British Journal of Nutrition (2021), 125, 194–202
doi:10.1017/S0007114520002287
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Foods, nutrient intakes and Mediterranean dietary pattern in midlife are not associated with reaction times: a longitudinal analysis of the UK Women's Cohort Study

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(Submitted 3 February 2020 – Final revision received 17 June 2020 – Accepted 19 June 2020 – First published online 29 June 2020)

Abstract

Associations between dietary factors and general cognition in the elderly have been documented; however, little is known about reaction time ability in relation to midlife diet. The present study aimed to investigate associations between reaction time and midlife dietary factors, specifically foods, nutrients and Mediterranean diet (MeDi) pattern. The UK Women's Cohort Study collected dietary information from middle-aged women (52 (SD 9·4) years old) using a validated 217-item FFQ in 1995–1998. In 2010–2011, a sub-group of 664 participants completed online reaction time ability tests including simple reaction time (SRT) and choice reaction time; 503 participants were eligible for analysis. Participants were grouped into fast and slow groups by their median reaction time. The intake of particular foods, nutrients, adherence to the MeDi and cooking methods (roasting/baking, frying and barbecuing/grilling) were explored in relation to reaction times. We did not find any significant associations between reaction times and investigated foods, nutrients or adherence to the MeDi in adjusted models. However, consumers of roasted/baked fish and fried vegetables were associated with slower SRT (adjusted OR 1·46, 95 % CI 1·00, 2·13, $P = 0·049$; and adjusted OR 1·64, 95 % CI 1·12, 2·39, $P = 0·010$, respectively) compared with non-consumers of that particularly cooked food. Overall, our findings show no significant associations between midlife diet and reaction time ability 10–15 years later.

Key words: Mediterranean diet: Cooking methods: Cognition: Simple reaction time: Choice reaction time

The global population aged 60 years and over is projected to reach 2 billion by 2050 which will be around 22 % of the people in the world[1]. Brain ageing is associated with a decline in several cognitive functions, including memory, attention, speed of processing and executive function[2], changes that may result in mild incapacity even prior to the onset of dementia[3]. The speed of processing is an important domain of cognitive function and can be assessed by reaction time. Researchers have proposed that the speed of processing might be a fundamental component of individual differences in relation to cognitive ageing[4]. Some studies have suggested that diet, a modifiable lifestyle factor, may play a key role in cognitive ageing[5]; however, current evidence about associations of foods as well as their cooking methods, nutrient intakes and dietary patterns with processing speed is limited.

Nutrients may influence the loss of cognitive function with ageing[6]. Neuroprotective effects of PUFA and several vitamins, especially antioxidant vitamins (including vitamin E), are supported by cell and animal experiments *in vitro* and *in vivo*, observational studies and randomised control trials[7–9]. However, several clinical trials do not support the positive effects across all cognitive function measures[10–12]. A systematic review and meta-analysis of supplementation trials with *n*-3 PUFA from infancy to old age showed that beneficial effects on cognition might happen only in infants but not in children, adults or the elderly[13], indicating that effects of nutrients on cognitive function may vary by age groups.

Cooking methods play an important role in dietary intake by modifying taste, palatability and nutrient composition of foods during the cooking process. For example, frying can reduce unsaturated fatty acids and antioxidant vitamins due to oxidation, but has little impact on protein and mineral content, whereas dietary fibre of potatoes can be increased by frying because of the formation of resistant starch[14]. Cooking can also influence fat content and fatty acid composition in meat. Gerber *et al*. showed considerable fat loss in several meat cuts cooked by grilling, broiling or pan-frying without fat being added, which affected the PUFA:SFA ratio[15]. In addition, some hazardous compounds can be produced as a by-product

Abbreviations: CRT, choice reaction time; MeDi, Mediterranean diet; SRT, simple reaction time.

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https://doi.org/10.1017/S0007114520002287 Published online by Cambridge University Press

https://doi.org/10.1017/S0007114520002287 Published online by Cambridge University Press

during the cooking process. When high-protein containing food such as meat and fish is heated to high temperatures, polycyclic aromatic hydrocarbons can be produced, particularly benzo[*a*]pyrene[16]. A cross-sectional study showed a 1 % increase of urinary 1-hydroxypyrene (a biomarker of polycyclic aromatic hydrocarbons) resulted in about 2 % poorer performance on cognitive function in individuals aged 60 years and older[17]. With regard to carbohydrate-rich food heated to high temperatures, acrylamide can be produced, a known neurotoxin and carcinogen[18]. Currently, evidence regarding effects of acrylamide on cognitive function is limited, but a study among non-smoking elderly Chinese men found that dietary acrylamide exposure was associated with mild cognitive decline[19]. Both loss of nutrients and production of hazardous compounds can vary by cooking method, and at present, very little information exists regarding the possible influence of cooking methods on cognitive function.

In relation to dietary patterns, accumulating studies suggest that higher adherence to the Mediterranean diet (MeDi) may be associated with better cognitive performance[20,21]. Nevertheless, a recent systematic review suggested that there was a high level of heterogeneity among thirty-two articles studying associations between adherence to the MeDi, cognitive function and dementia, with almost half reporting that the MeDi was not associated with cognitive function or dementia[22], indicating that the protective effect of the MeDi on cognitive function remains inconsistent.

This longitudinal observational study aimed to investigate associations between midlife dietary factors, specifically foods, nutrients and MeDi pattern, with reaction time ability 10–15 years later. Potential associations between cooking methods and reaction time ability were also explored. In the present study, consumption of unsaturated fatty acids and fish, vitamins and vegetables, as well as adherence to the MeDi was hypothesised to be positively associated with reaction time ability, whereas consumption of SFA and meat was assumed to be negatively linked to reaction time ability.

Methods

Study design and participants

The UK Women's Cohort Study[23] was initiated in 1995 to explore potential associations between diet and chronic disease and recruited 35 372 women aged 52 (SD 9·4) years (1995–1998). At recruitment, the baseline survey collected FFQ, lifestyle as well as demographic and anthropometric information.

Sample size to investigate the impact of diet on reaction ability in the UK Women's Cohort Study was estimated using the mean choice reaction time (CRT). A sample size of 530 women was computed from the estimation of the mean CRT using comparison of one mean to a reference value with the two-sided significance level of 0·05, marginal error of 15 ms and power of 0·8. This estimation was calculated using a reference mean CRT of 628 (SD 123) ms from a British study in which simple reaction time (SRT) and CRT were tested using the Deary–Liewald reaction time task for residents aged between 61 and 80 years in the City of Edinburgh[24]. There were no previous studies of diet and reaction time on which to base a sample size calculation.

In 2010/2011, a subset of 664 women was involved in our pre-designed online reaction time tests. Among them, 510 women had complete dietary records and cognitive testing results. Exclusion criteria were applied among individuals with unlikely fast reaction times (SRT < 200 ms; CRT < 250 ms) prior to analyses as these were likely to represent accidental screen presses which were adapted from previous studies[25]. We excluded participants if their reported energy intake was outside 1 % of the population distribution (<2 MJ/d (<500 kcal/d) and >25 MJ/d (>6000 kcal/d)) following previous studies[26]. We also excluded participants with stroke history because stroke could significantly impair cognitive function including the reaction time ability[27].

Ethical approval was granted from National Research Ethics Service Committee for Yorkshire & the Humber – Leeds East (reference 15/YH/0027) at the cohort's initiation in 1993, now covered by Health Research Authority REC reference: 17/YH/0144.

Reaction ability tests

The web-based cognitive measurement tasks (www.uk-wcs.co.uk) test participants' reaction ability including SRT and CRT described previously[24,28]. The SRT task required participants to respond to a letter 'Y' appearing on a screen by pressing the 'Y' key on the keyboard as soon as it appeared for twenty trials. The CRT task required participants to respond to one of four numbers (5, 6, 7 or 8) appearing randomly on a screen by pressing the corresponding number on the keyboard as soon as it appeared for forty trials. The mean values of reaction times were analysed as the outcome to reflect participants' cognitive ability. Each reaction time was grouped into two categories according to their median values, where the slow group was defined as less than the median and the fast group equal to or above the median. The median was used here to reduce the impact of outliers and skewed data.

Dietary measurement

Dietary information at baseline was obtained from self-administered FFQ with 217 British food items, which was based on the FFQ used in the UK for the European Prospective Investigation into Cancer and Nutrition study[29]. The baseline FFQ was compared against 4-d weighed food diaries and a second FFQ collected at the same time as the diary, on 283 women 3 years after baseline. Whilst accepting that each tool type is measuring different aspects of diet, correlations between the two dietary assessment methods were comparable to those found in other studies; for example, the correlation coefficients between the FFQ and the 4-d weighed food diaries were 0·39 for carbohydrate, 0·35 for fat, 0·43 for Ca and 0·62 for vitamin C[30,31]. Classification of food groups and derivation of nutrient intakes were detailed in previous studies[32,33]. Nutrients provided by supplements were not included in the nutritional analysis. The cooking methods of several common foods, including meat, fish, vegetables and potatoes, have been investigated by asking 'How often do you eat foods cooked by the following

British Journal of Nutrition

https://doi.org/10.1017/S0007114520002287 Published online by Cambridge University Press

methods?' The specific cooking methods included roasting/baking, frying and barbecuing/grilling, and the consumption frequencies ranged from never to more than once a day containing eight categories. Participants with the frequencies of never and less than once a month were treated as non-consumers of specific cooked food item, while others with the frequencies of once a month or more were considered as consumers of that food item. The consumption frequency of each cooking method was treated as a dichotomous variable: non-consumers and consumers. This was included in the regression models with non-consumers as the reference group.

To quantify adherence to the MeDi, a variable of MeDi score was created based on the 217-item FFQ. The MeDi score was derived from a modified ten-point version of the MeDi[34,35] covering ten food/nutrient components consumed in g/d. Of the ten components, six traditionally consumed in the MeDi (vegetables, legumes, fruits and nuts, cereals, fish and fatty acid ratio of MUFA plus PUFA to SFA, namely, MUFA + PUFA: SFA) considered beneficial were assigned 1 if consumed at or above the median. Another three foods (meat, poultry and dairy products) considered detrimental were given a score of 1 for consumption below the median. For alcohol, a score of 1 was given to women who had intakes of between 5 and 25 g/d. Details are given in online Supplementary Table S1. Thus, the total MeDi score ranges from a minimal adherence score of 0 to a maximal adherence score of 10, with higher scores indicating greater dietary adherence. Further the total MeDi score was divided into three groups: scores 0–3 (low adherence), 4–6 (moderate adherence) and 7–10 (high adherence).

Covariate assessment

Baseline socio-demographic information, such as age, ethnicity, educational level, marital status, was undertaken by self-report. BMI was calculated from self-reported height and weight by formula of 'weight/height^2 (kg/m^2)'. Sleep duration (h/d) was the weighted mean value calculated from self-reported sleep durations of weekdays and weekends. Socio-economic status was derived from the UK National Statistics-Socio-Economic Classification, where participants are classified into three categories (routine/manual, intermediate or managerial/professional)[36]. Due to overlapping properties among socio-economic indicators (education, social class, income or employment)[37], only socio-economic status was used as the adjustment factor in the present study. Physical activity was assessed as self-reported time spent on activities vigorous enough to cause sweating or a faster heartbeat (h/d).

A directed acyclic graph was constructed using the online DAGitty tool (http://www.dagitty.net) to determine the minimally sufficient set of confounding adjustments for the exposure–outcome relationship[38]. Potential confounding variables including age, ethnicity (white, Asian, African and others), socio-economic status, BMI, physical activity, sleep duration, smoking status (current, former and non-smoker), alcohol consumption (g/d) and marital status (married or living as married, separated or divorced, single or widowed) were considered in the directed acyclic graph. Actual or likely relationships between variables were based on *a priori* knowledge from the literature, and the minimally sufficient adjustment set was age, ethnicity, marital status, physical activity, socio-economic status, sleep duration, BMI, smoking status and alcohol consumption (online Supplementary Fig. S1).

Statistical analysis

Characteristics such as demographics and dietary consumption were summarised. For continuous variables, means and standard deviations are displayed with Student's *t* test for difference, while categorical variable characteristics are presented as percentages with the χ^2 test for difference. Nutrient intakes were adjusted for total energy using the nutrient density method[39] (for protein, carbohydrates and fat, the percentage of total energy derived from each one; for other nutrients, the ratio of selected nutrient intake to per 1000 kcal (4186 kJ) of total energy intake). Each energy-adjusted intake of foods and nutrients was entered in a multiple logistic regression model with total energy intake as a covariate using the multivariate nutrient density method recommended by Willett[39]. Due to skewed distributions, the two reaction time variables were dichotomously categorised taking the median values as cut points; the fast groups (reaction time less than the median) were treated as the reference group, while the slow groups (reaction time equal to or above the median) were treated as the case group. Logistic regression models were conducted to identify potential associations between dietary intake, cooking methods and reaction ability. All analyses were conducted using Stata version 16.1 (StataCorp LLC). Values of $P < 0.05$ were considered to be statistically significant.

Results

Of 510 women with complete records, one participant with an unlikely fast CRT (64 ms), two individuals with extremely high

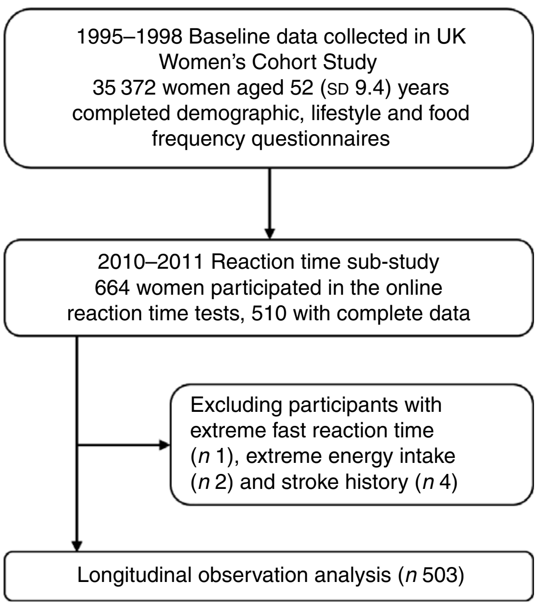

Fig. 1. Flow chart of reaction time study data collection and exclusion criteria.

https://doi.org/10.1017/S0007114520002287 Published online by Cambridge University Press

Table 1. Demographic characteristics of participants between fast groups and slow groups for simple and choice reaction times
(Mean values and standard deviations; percentages)

	Simple reaction time			Choice reaction time			
	Fast group (*n* 252)	Slow group (*n* 251)		Fast group (*n* 252)	Slow group (*n* 251)		Total (*n* 503)
	%	%	*P*	%	%	*P*	%
Age (years)							
Mean	61	64	<0·001	61	64	<0·001	62
SD	5·9	7·1		5·7	7·2		6·6
Ethnicity							
White	98·4	96·4	0·114	98·4	96·4	0·200	97·4
Asian	0·4	0·0		0·0	0·4		0·2
Other	1·2	3·6		1·6	3·2		2·4
Educational level							
No qualifications	2·8	9·9	0·009	3·2	9·6	0·023	6·3
O-level or equivalent	30·6	28·6		29·2	29·9		29·6
A-level or equivalent	26·6	27·0		26·9	26·7		26·8
University degree	40·0	34·5		40·7	33·9		37·3
Marital status							
Married or living as married	85·7	81·0	0·341	87·0	79·7	0·083	83·3
Separated or divorced	6·0	8·3		5·1	9·2		7·1
Single or widowed	8·3	10·7		7·9	11·2		9·5
Socio-economic status							
Routine and manual	4·4	4·4	0·109	4·0	4·8	0·876	4·4
Intermediate	17·4	25·0		21·7	20·7		21·2
Professional and managerial	78·2	70·6		74·3	74·5		74·4
Daily exercise (h)							
Mean	0·24	0·27	0·386	0·23	0·28	0·153	0·25
SD	0·4	0·4		0·3	0·5		0·4
BMI (kg/m^2)							
Mean	23·5	23·5	0·976	23·5	23·6	0·777	23·5
SD	3·8	3·3		3·6	3·6		3·6
Sleep duration (h)							
Mean	7·6	7·6	0·535	7·7	7·5	0·070	7·6
SD	0·9	0·9		0·9	0·9		0·9
Smoking status							
Never	68·6	66·3	0·817	66·4	68·5	0·708	67·5
Former	26·2	28·6		28·9	25·9		27·4
Current	5·2	5·1		4·7	5·6		5·1
Alcohol							
Once a month or less	20·6	19·9	0·843	16·2	24·3	0·043	20·2
Less than daily	60·7	59·5		61·3	59·0		60·1
Once a day or more	18·7	20·6		22·5	16·7		19·7

energy intake (26 MJ/d (6293 kcal/d), and 33 MJ/d (7780 kcal/d)) and four participants with self-reported stroke history were excluded. Therefore, 503 women were considered eligible for analysis (Fig. 1).

The characteristics of women who participated in the reaction time sub-study are summarised in Table 1. Participants who took part in reaction time tests had a mean age of 62 (SD 6·6) years. SRT and CRT were categorised into the 'fast group' and the 'slow group'. Women in slow groups were significantly older and had lower educational levels than women in fast groups (64 *v*. 61 years old for both SRT and CRT; 35 *v*. 40 % university degree for SRT; 34 *v*. 41 % university degree for CRT). Among the women, 97 % were white, 83 % were married or living as married, 74 % had a higher level of social economic status (professional or managerial) and 67 % were non-smokers. The participants had a mean BMI of 23·5 kg/m^2, a mean sleep duration of 7·6 h/d and 0·25 h/d of vigorous activities. With regard to alcohol consumption, 60 % of the women drank less than once a day but more than once a month, while 20 % consumed alcohol once a day or more and for the remaining 20 % consumption was once a month or less.

There was no significant difference in daily consumption of energy-adjusted total meat, total fish, vegetables and total energy intake, as well as energy-adjusted nutrients intake between fast groups and slow groups for both SRT and CRT (Table 2). In addition, multivariate logistic regressions showed that associations between these dietary exposures and reaction times were not statistically significant (Table 3).

As shown in Table 4, consumers of roasted/baked fish were 46 % more likely to be in the slow SRT group (adjusted OR 1·46, 95 % CI 1·00, 2·13). Consumers of fried vegetables were 64 % more likely to be in the slow SRT group (adjusted OR 1·64, 95 % CI 1·12, 2·39) with adjustment for confounding factors. However, the consumption of fish or vegetables cooked by any of these three methods did not change the risk of being in slow CRT groups. In addition, neither meat nor potato

Table 2. Profiles of main foods and nutrient intakes comparing women with fast and slow reaction times
(Mean values and standard deviations; differences and 95 % confidence intervals)

	Simple reaction time							Choice reaction time								
	Fast group (*n* 252)		Slow group (*n* 251)					Fast group (*n* 252)		Slow group (*n* 251)					Total (*n* 503)	
	Mean	SD	Mean	SD	Difference	95 % CI	*P*	Mean	SD	Mean	SD	Difference	95 % CI	*P*	Mean	SD
Main foods																
Total meat (g/d)	57	67	58	58	−0·5	−11, 10	0·933	60	64	55	60	5	−6, 16	0·354	58	62
Total fish (g/d)	23	23	25	21	−2	−6, 2	0·272	25	23	23	22	2	−2, 6	0·357	24	22
Vegetables (g/d)	307	169	312	159	−5,	−34, 24	0·724	310	164	309	164	1	−27, 30	0·923	310	164
Nutrient intakes																
Energy intake (kcal/d)	2326	614	2343	676	−17	−130, 96	0·770	2375	601	2293	685	82	−31, 195	0·154	2334	645
Energy intake (MJ/d)	10	3	10	3	0	−0·5, 0·5	0·770	10	3	10	3	0	−0, 1	0·154	10	3
Protein (g/d)	86	27	88	26	−2	−6, 3	0·446	89	25	85	27	3	−1, 8	0·174	87	26
Protein (% energy)	15	3	15	3	−0·3	−0·8, 0·1	0·175	15	3	15	3	0	−0·5, 0·5	0·981	15	3
Carbohydrate (g/d)	311	93	309	99	3	−14, 19	0·759	314	88	306	103	7	−9, 24	0·380	310	96
Carbohydrate (% energy)	54	7	53	7	1	−0·4, 2	0·183	53	7	53	7	−0·2	−2, 1	0·703	53	7
Fat (g/d)	84	29	87	31	−2	−8, 3	0·391	88	30	83	30	4	−1, 10	0·104	85	30
Fat (% energy)	32	6	33	6	−1	−2, 0·5	0·258	33	6	33	6	0·2	−1, 1	0·740	33	6
SFA (g/d)	29	13	30	13	−1	−3, 1	0·476	30	13	29	13	1	−1, 3	0·330	30	13
SFA (% energy)	11	3	11	3	−0·2	−1, 0·4	0·451	11	3	11	3	−0·1	−1, 1	0·853	11	3
PUFA (g/d)	16	6	17	6	−0·3	−1, 1	0·556	17	6	16	6	1	0, 2	0·029	16	6
PUFA (% energy)	6	2	6	2	−0·1	−0·4, 0·2	0·514	6	2	6	2	0·1	−0·2, 0·5	0·357	6	2
MUFAs (g/d)	28	10	28	11	−1	−2, 1	0·463	29	10	27	10	2	−0·2, 3	0·081	28	10
MUFAs (% energy)	11	3	11	2	−0·2	−1, 0·3	0·509	11	2	11	3	0·1	−0·4, 0·5	0·711	11	3
Vitamin C (mg/1000 kcal)	74	33	73	32	1	−5, 6	0·822	72	32	75	33	−3	−9, 2	0·254	73	33
Vitamin B_1 (μg/1000 kcal)	1281	810	1228	634	53	−74, 180	0·414	1294	842	1215	588	79	−48, 206	0·224	1255	727
Vitamin B_2 (μg/1000 kcal)	1075	289	1100	254	−25	−72, 23	0·314	1086	275	1088	271	−3	−50, 45	0·918	1087	273
Vitamin B_6 (μg/1000 kcal)	1176	264	1171	223	4	−38, 47	0·839	1172	254	1175	235	−4	−46, 39	0·871	1173	244
Vitamin B_{12} (μg/1000 kcal)	2	1	2	1	−0·1	−0·3, 0·1	0·154	2	1	2	1	0	−0·2, 0·2	0·908	2	1
Folate (μg/1000 kcal)	170	39	172	40	−2	−9, 5	0·608	169	41	172	37	−3	−10, 4	0·366	171	39
Vitamin A (μg/1000 kcal)	392	179	416	188	−23	−55, 9	0·156	392	178	416	189	−24	−56, 8	0·146	404	184
Vitamin D (μg/1000 kcal)	1	1	1	1	0	−0·1, 0·1	0·763	1	1	1	1	0·1	−0·1, 0·2	0·351	1	1
Vitamin E (μg/1000 kcal)	4135	1380	4287	1266	−152	−384, 80	0·199	4249	1244	4173	1403	77	−156, 309	0·517	4211	1325
Ca (mg/1000 kcal)	486	116	505	131	−20	−41, 2	0·074	488	114	503	132	−14	−36, 7	0·196	496	124
Fe (mg/1000 kcal)	8	3	8	2	0·3	−0·2, 1	0·238	8	2	8	2	−0·1	−1, 0·3	0·605	8	2
Zn (mg/1000 kcal)	5	1	5	1	−0·1	−0·2, 0·1	0·494	5	1	5	1	0	−0·2, 0·2	0·856	5	1

https://doi.org/10.1017/S0007114520002287 Published online by Cambridge University Press

https://doi.org/10.1017/S0007114520002287 Published online by Cambridge University Press

British Journal of Nutrition

Table 3. Associations of main foods and energy-adjusted nutrient intakes with reaction times
(Odds ratios and 95 % confidence intervals)

	Simple reaction time					Choice reaction time				
	Unadjusted		Adjusted*			Unadjusted		Adjusted*		
	OR	95 % CI	OR	95 % CI	*P**	OR	95 % CI	OR	95 % CI	*P**
Main foods										
Total meat (per g/1000 kcal)	1·00	0·93, 1·07	0·98	0·91, 1·06	0·634	0·98	0·91, 1·05	0·99	0·91, 1·07	0·746
Total fish (per g/1000 kcal)	1·15	0·95, 1·38	1·11	0·91, 1·34	0·306	0·99	0·82, 1·19	0·96	0·79, 1·17	0·685
Vegetables (per g/1000 kcal)	1·01	0·99, 1·04	1·01	0·98, 1·04	0·458	1·01	0·99, 1·04	1·00	0·98, 1·03	0·742
Nutrient consumption										
Energy intake (per 1000 kcal)	1·04	0·79, 1·37	1·10	0·83, 1·47	0·501	0·82	0·62, 1·08	0·87	0·65, 1·17	0·360
Protein (per % energy)	1·05	0·98, 1·12	1·04	0·97, 1·12	0·276	1·00	0·94, 1·07	0·99	0·92, 1·06	0·770
Carbohydrate (per % energy)	0·98	0·96, 1·01	0·98	0·95, 1·01	0·130	1·00	0·98, 1·03	1·00	0·97, 1·03	0·801
Fat (per % energy)	1·02	0·99, 1·05	1·02	0·99, 1·05	0·217	1·00	0·97, 1·02	1·01	0·98, 1·04	0·690
SFA (per % energy)	1·02	0·97, 1·08	1·02	0·97, 1·08	0·428	1·01	0·95, 1·06	1·03	0·97, 1·09	0·305
PUFA (per % energy)	1·03	0·94, 1·14	1·05	0·95, 1·16	0·374	0·95	0·87, 1·05	0·96	0·87, 1·06	0·443
MUFA (per % energy)	1·02	0·96, 1·10	1·03	0·96, 1·11	0·430	0·99	0·92, 1·06	1·01	0·94, 1·08	0·807
Vitamin C (per mg/1000 kcal)	1·00	0·99, 1·00	1·00	0·99, 1·00	0·741	1·00	1·00, 1·01	1·00	0·99, 1·01	0·842
Vitamin B_1 (per μg/1000 kcal)	1·00	1·00, 1·00	1·00	1·00, 1·00	0·819	1·00	1·00, 1·00	1·00	1·00, 1·00	0·300
Vitamin B_2 (per μg/1000 kcal)	1·00	1·00, 1·00	1·00	1·00, 1·00	0·294	1·00	1·00, 1·00	1·00	1·00, 1·00	0·773
Vitamin B_6 (per μg/1000 kcal)	1·00	1·00, 1·00	1·00	1·00, 1·00	0·845	1·00	1·00, 1·00	1·00	1·00, 1·00	0·549
Vitamin B_{12} (per μg/1000 kcal)	1·12	0·96, 1·31	1·09	0·92, 1·30	0·304	0·99	0·85, 1·16	0·97	0·82, 1·15	0·728
Folate (per μg/1000 kcal)	1·00	1·00, 1·01	1·00	1·00, 1·01	0·460	1·00	1·00, 1·01	1·00	1·00, 1·01	0·826
Vitamin A (per μg/1000 kcal)	1·00	1·00, 1·00	1·00	1·00, 1·00	0·308	1·00	1·00, 1·00	1·00	1·00, 1·00	0·398
Vitamin D (per μg/1000 kcal)	1·04	0·79, 1·37	0·97	0·73, 1·29	0·832	0·88	0·67, 1·15	0·86	0·64, 1·15	0·310
Vitamin E (per μg/1000 kcal)	1·00	1·00, 1·00	1·00	1·00, 1·00	0169	1·00	1·00, 1·00	1·00	1·00, 1·00	0·401
Ca (per mg/1000 kcal)	1·00	1·00, 1·00	1·00	1·00, 1·00	0·111	1·00	1·00, 1·00	1·00	1·00, 1·00	0·489
Fe (per mg/1000 kcal)	0·96	0·89, 1·03	0·95	0·88, 1·03	0·225	1·02	0·95, 1·10	1·00	0·93, 1·08	0·966
Zn (per mg/1000 kcal)	1·07	0·89,1·28	1·02	0·84, 1·23	0·876	1·02	0·85, 1·22	0·96	0·79, 1·17	0·693

* Adjusted for age, ethnicity, marital status, socio-economic status, physical activity, BMI, sleep duration, smoking status, alcohol consumption and total energy intake.

Table 4. Comparison of reaction times between consumers and non-consumers of specific foods cooked by roasting/baking, frying and barbecuing/grilling
(Odds ratios and 95 % confidence intervals)

			Simple reaction time					Choice reaction time				
			Unadjusted		Adjusted*			Unadjusted		Adjusted*		
	No. of consumers	No. of non-consumers	OR	95 % CI	OR	95 % CI	*P**	OR	95 % CI	OR	95 % CI	*P**
Roasted/baked meat	292	211	1·11	0·78, 1·59	1·05	0·68, 1·61	0·824	0·89	0·62, 1·26	0·89	0·57, 1·37	0·586
Fried meat	123	380	1·22	0·81, 1·83	1·11	0·71, 1·74	0·637	0·94	0·63, 1·42	0·91	0·58, 1·42	0·669
Barbecued/grilled meat	273	230	0·99	0·70, 1·41	0·95	0·63, 1·45	0·819	1·03	0·72, 1·46	1·13	0·74, 1·73	0·570
Roasted/baked fish	271	232	1·51	1·06, 2·14	1·46	1·00, 2·13	0·049	1·06	0·75, 1·50	0·99	0·68, 1·45	0·953
Fried fish	144	359	1·27	0·86, 1·87	1·12	0·75, 1·69	0·579	0·93	0·63, 1·37	0·85	0·56, 1·29	0·451
Barbecued/grilled fish	239	264	1·28	0·90, 1·82	1·35	0·93, 1·96	0·118	0·93	0·66, 1·32	0·97	0·66, 1·41	0·863
Roasted/baked vegetables	338	165	1·21	0·84, 1·76	1·29	0·87, 1·93	0·205	1·17	0·81, 1·70	1·27	0·85, 1·91	0·240
Fried vegetables	206	297	1·55	1·08, 2·21	1·64	1·12, 2·39	0·010	0·88	0·62, 1·26	0·95	0·65, 1·38	0·787
Barbecued/grilled vegetables	216	287	0·88	0·62, 1·26	0·92	0·63, 1·35	0·680	0·83	0·58, 1·18	0·88	0·60, 1·29	0·505
Roasted/baked potatoes	444	59	0·76	0·44, 1·31	0·87	0·48, 1·57	0·635	1·03	0·60, 1·78	1·37	0·74, 2·51	0·312
Fried potatoes	219	284	1·16	0·82, 1·66	1·16	0·79, 1·69	0·445	0·74	0·52, 1·05	0·76	0·52, 1·11	0·150
Barbecued/grilled potatoes	67	436	1·19	0·71, 2·00	1·21	0·70, 2·08	0·494	1·19	0·71, 2·00	1·18	0·68, 2·04	0·560

* Adjusted for age, ethnicity, marital status, socio-economic status, physical activity, BMI, sleep duration, smoking status, alcohol consumption and total energy intake.

consumption cooked by any of these three methods changed the likelihood of being in slow groups for both SRT and CRT.

Adherence to MeDi and its association with reaction ability is summarised in Table 5. Most women included in this analysis had moderate adherence to the MeDi (53 %), and the percentages of adherence among fast groups and slow groups for SRT and CRT were similar. Logistic regression results showed that SRT or CRT was not associated with adherence to the MeDi both in unadjusted and adjusted models.

Discussion

The prevalence of dementia in the general population aged 60 years and over is 5–8 %, and this figure is expected to rise in coming decades[40]. There is an emerging awareness that women may disproportionately bear the burden of dementia almost globally compared with men[41]. Age is a strong risk factor for dementia and cognitive decline, and the average life expectancy worldwide is greater for women than men which

Table 5. Adherence to the Mediterranean diet and its associations with reaction times
(Numbers and percentages; odds ratios and 95 % confidence intervals)

	Mediterranean diet							
	Low adherence		Moderate adherence		High adherence		Total	
	n	%	*n*	%	*n*	%	*n*	%
No. of participants	117	23·2	265	52·7	121	24·1	503	100
Simple reaction time								
Fast group	60	23·8	126	50·0	66	26·2	252	100
Slow group	57	22·7	139	55·4	55	21·9	251	100
Choice reaction time								
Fast group	54	21·4	138	54·8	60	23·8	252	100
Slow group	63	25·1	127	50·6	61	24·3	251	100
			OR	95 % CI	OR	95 % CI	*P* trend†	
OR (slow group *v.* fast group)								
Simple reaction time								
Unadjusted	Ref.		1·16	0·75, 1·79	0·88	0·53, 1·46	0·944	
Adjusted*	Ref.		1·34	0·83, 2·17	0·94	0·52, 1·70	0·222	
Choice reaction time								
Unadjusted	Ref.		0·79	0·51, 1·22	0·87	0·52, 1·45	0·724	
Adjusted*	Ref.		0·83	0·51, 1·35	0·83	0·45, 1·51	0·739	

Ref., reference.
* Adjusted age, ethnicity, marital status, socio-economic status, physical activity, BMI, sleep duration, smoking status, alcohol consumption and total energy intake.
† Tests for linear trend of adherence to the Mediterranean diet in relation to reaction times.

makes dementia an important concern for women[42]. There are also sex-specific biological mechanisms that could possibly result in increased susceptibility of women to Alzheimer's dementia[43]. The present longitudinal observational analysis was conducted in a female-only cohort study, allowing exploration of dietary exposures and subsequent reaction ability in women for the first time.

Our results showed that consumption of meat, fish, vegetables and nutrient intakes in middle-aged women were not associated with reaction ability 10–15 years later. Compared with low adherence to the MeDi, moderate and high adherence did not influence the risk of being in the slow reaction time groups. A similar longitudinal observational analysis, however, suggested that adherence to the MeDi assessed 22 years previously was positively associated with cognitive function in the Health Professionals Follow-up Study, a prospective cohort study initiated in 1986 among 51 529 US men aged 40–75 years[44]. Although some evidence shows that there is a protective effect of the MeDi against cognitive decline, most studies focus on memory and attention which tends to be assessed by the mini-mental state examination[45,46]. Few studies have been done on the associations between the MeDi and reaction time ability. A cross-sectional study involving ninety-three participants in Australia showed that the MeDi score did not differ significantly between the faster reaction time group and the slower reaction time group[47], consistent with our results.

Although in this study cooking methods of meat did not show effects on reaction times, the roasted/baked fish appeared to increase the risk of having a slow SRT with adjustment for confounding factors. However, since both non-consumers and consumers of roasted/baked fish were likely meddled with those who may also have selected different cooking methods for fish, confounding bias might have occurred with this association and some caution should be exercised when interpreting these significant results. Oily fish is high in unsaturated fatty acids which could be reduced during the long-lasting and high-temperature cooking process required for roasting/baking. Unsaturated fatty acids such as *n*-3 fatty acids are associated with better global cognition[9]. Therefore, oxidation of unsaturated fatty acids could be the potential reason that roasted/baked fish increased the risk of having a slow SRT. In addition, fried vegetables were also associated with a slower SRT. This could be due to acrylamide produced in carbohydrate-rich food during frying, another high-temperature cooking process[18,19]. However, fried potatoes, a carbohydrate-rich food, did not show a similar negative association with reaction times. Potential mechanisms why only roasted/baked fish and fried vegetables had detrimental effects on SRT are unclear and similar studies are limited; more evidence needs be provided from other populations including cooking methods.

Strengths of this study include its novelty to explore effects of cooking methods on cognitive function, the longitudinal design and a fully adjusted regression model. The exploration of frequencies of cooking methods is novel in relation to health-related outcomes and has not been conducted in other studies to date. There is a possibility that these frequencies might be under- or over-reported. These potential measurement errors could reduce the power to detect real associations between dietary exposures and reaction ability; therefore, results should be interpreted with caution. Moreover, as an observational study, causality cannot be established, and potential confounding bias is always a possibility.

Our study is also limited that we did not include any assessment of nutritional supplement use resulting in underestimation of nutrient intakes; we have also not taken into account other diet quality indices apart from the MeDi in our analyses. It may be that combinations of nutrients and foods are more comprehensive than individual nutrients in relation to

British Journal of Nutrition

https://doi.org/10.1017/S0007114520002287 Published online by Cambridge University Press

https://doi.org/10.1017/S0007114520002287 Published online by Cambridge University Press

reaction times. In addition, most studies on the prevalence of dementia focus on people aged over 65 years; for those aged 45–64 years, the prevalence is relatively low at 98 per 100 000[48]. The mean age of women who took part in the reaction time tests may be not old enough to show changes of reaction ability.

Overall, our study indicates no associations between reaction ability and consumption of total meat, fish, vegetables, energy-adjusted nutrient intakes and MeDi . However, there was a suggestion that foods cooked by specific methods may be related to reaction ability. This needs further exploration in additional studies.

Acknowledgements

The authors thank the participants of the UK Women's Cohort Study for the provision of the data, the cohort team members who contributed to data collection, Mr Gareth Hagger-Johnson for carrying out reaction time tests and Mr Neil Hancock for his contributions to data management and technical assistance for the cohort.

H. Z. received funding from the China Council Scholarship (CSC ID: 201806010423). The UK Women's Cohort was supported by funding from the World Cancer Research Fund (to J. C.). The funders of CSC and the World Cancer Research Fund had no role in the design, analysis or writing of this article.

The authors declare that this work had no commercial or not-for-profit sectors involved.

All authors were involved in the study conception and design. H. Z. contributed to the data analysis and wrote the manuscript. All authors interpreted the findings, and edited and approved the final manuscript.

The authors declare that there are no conflicts of interest.

Supplementary material

For supplementary material referred to in this article, please visit https://doi.org/10.1017/S0007114520002287

References

1. World Health Organization (2018) Key facts of ageing and health. https://www.who.int/news-room/fact-sheets/detail/ageing-and-health (accessed October 2019).
2. Harada CN, Natelson Love MC & Triebel KL (2013) Normal cognitive aging. *Clin Geriatr Med* **29**, 737–752.
3. Phillips C (2017) Lifestyle modulators of neuroplasticity: how physical activity, mental engagement, and diet promote cognitive health during aging. *Neural Plast* **2017**, 3589271.
4. Deary IJ, Johnson W & Starr JM (2010) Are processing speed tasks biomarkers of cognitive aging? *Psychol Aging* **25**, 219–228.
5. van de Rest O, Berendsen AA, Haveman-Nies A, *et al.* (2015) Dietary patterns, cognitive decline, and dementia: a systematic review. *Adv Nutr* **6**, 154–168.
6. Poulose SM, Miller MG, Scott T, *et al.* (2017) Nutritional factors affecting adult neurogenesis and cognitive function. *Adv Nutr* **8**, 804–811.
7. de Jager CA, Oulhaj A, Jacoby R, *et al.* (2012) Cognitive and clinical outcomes of homocysteine-lowering B-vitamin treatment in mild cognitive impairment: a randomized controlled trial. *Int J Geriatr Psychiatry* **27**, 592–600.
8. Oyarce K, Bongarzone ER & Nualart F (2014) Unconventional neurogenic niches and neurogenesis modulation by vitamins. *J Stem Cell Res Ther* **4**, 184.
9. Masana MF, Koyanagi A, Haro JM *et al.* (2017) *n*-3 Fatty acids, Mediterranean diet, cognitive function in normal aging: a systematic review. *Exp Gerontol* **91**, 39–50.
10. Dangour AD, Allen E, Elbourne D, *et al.* (2010) Effect of 2-y *n*-3 long-chain polyunsaturated fatty acid supplementation on cognitive function in older people: a randomized, double-blind, controlled trial. *Am J Clin Nutr* **91**, 1725–1732.
11. Yurko-Mauro K, McCarthy D, Rom D, *et al.* (2010) Beneficial effects of docosahexaenoic acid on cognition in age-related cognitive decline. *Alzheimers Dement* **6**, 456–464.
12. van de Rest O, Geleijnse JM, Kok FJ, *et al.* (2008) Effect of fish oil on cognitive performance in older subjects: a randomized, controlled trial. *Neurology* **71**, 430–438.
13. Jiao J, Li Q, Chu J, *et al.* (2014) Effect of *n*-3 PUFA supplementation on cognitive function throughout the life span from infancy to old age: a systematic review and meta-analysis of randomized controlled trials. *Am J Clin Nutr* **100**, 1422–1436.
14. Fillion L & Henry CJK (1998) Nutrient losses and gains during frying: a review. *Int J Food Sci Nutr* **49**, 157–168.
15. Pereira PMdCC & Vicente AFdRB (2013) Meat nutritional composition and nutritive role in the human diet. *Meat Sci* **93**, 586–592.
16. Janoszka B, Warzecha L, Blaszczyk U, *et al.* (2004) Organic compounds formed in thermally treated high-protein food. Part I: polycyclic aromatic hydrocarbons. *Acta Chromatographica* **14**, 115–128.
17. Best EA, Juarez-Colunga E, James K, *et al.* (2016) Biomarkers of exposure to polycyclic aromatic hydrocarbons and cognitive function among elderly in the United States (National Health and Nutrition Examination Survey: 2001–2002). *PLOS ONE* **11**, e0147632.
18. Skog K & Alexander J (2006) *Acrylamide and Other Hazardous Compounds in Heat-Treated Foods*. Cambridge: Woodhead Publishing.
19. Liu Z-m, Tse LA, Chen B, *et al.* (2017) Dietary acrylamide exposure was associated with mild cognition decline among non-smoking Chinese elderly men. *Sci Rep* **7**, 6395.
20. Féart C, Samieri C, Rondeau V, *et al.* (2009) Adherence to a Mediterranean diet, cognitive decline, and risk of dementia. *JAMA* **302**, 638–648.
21. Calil SRB, Brucki SMD, Nitrini R, *et al.* (2018) Adherence to the Mediterranean and MIND diets is associated with better cognition in healthy seniors but not in MCI or AD. *Clin Nutr ESPEN* **28**, 201–207.
22. Petersson SD & Philippou E (2016) Mediterranean diet, cognitive function, and dementia: a systematic review of the evidence. *Adv Nutr* **7**, 889–904.
23. Cade JE, Burley VJ, Alwan NA, *et al.* (2017) Cohort Profile: the UK Women's Cohort Study (UKWCS). *Int J Epidemiol* **46**, e11.
24. Deary IJ, Liewald D & Nissan J (2011) A free, easy-to-use, computer-based simple and four-choice reaction time programme: the Deary–Liewald reaction time task. *Behav Res Methods* **43**, 258–268.
25. Bunce D, Haynes BI, Lord SR, *et al.* (2017) Intraindividual stepping reaction time variability predicts falls in older adults with mild cognitive impairment. *J Gerontol A Biol Sci Med Sci* **72**, 832–837.

26. Merchant AT, Vatanparast H, Barlas S, *et al.* (2009) Carbohydrate intake and overweight and obesity among healthy adults. *J Am Diet Assoc* **109**, 1165–1172.
27. Kal E, Winters M, van der Kamp J, *et al.* (2016) Is implicit motor learning preserved after stroke? A systematic review with meta-analysis. *PLOS ONE* **11**, e0166376.
28. Reimers S & Stewart N (2007) Adobe Flash as a medium for online experimentation: a test of reaction time measurement capabilities. *Behav Res Methods* **39**, 365–370.
29. Riboli E & Kaaks R (1997) The EPIC Project: rationale and study design. European Prospective Investigation into Cancer and Nutrition. *Int J Epidemiol* **26**, Suppl. 1, S6–S14.
30. Cade JE, Burley VJ & Greenwood DC (2004) The UK Women's Cohort Study: comparison of vegetarians, fish-eaters and meat-eaters. *Public Health Nutr* **7**, 871–878.
31. Spence M, Cade J, Burley V, *et al.* (2002) Ability of the UK Women's Cohort Study Food Frequency Questionnaire to rank dietary intakes: a preliminary validation study. *Proc Nutr Soc London* **61**, 117A.
32. Jones P, Cade JE, Evans CEL, *et al.* (2017) The Mediterranean diet and risk of colorectal cancer in the UK Women's Cohort Study. *Int J Epidemiol* **46**, 1786–1796.
33. Rada-Fernandez de Jauregui D, Evans CEL, Jones P, *et al.* (2018) Common dietary patterns and risk of cancers of the colon and rectum: analysis from the United Kingdom Women's Cohort Study (UKWCS). *Int J Cancer* **143**, 773–781.
34. Trichopoulou A, Kouris-Blazos A, Wahlqvist ML, *et al.* (1995) Diet and overall survival in elderly people. *BMJ* **311**, 1457–1460.
35. Trichopoulou A, Orfanos P, Norat T, *et al.* (2005) Modified Mediterranean diet and survival: EPIC-elderly prospective cohort study. *BMJ* **330**, 991.
36. Office of National Statistics (2005) The national statistics socio-economic classification user manual. https://www.ons.gov.uk/ons/guide-method/classifications/archived-standard-classifications/soc-and-sec-archive/the-national-statistics-socio-economic-classification–user-manual.pdf (accessed October 2019).
37. Darin-Mattsson A, Fors S & Kareholt I (2017) Different indicators of socioeconomic status and their relative importance as determinants of health in old age. *Int J Equity Health* **16**, 173.
38. VanderWeele TJ, Hernan MA & Robins JM (2008) Causal directed acyclic graphs and the direction of unmeasured confounding bias. *Epidemiology* **19**, 720–728.
39. Willett W (2012) *Nutritional Epidemiology*, 3rd ed. New York: Oxford University Press.
40. World Health Organization (2019) Key facts of dementia. https://www.who.int/news-room/fact-sheets/detail/dementia (accessed October 2019).
41. Bamford S-M & Walker T (2012) Women and dementia – not forgotten. *Maturitas* **73**, 121–126.
42. Alzheimer's Association (2014) 2014 Alzheimer's disease facts and figures. *Alzheimers Dement* **10**, e47–e92.
43. Mayeda ER (2019) Invited Commentary: Examining sex/gender differences in risk of Alzheimer disease and related dementias – challenges and future directions. *Am J Epidemiol* **188**, 1224–1227.
44. Bhushan A, Fondell E, Ascherio A, *et al.* (2018) Adherence to Mediterranean diet and subjective cognitive function in men. *Eur J Epidemiol* **33**, 223–234.
45. Loughrey DG, Lavecchia S, Brennan S, *et al.* (2017) The impact of the Mediterranean diet on the cognitive functioning of healthy older adults: a systematic review and meta-analysis. *Adv Nutr* **8**, 571–586.
46. Martinez-Lapiscina EH, Clavero P, Toledo E, *et al.* (2013) Mediterranean diet improves cognition: the PREDIMED-NAVARRA randomised trial. *J Neurol Neurosurg Psychiatry* **84**, 1318–1325.
47. Hardman RJ, Meyer D, Kennedy G, *et al.* (2018) The association between adherence to a Mediterranean style diet and cognition in older people: the impact of medication. *Clin Nutr* **37**, 2156–2165.
48. van der Flier WM & Scheltens P (2005) Epidemiology and risk factors of dementia. *J Neurol Neurosurg Psychiatry* **76**, v2–v7.

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https://doi.org/10.1017/S0007114520002287 Published online by Cambridge University Press