude model	1.00	–	–	0.71 (0.45; 1.14)	0.15
Adjusted model*	1.00	–	–	0.72 (0.43; 1.21)	0.22

*Adjusted model was after adjustment of age, sex, marital status, education level, *SEIFA* (socio-economic indexes for areas), alcohol drinking, smoking, *BMI* (body mass index) and physical activity levels

was found between food groups and comorbid diabetes in people with memory loss.

Our study results show that people with low education and who lived in low socio-economic area had reported lower percentage of memory loss, than those with higher education and those lived in higher socio-economic area. While there were limited studies which explored the associations between socioeconomic status and memory status, socioeconomic status and Alzheimer's disease or dementia have been examined, and the results were consistent with our study (Karp et al. 2004; Weng et al. 2018). For example, a cohort study following 931 people without dementia for 3 years showed an increased risk of Alzheimer's disease and dementia for people with a low level of education and socio-economic status (Karp et al. 2004).

In the previous literature, there were inconsistent results regarding the relationship between health behaviour factors and memory loss, cognitive change or dementia, in particular alcohol consumption (Peters et al. 2008; Sabia et al. 2014; Weng et al. 2018). Our study results show that people with drinking alcohol had a lower percentage of memory loss than those not drinking alcohol. It may be explained by the reverse causation between alcohol consumption and memory status which have been reported in the previous literature (Koch et al. 2019; Sabia et al. 2014). However, we cannot examine different levels of alcohol consumption (i.e. light, moderate or heavy drinking) in relation to memory loss because the questionnaire does not capture the detailed information. Further studies are needed in examining the relationship between alcohol consumption and memory loss, cognitive change or dementia.

Previous studies have shown comorbidities are common in people with chronic diseases and conditions (Gnädinger et al. 2018). Our results show that compared with people who had no comorbid heart disease or diabetes in people with memory loss, people with comorbid heart disease or diabetes were more likely to report memory loss. These results are supported by previous studies (Cheng et al. 2012; Haring et al. 2013). For example, in the Women's Health Initiative Memory Study, after a median follow-up time of 8.4 years, older women (aged 65–79 years) with cardiovascular diseases tended to be at increased risk for cognitive decline compared to those free of cardiovascular diseases (Haring et al. 2013). The results from a meta-analysis of longitudinal studies show that people with diabetes were more than twice as likely at risk to develop vascular dementia, than those without diabetes (Cheng et al. 2012).

Our results highlight the associations between high FV consumption and low odds of memory loss, and the comorbid heart disease in people with memory loss. Epidemiological studies support the protective effect of FV against cognitive impairment and dementia as antioxidants are rich in FV, which protect the oxidative and neuronal damage in the brain (Jiang et al. 2017). The results from a recent systematic review and meta-analysis, which includes a total of 31,104 participants and 4583 incidence cases of cognitive impairment and dementia, show that the increased consumption of FV is associated with a reduced risk of cognitive impairment and dementia (Jiang et al. 2017). The previous studies have reported the link between increased level of homocysteine associated with the risk of cognitive function (Astell-Burt et al. 2013) and heart disease (Ganguly and Alam 2015). Folate deficiency is linked with an increase in the level of homocysteine, which has direct neurotoxic effects in cell lines and animal models (Jiang et al. 2017). FV is high in folate (Kang et al. 2005), which may partly explain the inverse association between FV and memory loss, as well as the comorbid heart disease in our study. The benefit of FV has also been reported in other health outcomes; for example, the study results from ten European countries show that high FV consumption is positively associated with total life expectancy and disability-free life expectancy (Baars et al. 2019).

Our results show that higher consumption of protein-rich food (including meat and protein food alternatives, and milk and milk alternatives) was significantly associated with better memory than people with lower protein-rich food consumption. Epidemiological studies on the associations between protein-rich diet and memory or cognition were inconsistent, which has been discussed in our previous study (Xu et al. 2018). Our previous study results support that a protein-rich dietary pattern, with milk and soy milk are the most influential diet factors, prevented the cognitive decline in older people (Xu et al. 2018). Another possibility for the association in the present study may be due to fish and seafood consumption, which were included in the food group of meat and protein food alternatives. Fish plays an important role in memory loss prevention (Bakre et al. 2018). This is due to presence of anti-oxidative omega-3 fatty acids and their effects on the attenuation of cerebrovascular disease, improvement of mood-related disorders, and their support of neuronal health (Barberger-Gateau et al. 2007). However, when we examine the association between protein-rich food and comorbid heart disease and diabetes in people with memory loss, no significant associations were found. There were limited studies that have been exploring protein-rich food in relation to comorbidities in people with memory loss or dementia; therefore, further studies are needed, and the underlying mechanism needs to be further explored.

The results of this paper are consistent with previous studies that age increases the likelihood of developing memory loss (Parikh et al. 2015). Our study also highlighted the interaction between cereals and age that may affect memory loss, as well as its comorbid heart disease. Specifically, people who aged 80 years and over with low consumption of cereals had the highest risk odds of memory loss and its comorbid heart disease than people in other age groups. There is a paucity of studies exploring the interaction effect between cereals and age groups in health, while studies have indicated that people tend to make different food choices when they get older, which may affect their health status (Drewnowski and Shultz 2001). People are often encouraged to eat cereals for their health (Australian Government 2013); however, our present study implies that the healthy eating suggestions of cereals consumption in the prevention of memory loss and comorbid heart disease for older people may differ compared to other age groups. This result was consistent with our recent publication (Xu et al. 2019), which showed the associations between different type of cereals and cardiovascular diseases differed by age groups. It highlights the benefit of muesli in prevention of heart disease across all age groups, but that the association between other types of cereals (e.g. oat cereals) and cardiovascular diseases differ across age groups for older Australians (Xu et al. 2019). This implies that there is a need for age-specific healthy dietary guideline development in prevention of memory loss and its comorbidities in an older population.

The strength of the present study is that it involved a large population sample. A longitudinal study assists in making an aetiological link between food groups and memory and the comorbidities of heart disease and diabetes. However, there are some limitations. Principally, this includes the use of self-reported data, which may have bias on self-rated memory reporting. For dietary data, it does not capture all relevant food therefore we are unable to include these foods in the analysis. For example, dairy (such as yogurt) is a main resource of protein; other food groups, such as eggs and plant-based alternatives such as tofu, legumes/beans, nuts and seeds are also rich in protein, which should belong to the food group of "lean meat and protein food alternatives". Also, the questionnaire does not have information on the fat content of the pork, beef and lamb; therefore, analysis was unable to distinguish them in different food categories. Further data collection which includes detailed food consumption questionnaires is needed in this large cohort study. Although there was a space for free text which allowed participants to specify the types of heart disease, these free text data have not been released to researchers yet, which limited us to examine the association between food group and specific type of heart disease.

Conclusion

By using large longitudinal data, our results provide strong evidence of the association between food group and memory as well as comorbidities. This evidence could be used to design public health intervention programs, in particular effective diet-focused health promotion interventions in the prevention of memory loss, comorbid heart disease and diabetes in people with memory loss.

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Compliances with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval The conduct of the 45 and Up Study was approved by the University of New South Wales Human Research Ethics Committee. Analysis of the 45 and Up Study for the present paper was approved by The University of Technology Sydney (ETH18-2145).

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