British Journal of Nutrition (2013), **109**, 2079–2088
doi:10.1017/S0007114512004291

Intake of specific nutrients and foods and hearing level measured 13 years later

Sandrine Péneau[1,2]*, Claude Jeandel[1,2], Philippe Déjardin[3], Valentina A. Andreeva[2], Serge Hercberg[2,4,5], Pilar Galan[2], Emmanuelle Kesse-Guyot[2] and the SU.VI.MAX 2 Research Group

[1]*Centre de Gérontologie, Clinique Antonin Balmes, Université I, CHU Montpellier, France*
[2]*UREN Unité de Recherche en Epidémiologie Nutritionnelle, Université Paris 13 Sorbonne Paris Cité Inserm (U557), Inra (U1125), Cnam, 93017 Bobigny Cedex, France*
[3]*Centre de Prévention les Arcades, Troyes, France*
[4]*Unité de Surveillance et d'Epidémiologie Nutritionnelle, InVS, Université Paris 13, Bobigny, France*
[5]*Département de Santé Publique, Hôpital Avicenne, Bobigny, France*

(Submitted 1 February 2012 – Final revision received 16 August 2012 – Accepted 16 August 2012 – First published online 19 November 2012)

Abstract

Only a few studies have investigated the impact of nutrients and food groups on hearing level (HL) with a population-based approach. We examined the 13-year association between intake of specific nutrients and food groups and HL in a sample of French adults. A total of 1823 subjects, aged 45–60 years at baseline, participating in the Supplementation with Antioxidant Vitamins and Minerals 2 cohort were selected. Nutrient and food intake was estimated at baseline among participants who had completed at least six 24 h dietary records. HL was assessed 13 years after baseline and was defined as the pure-tone air conduction of the worse ear at the following thresholds: 0·5, 1, 2 and 4 kHz. The relationship between quartiles of energy-adjusted nutrient and food intake and HL was assessed by multivariate linear regression analyses, in men and women separately. Intakes of retinol (*P*-trend = 0·058) and vitamin B_{12} (*P*-trend=0·068) tended to be associated with better HL in women. Intakes of meat as a whole (*P*-trend=0·030), red meat (*P*-trend=0·014) and organ meat (*P*-trend=0·017) were associated with better HL in women. Higher intake of seafood as a whole (*P*-trend=0·07) and of shellfish (*P*-trend=0·097) tended to be associated with better HL in men. Consumption of meat is therefore associated with a better HL in women. Further research is required to better elucidate the mechanisms behind the associations between diet and hearing.

Key words: Hearing: Diet: Nutrients: Meat

Hearing loss is one of the most common chronic conditions in the elderly and has become a major public health issue worldwide[1–3], given its consequences on quality of life[4]. In the USA, between 2001 and 2008, 17 % of women and 39 % of men aged 60–69 years suffered from hearing loss (≥25 decibels (dB))[3], while in France, in the period between 1998 and 2000, 22 % of men and women aged 60–74 years reported suffering from a hearing impairment[5]. Hearing loss increases as a function of age, with poorer hearing in men compared with women[2]. The public health burden of age-related hearing loss is expected to increase drastically in the coming decades with the ageing of the population[1,2]. Numerous underlying factors have been suggested regarding hearing loss, including exposure to noise and toxic substances, genetic factors, CVD, diabetes and obesity[6–9].

An independent role of nutritional factors in audition has been suggested in several studies. In a cross-sectional study involving fifty-five women aged 60–71 years, low intakes of folates and vitamin B_{12} and decreased serum concentrations of these vitamins were shown to be associated with impaired hearing[10]. In addition, in a randomised controlled trial of folate supplementation involving 728 older men and women, the supplementation slowed the age-related decline in hearing acuity regarding speech frequencies[10,11]. Hypotheses behind these associations involve an impact of folate and vitamin B_{12} on the nervous system as well as on vascular function with a potential link with homocysteine concentration[10–12]. The role of antioxidants in the management of hearing loss has also generated considerable interest over the past few years. A protective effect of antioxidants on several types of hearing impairment including age-related,

Abbreviations: dB, decibels; HL, hearing level; SU.VI.MAX, Supplementation with Antioxidant Vitamins and Minerals.

* **Corresponding author:** S. Péneau, fax +33 1 48 38 89 31, email s.peneau@uren.smbh.univ-paris13.fr

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noise-induced and drug-induced hearing loss has been suggested[13]. Two cross-sectional studies with subjects older than 50 years showed positive associations between auditory function and intake of specific antioxidants, in particular, vitamin C[14], vitamin E[14,15], riboflavin[14], Mg[14] and lycopene[14]. However, antioxidant intake did not modify the risk of incident hearing loss[15]. Except for these two population-based studies, most other research has been experimental[13], and evidence of an association between antioxidant intake and hearing function is still lacking. Finally, vitamin A intake was inversely associated with hearing impairment in 50-year-old subjects, while it did not modify the risk of incident hearing loss[15]. On the other hand, retinol intake worsened hearing performance in 49- to 99-year-old subjects[14]. Finally, serum retinol was inversely associated with hearing impairment in cross-sectional studies of 65-year-old adults[16]. Overall, the impact of retinol on hearing is unclear and has been insufficiently evaluated in the literature.

Hence, more data are needed in order to elucidate the association between micronutrient intake and hearing. Further, to our knowledge, the role of food groups containing specific micronutrients has not been investigated in the literature, apart from a recent longitudinal study showing that regular consumption of fish might protect against hearing loss in subjects aged 50 years or more[17].

Identifying food groups that have an impact on hearing level (HL) could be of great importance from a public health perspective. We therefore aimed at investigating the potential association of HL with intake of specific micronutrients and food groups rich in those nutrients in a large sample of healthy volunteers.

Subjects and methods

Study population

Subjects were participants in the Supplementation with Antioxidant Vitamins and Minerals (SU.VI.MAX) and SU.VI.MAX 2 (a full list of the SU.VI.MAX 2 Research Group Members is available in Appendix 1) studies. The SU.VI.MAX study (1994–2002; *n* 12 741) is a randomised, double-blind, placebo-controlled, primary prevention trial initially designed to evaluate the effect of daily supplementation with antioxidant vitamins (E (30 mg), C (120 mg) and β-carotene (6 mg)) and minerals (Se (100 μg) and Zn (20 mg)) at nutritional doses on the incidence of cancer and IHD[18,19]. At the end of the supplementation (2002), a total of 6850 subjects, who had agreed to participate in a post-supplementation follow-up, were included in the SU.VI.MAX 2 observational study (2007–9) which sought to investigate the impact of nutrition on the quality of ageing.

The SU.VI.MAX and SU.VI.MAX 2 studies were conducted according to the Declaration of Helsinki guidelines and were approved by the Ethics Committee for Studies with Human Subjects of Paris-Cochin Hospital (CCPPRB no. 706 and no. 2364, respectively) and the Comité National Informatique et Liberté (CNIL no. 334 641 and no. 907094, respectively). Written informed consent was obtained from all participants. The present trial was registered at clinicaltrials.gov as NCT00272428.

Dietary assessment

During the SU.VI.MAX study, subjects were invited to provide a 24 h dietary record every 2 months, for a total of six records per year. Days of the week for these records were randomised and fixed for each subject so that each day of the week and all seasons were covered. Information was collected via computerised questionnaires with the use of the Minitel Telematic Network loaded with study-specific software. The Minitel was a small terminal widely used in France as an adjunct to the telephone. A validated instruction manual[20] was used for coding food portions. It included photographs of >250 generic items (corresponding to 1000 specific foods). Subjects could choose from three main portion sizes, two intermediate or two extreme portions, for a total of seven different portion sizes. We included participants with a minimum of six 24 h records provided during the first 2 years of follow-up (Fig. 1). Mean intake of meat as a whole and meat sub-groups (red meat, poultry and game, organ meat and processed meat), seafood as a whole and seafood sub-groups (fish and shellfish), fruits and vegetables as a whole and sub-groups (fruits and vegetables) was evaluated (g/d). A French food composition table[21] was used to calculate nutrient contents. Mean intake of retinol (μg/d), β-carotene (μg/d), folate (μg/d), vitamin B_6 (mg/d), vitamin B_{12} (μg/d), vitamin C (mg/d) and vitamin E (mg/d) was assessed.

Auditory assessment

As part of the SU.VI.MAX 2 study, all participants were invited to undergo a check-up which included a clinical examination. Only participants without auditory devices could participate in the auditory assessment, which was performed in a quiet room by trained technicians. We measured pure-tone air conduction thresholds at 0·5, 1, 2 and 4 kHz using a portable diagnostic audiometer (ST20, Maico Diagnostic GmbH), first in the right ear and then followed by the left ear. Audiometric testing relied on the automated testing mode of the audiometer and was based on ascending responses using 5 dB steps. The instruments were calibrated once a year. Participants with present or previous ear disease (7 % within the year of auditory assessment) leading to full or partial deafness, unilateral or bilateral and necessitating treatment or follow-up by a medical practitioner were excluded. In addition, as unilateral hearing loss is a pathologic ear condition unrelated to ageing, subjects with a ≥20 dB difference in the average pure-tone hearing thresholds between the right and left ear were excluded. Finally, in order to focus on age-related rather than genetically determined hearing loss, only participants without first-degree family history of hearing diseases or hearing loss were included (Fig. 1). Mean HL was assessed as the pure-tone average of the 0·5, 1, 2 and 4 kHz air conduction thresholds for each ear, and the value for the worse ear was retained for analyses. Impaired hearing was defined as a failure to hear a 25 dB HL signal in the better ear.

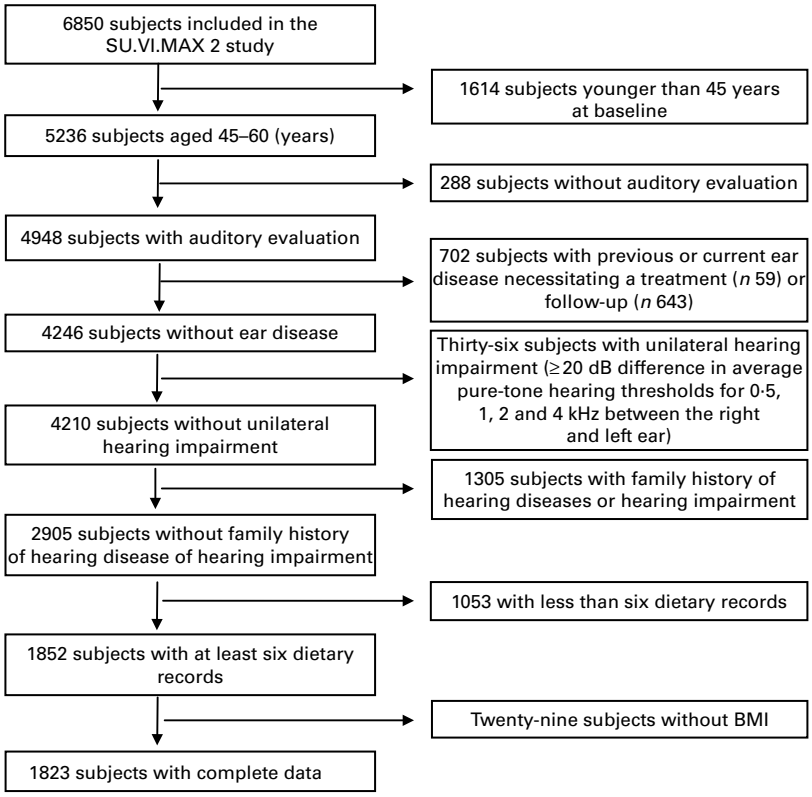

Fig. 1. Flow chart of subjects from the Supplementation with Antioxidant Vitamins and Minerals 2 (SU.VI.MAX 2) study cohort (2007–9) included in the present analysis.

Covariate assessment

At baseline, age, sex, educational level (primary, secondary or university level), physical activity (irregular, <1 h walking/d or ≥ 1 h walking/d) and smoking status (never smoked, former smoker or current smoker) were provided by a self-report questionnaire. At the first follow-up (1995–6), anthropometric measurements were obtained. Weight was measured with an electronic scale, with subjects wearing indoor clothing and no shoes. Height was measured under the same conditions with a wall-mounted stadiometer. BMI was calculated as the ratio of weight in kg to height in m^2 (kg/m^2). Blood pressure was measured by using a standardised procedure with a standard mercury sphygmomanometer. Blood pressure was taken once from each arm in subjects who had been lying down for 10 min. The mean of these two measurements was used for analyses. Subjects with missing values for BMI were excluded (Fig. 1). During follow-up, cases of cardio- or cerebrovascular disease were reviewed and validated by an independent expert committee.

Statistical methods

Included and excluded subjects were compared using the χ^2 test or the non-parametric Wilcoxon rank sums test. Descriptive results from χ^2 tests, non-parametric Wilcoxon rank sums tests or Student's t tests are reported as percentage, mean values and their standard deviations or geometric mean (95 % CI) across sex, as appropriate. Multivariate linear regression models were used to estimate the association between sex-specific quartiles of nutrient and food intake and HL. We adjusted for total dietary energy intake via the residual method[22] based on energy intake other than from alcohol. All analyses were adjusted for potential confounders of the association between food and nutrient intake and HL identified in the literature, i.e. age at hearing assessement, BMI, educational level, physical activity, supplementation group (intervention *v.* placebo), energy intake (excluding alcohol), alcohol intake and smoking habits and systolic and diastolic blood pressure. In addition to these variables, we fit a supplementary model adjusted for intake of total meat, seafood and fruits and vegetables, as appropriate. Results of the linear regression are presented as the adjusted mean difference of HL (95 % CI) in comparison to the first quartile of intake. A multivariate logistic regression was further performed to evaluate the association between food and nutrient intake and hearing loss (≥ 25 dB HL). In order to retain the sample size for the multivariate analyses, we performed imputation with the method of regression using BMI, age and sex to account for missing covariate data. Sensitivity analyses were performed after exclusion of subjects who developed diabetes or cardio- or cerebrovascular disease during the follow-up. All tests of statistical significance were two-sided and the type I error was set at 5 %. Statistical analyses were performed using SAS software (version 9.1, SAS Institute, Inc.).

Table 1. Characteristics of the study population at baseline and at the time of the hearing assessment in the Supplementation with Antioxidant Vitamins and Minerals (SU.VI.MAX and SU.VI.MAX 2) studies, 1994–2007 (*n* 1823)

(Mean values and standard deviations; geometric means and 95 % confidence intervals; percentages)

	Men (*n* 1002)		Women (*n* 821)		
	Mean	SD	Mean	SD	*P**
Age (years)†	64·8	4·6	64·1	4·4	<0·001
BMI (kg/m^2)‡	25·2	3·0	23·6	3·8	<0·0001
Smoking status‡ (%)					
Never smoker	36·2		67·2		<0·0001
Former smoker	52·5		22·4		
Current smoker	11·3		10·4		
Educational level‡ (%)					
Primary school	22·8		23·0		<0·0001
High school	36·2		45·2		
University or equivalent	41·0		31·8		
Physical activity‡ (%)					
Irregular	23·4		23·4		<0·0001
< 1 h walking/d	22·2		34·2		
≥ 1 h walking/d	54·5		42·4		
Intervention group (%)	53·0		53·2		0·92
Systolic blood pressure (mmHg)‡	128·8	12·8	121·7	12·1	<0·0001
Diastolic blood pressure (mmHg)‡	83·1	8·1	78·1	7·5	<0·0001
Number of 24 h records completed‡	11·07	2·22	10·81	2·20	<0·0001
Food intakes‡					
Energy intake§ (kJ/d)	9655·6	2112·2	7311·4	1817·9	<0·0001
Alcohol intake (g/d)	30·0	24·0	11·9	13·5	<0·0001
Meat (g/d)	154·5	56·3	106·5	42·4	<0·0001
Red meat (g/d)	68·4	38·4	48·5	28·4	<0·0001
Poultry and game (g/d)	35·1	27·4	24·0	19·4	<0·0001
Organ meat (g/d)	5·1	9·9	3·7	6·8	0·04
Processed meat (g/d)	46·0	26·8	30·2	18·9	<0·0001
Seafood (g/d)	51·7	35·3	42·0	30·8	<0·0001
Fish (g/d)	39·2	29·7	31·5	24·5	<0·0001
Shellfish (g/d)	12·5	16·3	10·5	14·5	0·003
Fruit and vegetables (g/d)	466·0	182·6	437·0	161·0	0·002
Fruits (g/d)	208·6	131·1	192·9	107·1	0·09
Vegetables (g/d)	216·1	85·3	203·8	82·6	0·001
Nutrient intakes‡					
Retinol (μg/d)					<0·0001‖
Geometric mean	708·5		530·8		
95 % CI	681·1, 737·0		508·1, 554·4		
β-Carotene (μg/d)					0·02‖
Geometric mean	3586·2		3378·1		
95 % CI	3464·2, 3712·5		3251·3, 3509·8		
Folate (μg/d)	343·6	90·5	289·2	88·6	<0·0001
Vitamin B_6 (mg/d)	1·99	0·49	1·52	0·43	<0·0001
Vitamin B_{12} (μg/d)					<0·0001‖
Geometric mean	7·42		5·60		
95 % CI	7·20, 7·64		5·42, 5·78		
Vitamin C (mg/d)					0·047‖
Geometric mean	88·6		85·0		
95 % CI	86·2, 91·1		82·4, 87·6		
Vitamin E (mg/d)					<0·0001‖
Geometric mean	13·4		11·1		
95 % CI	13·2, 13·7		10·8, 11·3		
Hearing assessment†					
HL, both ears (dB HL)	26·3	8·4	24·8	7·3	0·0001
HL, worse ear (dB HL)	28·6	9·0	26·7	7·6	<0·0001
HL, better ear (dB HL)	24·1	8·4	22·9	7·3	0·002
Impaired hearing (≥25 dB HL) (%)	55·1		47·1		<0·001

HL, hearing level; dB, decibels.

* *P* values were based on χ^2 tests, Student's *t* tests and non-parametric Wilcoxon rank sums tests, as appropriate.

† Characteristic measured at hearing assessment.

‡ Characteristic measured at baseline.

§ Excluding energy from alcohol.

‖ Based on the log-transformed variables.

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Results

Subject characteristics

Of the 6850 adults included in the SU.VI.MAX 2 study, 1823 individuals aged 45–60 years at baseline were included in the present analysis (Fig. 1). Included subjects were older ($P<0·0001$), more often male ($P<0·0001$), more physically active ($P<0·01$) and had a higher BMI ($P<0·0001$), higher systolic and diastolic blood pressure ($P<0·0001$) and lower educational level ($P<0·0001$) compared with the excluded subjects. However, they had better HL ($P<0·01$) than excluded subjects and showed no difference in hearing impairment ($P>0·05$). Participants with less than or equal to six 24 h records provided during the first 2 years of follow-up did not differ from those excluded due to fewer dietary records ($P>0·05$ for all characteristics).

Characteristics of the 1002 men and 821 women retained for the present analysis are presented in Table 1. Men were slightly older, had a higher BMI and higher educational level than women. In addition, they were more physically active, more likely to be former/current smokers and had higher systolic and diastolic blood pressure compared with women. Impaired hearing was greater in men than in women. Men had higher food and energy intakes than women, except for fruits. However, after adjustment for energy intake, daily consumption of fruits ($P<0·0001$), vegetables ($P<0·0001$) and fruit and vegetables ($P<0·0001$) was higher in women than in men, while intake of organ meat and shellfish was not significantly different between the groups ($P>0·05$; data not tabulated). Among the assessed nutrients, men had higher intakes than women. The dietary records were similarly distributed among week days (14·0 % of records were completed on a week day) and weekend days (14·9 %), although more records were completed in the winter (29·5 %) and spring (27·1 %) than in the summer (22·0 %) or autumn (21·4 %). Median sex-specific quartiles of food and nutrient intakes are given in Table 2.

Association between nutrient intake and hearing level

Table 3 shows the associations between intake of vitamins and HL. The adjusted mean differences of HL in comparison to the first quartile of nutrient intake are presented. Women with higher intake of retinol and vitamin B_{12} tended to have better HL compared with those having lower intake. No association was found for β-carotene, folate, and vitamins B_6, C and E. Results of the logistic regression analysis in women indicated a significant association between vitamin B_{12} and hearing loss ($P=0·03$), but no associations were observed with retinol ($P=0·11$) or other nutrients (all $P>0·05$). Among men, no significant association emerged with either linear (regarding HL) or logistic (regarding hearing loss) regression (all $P>0·05$). Exclusion of subjects who developed diabetes or vascular disease (n 111) during follow-up did not substantially modify the results.

Association between food intake and hearing level

Table 4 shows the associations between intake of total meat, seafood, fruit and vegetable groups and HL. The adjusted mean differences of HL in comparison to the first quartile of food intake are presented. Women with a higher consumption of meat as a whole, red meat and organ meat had a better HL compared with those having lower consumption of these food

Table 2. Median sex-specific energy-adjusted quartiles (Q) of intake of meat, seafood and fruit/vegetable groups in the Supplementation with Antioxidant Vitamins and Minerals (SU.VI.MAX and SU.VI.MAX 2) studies, 1994–2007 (n 1823)

	Men (n 1002)				Women (n 821)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Food intakes								
Meat (g/d)	91·7*	136·1	167·6	222·7	61·4	93·1	116·8	154·8
Red meat (g/d)	26·9	52·3	75·9	118·6	17·6	37·3	54·6	84·6
Poultry and game (g/d)	8·2	23·1	37·7	71·4	4·4	15·6	25·8	50·3
Organ meat (g/d)†	0	5·2	20·2	–	0	4·9	15·9	–
Processed meat (g/d)	17·3	35·3	50·7	80·6	10·1	23·2	33·7	53·9
Seafood (g/d)	14·4	35·4	57·2	99·9	10·2	27·5	45·2	84·9
Fish (g/d)	8·8	25·8	42·0	80·1	5·9	20·2	34·4	65·4
Shellfish (g/d)	0	3·3	11·7	35·2	−0·6	2·6	9·7	30·0
Fruit and vegetables (g/d)	276·3	398·1	499·2	690·7	266·8	384·3	468·7	627·9
Fruits (g/d)	74·7	156·5	227·1	376·3	78·6	151·3	210·6	331·2
Vegetables (g/d)	124·4	184·2	233·3	322·5	119·5	172·5	217·4	305·7
Nutrient intakes								
Retinol (μg/d)	386·5	583·0	796·3	1766·8	297·5	448·2	571·6	1393·1
β-Carotene (μg/d)	1901·9	3199·3	4510·8	7046·7	1837·7	3002·3	4093·1	6750·6
Folate (μg/d)	266·7	318·4	358·6	430·6	216·3	263·0	302·0	375·8
Vitamin B_6 (mg/d)	1·61	1·84	2·05	2·48	1·21	1·41	1·57	1·91
Vitamin B_{12} (μg/d)	4·50	6·37	8·46	13·55	3·36	4·90	6·39	10·76
Vitamin C (mg/d)	54·6	79·3	102·9	153·3	52·8	76·6	98·5	147·2
Vitamin E (mg/d)	9·7	12·6	14·9	19·5	8·2	10·5	12·4	16·1

* Adjusted on energy (all such values).

† Due to low consumption, individuals reporting organ meat consumption were divided into non-consumers, consumers with low intake (<median of residuals calculated within organ meat consumers) and consumers with high intake (>median).

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Table 3. Linear regression analysis of the sex-specific association between quartiles (Q) of nutrient intake at baseline and hearing level (HL) 13 years later in the Supplementation with Antioxidant Vitamins and Minerals (SU.VI.MAX and SU.VI.MAX 2) studies, 1994–2007 (*n* 1823)
(Mean differences and 95% confidence intervals)

	Men (*n* 1002)									Women (*n* 821)								
	Q1	Q2		Q3		Q4		*P*-trend	Q1	Q2		Q3		Q4		*P*-trend
		Mean difference	95 % CI	Mean difference	95 % CI	Mean difference	95 % CI			Mean difference	95 % CI	Mean difference	95 % CI	Mean difference	95 % CI	
Retinol*	Ref	0·02†	−1·50, 1·55	−0·52	−2·05, 1·01	0·80	−0·75, 2·34	0·46	Ref	−0·73	−2·24, 0·78	0·13	−1·42, 1·67	−1·79	−3·26, −0·32	0·058
β-Carotene*	Ref	0·19	−1·32, 1·70	0·28	−1·24, 1·79	−0·15	−1·69, 1·39	0·88	Ref	0·03	−1·44, 1·50	−0·67	−2·14, 0·80	0·21	−1·28, 1·70	0·98
Folate*	Ref	1·04	−0·49, 2·56	0·03	−1·49, 1·55	0·09	−1·44, 1·62	0·77	Ref	0·22	−1·26, 1·69	0·41	−1·07, 1·89	0·16	−1·32, 1·63	0·78
Vitamin B_6*	Ref	−0·29	−1·80, 1·22	0·27	−1·28, 1·83	0·54	−0·98, 2·06	0·38	Ref	0·22	−1·26, 1·70	−0·08	−1·56, 1·39	0·24	−1·25, 1·72	0·87
Vitamin B_{12}*	Ref	0·07	−1·45, 1·59	−0·97	−2·49, 0·55	0·03	−1·50, 1·57	0·70	Ref	−0·83	−2·30, 0·64	−0·46	−1·92, 1·00	−1·57	−3·04, −0·09	0·068
Vitamin C*	Ref	−0·81	−2·33, 0·71	−0·03	−1·55, 1·49	−0·92	−2·45, 0·61	0·42	Ref	0·40	−1·05, 1·86	−0·13	−1·60, 1·34	0·35	−1·13, 1·82	0·83
Vitamin E*	Ref	−0·38	−1·90, 1·14	−0·67	−2·19, 0·85	0·35	−1·17, 1·87	0·75	Ref	−1·20	−2·67, 0·27	−0·63	−2·10, 0·84	−0·75	−2·21, 0·71	0·47

Ref, reference.
*Adjusted for age (years), BMI (kg/m^2), educational level (primary, secondary or university level), physical activity (irregular, <1 h walking/d, ≥1 h walking/d), supplementation group (yes or no), energy intake (excluding energy from alcohol) (kJ/d), alcohol use (g/d), smoking status (never smoker, former smoker or current smoker), systolic and diastolic blood pressure (mmHg).
†Adjusted mean difference of HL (decibels hearing level) (95 % CI) in comparison to Q1 (all such values).

groups, as shown by both models. However, no association was found for poultry/game, processed meat or other food groups (seafood and fruits/vegetables). Among men, higher intake of seafood as a whole and of shellfish tended to be associated with better HL, while no association was observed for the other food groups. Results of the logistic regression analysis indicated a significant association between intake of meat ($P=0·03$), poultry and game ($P=0·01$) and organ meat ($P=0·01$) and hearing loss in women, while no association was observed in men (all $P>0·05$). Exclusion of subjects who developed diabetes or vascular disease during follow-up (*n* 111) did not substantially modify the results.

Discussion

In the present large prospective study, a long-term, sex-specific association was observed between diet and HL. Specifically, higher intakes of retinol and vitamin B_{12} tended to be associated with better HL in women, while no association was found in men. In addition, food groups known to be significant sources of these micronutrients, i.e. meat as a whole, red meat and organ meat, were associated with better HL in women. Higher intake of seafood as a whole and shellfish tended to be associated with better HL in men.

Association with intake of nutrients

There are relatively limited data on nutrient intake and HL, although potential associations between HL and nutrient serum concentrations have received some attention. In the present sample, intake of vitamin B_{12} tended to be associated with better HL in women. The present results are in line with those of a study showing that reduced vitamin B_{12} intake and serum vitamin B_{12} concentration were associated with age-related auditory dysfunction in a sample of fifty-five females[10]. However, in an intervention study involving ninety-three older adults, a short-term vitamin B_{12} supplementation was unrelated to improvement in hearing status in vitamin B_{12}-deficient individuals[23]. Observational studies conclude that there is no association between serum concentrations of vitamin B_{12} and age-related hearing loss either in cross-sectional[12,24] or longitudinal[12] settings, possibly due to insufficient power for analyses. Hearing loss in the elderly is believed to be mostly due to cochlear dysfunction[10,25], which is highly dependent on vascular supply[25]. Homocysteine has been shown to be a risk factor for CVD[26]; meanwhile, folic acid and vitamin B_{12} are known to be important determinants of homocysteine status[27,28]. Therefore, the potential association between poor vitamin B_{12} intake and HL could be partly mediated by unfavourable homocysteine concentrations. However, this interpretation is limited by the lack of an association between vitamin B_{12} intake and vitamin B_{12} blood concentration status, due to issues of malabsorption in the elderly[29], and by the fact that homocysteine has a stronger association with vitamin B_{12} status compared with intake[28,29]. Another pathway for the potential impact of vitamin B_{12} deficiency on audition might be through inhibition of neuron myelination in the cochlear nerve[10].

Table 4. Linear regression analysis of the sex-specific association between quartiles (Q) of food intake at baseline and hearing level (HL) 13 years later in the Supplementation with Antioxidant Vitamins and Minerals (SU.VI.MAX and SU.VI.MAX 2) studies, 1994–2007 (*n* 1823)

(Mean differences and 95% confidence intervals)

	Men (*n* 1002)								Women (*n* 821)							
		Q2		Q3		Q4				Q2		Q3		Q4		
	Q1	Mean difference	95 % CI	Mean difference	95 % CI	Mean difference	95 % CI	*P*-trend	Q1	Mean difference	95 % CI	Mean difference	95 % CI	Mean difference	95 % CI	Mean difference
Meat																
Model 1*	Ref	0·55†	−0·98, 2·07	0·69	−0·85, 2·23	1·32	−0·25, 2·90	0·11	Ref	−1·52	−2·99, −0·05	−2·63	−4·11, −1·15	−1·39	−2·90, 0·12	0·031
Model 2‡	Ref	0·51	−1·03, 2·05	0·65	−0·91, 2·21	1·26	−0·35, 2·88	0·13	Ref	−1·53	−3·00, −0·06	−2·64	−4·12, −1·15	−1·42	−2·94, 0·10	0·030
Red meat																
Model 1*	Ref	0·95	−0·57, 2·47	0·67	−0·84, 2·19	0·70	−0·85, 2·24	0·47	Ref	−1·04	−2·49, 0·41	−1·05	−2·51, 0·41	−1·89	−3·37, −0·41	0·018
Model 2‡	Ref	0·92	−0·62, 2·45	0·66	−0·87, 2·19	0·76	−0·81, 2·34	0·42	Ref	−1·00	−2·46, 0·46	−1·10	−2·58, 0·37	−1·96	−3·46, −0·47	0·014
Poultry and game																
Model 1*	Ref	0·53	−0·98, 2·04	0·52	−0·99, 2·04	0·98	−0·53, 2·50	0·23	Ref	0·33	−1·14, 1·80	−0·02	−1·48, 1·44	−1·00	−2·45, 0·46	0·15
Model 2‡	Ref	0·50	−1·01, 2·02	0·49	−1·03, 2·02	1·05	−0·48, 2·57	0·20	Ref	0·30	−1·17, 1·77	−0·07	−1·54, 1·40	−1·09	−2·55, 0·37	0·12
Organ meat																
Model 1*	Ref	−0·53	−1·92, 0·87	−0·45	−1·84, 0·93			0·52	Ref	−0·87	−2·24, 0·51	−1·75	−3·12, −0·38			0·012
Model 2‡	Ref	−0·45	−1·85, 0·95	−0·55	−1·94, 0·84			0·44	Ref	−0·87	−2·25, 0·51	−1·68	−3·05, −0·31			0·017
Processed meat																
Model 1*	Ref	−0·85	−2·36, 0·67	0·35	−1·17, 1·88	−0·15	−1·70, 1·41	0·76	Ref	−0·80	−2·25, 0·65	−0·58	−2·04, 0·88	−0·48	−1·96, 1·00	0·61
Model 2‡	Ref	−0·77	−2·30, 0·75	0·46	−1·10, 2·01	0·02	−1·57, 1·61	0·62	Ref	−0·81	−2·27, 0·65	−0·60	−2·06, 0·87	−0·53	−2·01, 0·96	0·57
Seafood																
Model 1*	Ref	0·15	−1·37, 1·67	−1·27	−2·79, 0·24	−1·13	−2·65, 0·39	0·049	Ref	−0·24	−1·70, 1·22	−0·32	−1·79, 1·16	−0·12	−1·59, 1·36	0·86
Model 2‡	Ref	0·22	−1·30, 1·74	−1·21	−2·73, 0·32	−1·03	−2·57, 0·51	0·070	Ref	−0·26	−1·73, 1·20	−0·37	−1·84, 1·10	−0·30	−1·79, 1·18	0·67
Fish																
Model 1*	Ref	−0·08	−1·60, 1·44	−0·14	−1·67, 1·40	−0·25	−1·77, 1·27	0·74	Ref	−0·61	−2·07, 0·84	0·15	−1·32, 1·61	0·07	−1·41, 1·54	0·69
Model 2‡	Ref	0·06	−1·46, 1·58	0·07	−1·48, 1·62	0·01	−1·55, 1·57	0·99	Ref	−0·68	−2·14, 0·78	0·07	−1·39, 1·54	−0·10	−1·61, 1·42	0·85
Shellfish																
Model 1*	Ref	0·40	−1·14, 1·94	−0·75	−2·28, 0·78	−0·94	−2·47, 0·58	0·106	Ref	−1·20	−2·76, 0·36	−0·77	−2·28, 0·74	−0·97	−2·45, 0·52	0·30
Model 2‡	Ref	0·32	−1·23, 1·86	−0·79	−2·33, 0·75	−1·00	−2·55, 0·54	0·097	Ref	−1·14	−2·70, 0·42	−0·69	−2·20, 0·82	−0·93	−2·44, 0·58	0·33
Fruit and vegetables																
Model 1*	Ref	−0·21	−1·73, 1·31	0·27	−1·27, 1·80	−0·03	−1·60, 1·54	0·88	Ref	−0·09	−1·55, 1·38	0·07	−1·40, 1·53	0·27	−1·24, 1·78	0·69
Model 2‡	Ref	−0·13	−1·65, 1·40	0·36	−1·18, 1·91	0·24	−1·35, 1·84	0·64	Ref	−0·16	−1·63, 1·31	0·03	−1·43, 1·49	0·21	−1·30, 1·72	0·74
Fruits																
Model 1*	Ref	−0·66	−2·19, 0·87	−0·02	−1·56, 1·53	−0·19	−1·77, 1·39	0·98	Ref	−0·12	−1·60, 1·37	−0·34	−1·83, 1·14	−0·13	−1·63, 1·38	0·80
Model 2‡	Ref	−0·52	−2·07, 1·02	0·06	−1·48, 1·61	−0·02	−1·63, 1·59	0·84	Ref	−0·26	−1·74, 1·23	−0·59	−2·09, 0·90	−0·46	−1·99, 1·08	0·49
Vegetables																
Model 1*	Ref	−0·26	−1·76, 1·25	1·14	−0·37, 2·64	−0·24	−1·77, 1·29	0·79	Ref	−0·95	−2·40, 0·49	0·15	−1·31, 1·61	0·50	−0·98, 1·98	0·28
Model 2‡	Ref	−0·25	−1·76, 1·27	1·16	−0·35, 2·67	−0·17	−1·73, 1·38	0·72	Ref	−0·87	−2·32, 0·58	0·39	−1·09, 1·88	0·74	−0·78, 2·26	0·16

Ref, reference.

* Adjusted for age (years), BMI (kg/m^2), educational level (primary, secondary or university level), physical activity (irregular, <1 h walking/d, ≥ 1 h walking/d), supplementation group (yes or no), energy intake (excluding energy from alcohol) (kJ/d), alcohol use (g/d), smoking status (never smoked, former smoker or current smoker), systolic and diastolic blood pressure (mmHg).

† Adjusted mean difference of HL (decibels HL) (95 % CI) in comparison to Q1 (all such values).

‡ Model 2: model 1 + food groups, as appropriate (for meat: groups of seafood and fruit/vegetables, and subgroups of meat as appropriate; for seafood: groups of meat and fruit/vegetables, and subgroups of seafood as appropriate; for fruit and vegetables: groups of meat and seafood, and subgroups of fruit/vegetable as appropriate).

https://doi.org/10.1017/S0007114512004291 Published online by Cambridge University Press

The present results indicated no association between HL and folate or vitamin B_6 intake, which are also cofactors of homocysteine metabolism. In the literature, folate intake was significantly associated with hearing function in an observational study[10], while folic acid supplementation slowed the decline in hearing acuity[11]. In addition, folate status has been either negatively associated with hearing impairment[17,30] or has showed no relationship[24]. Differences across results might be partly due to cross-sample variations in nutrient intake or blood status, and/or folate assessment methods[31]. The potential audio-protective effect of vitamin B_6 has received little attention in the literature. We are aware of only one study that reported no association between vitamin B_6 blood status and hearing[32], consistent with the present findings.

The role of antioxidants in the management of hearing loss has generated considerable interest over the past few years. Although antioxidants were shown to be protective against several types of hearing impairment, including those related to age, most studies have been experimental[13]. The present findings indicated no association between HL and vitamins C and, E and β-carotene. Consistent with the present findings, no association was found between intake of vitamin C and β-carotene and hearing loss prevalence or incidence[15]. In addition, vitamin E intake was negatively associated with the prevalence of age-related hearing loss, but showed no association with its incidence[15]. In another study, a negative association was found between sensorineural hearing loss and intake of vitamins C and E, while no association was observed for β-carotene[14]. Research with cancer patients showed that subjects who achieved the highest plasma concentrations of vitamins C and, E and Se after supplementation had significantly less loss of high-tone hearing during chemotherapy[33]. Finally, serum levels of β-carotene were negatively associated with the prevalence of hearing impairment in older adults[16].

The present results showed that retinol intake tended to be associated with a better HL in women. Similarly, in a recent study, vitamin A intake was inversely associated with the prevalence of hearing loss in a sample of men and women[15]. However, in the same study, vitamin A intake did not modify the risk of incident hearing loss, while it was suggested that retinol intake could even worsen hearing performance in older adults[14]. Increased serum retinol was shown to prevent hearing impairment in older adults[16]. The role of retinol in preventing hearing impairment is not yet clearly understood. Mechanisms of action may involve its antioxidant properties, although there are conflicting data in the literature about retinol being antioxidant[34]. Other potential mechanisms of the retinol-audition link include the inhibition of a c-Jun *N*-terminal kinase signal pathway known to be involved in apoptosis[35] or enhancement of hair cell renewal[36].

Association with intake of food

Potential associations between intake of various food groups and HL have thus far received little attention in the literature. To our knowledge, the present study is the first to show an association between meat intake, in particular, organ meat and red meat, and hearing function. Meat, especially organ meat, is the richest dietary source of both retinol and vitamin B_{12}, and helps explain the observed association between these nutrients and HL. In addition, the present results indicated that seafood, in particular, shellfish, tended to be associated with HL in men. This supports data from the literature indicating that regular consumption of fish protected against hearing loss[17]. Fish rich in *n*-3 fatty acids could have a role in maintaining healthy auditory function[17].

Difference by sex

In the present study, HL was associated with various nutrients and food groups, mostly in women. No association was observed in men, apart from the role of seafood (especially shellfish) intake, which tended to be associated with HL. Reasons behind these differences can be various. First, the prevalence of age-related hearing loss is clearly sex dependent. Cochlear and sensorineural functions of the ears are more affected in men in the course of ageing and might be less sensitive to nutrition factors. Second, as women had lower intakes of nutrients and food groups than men, they are therefore more likely to benefit from an increase in intake of beneficial dietary components. The present analyses indicated no interaction by sex, which supports the idea that mechanisms behind the association between diet and hearing might be similar in men and women. It was, however, important to present the models by sex, as previously emphasised[37].

Strengths and limitations

Strengths of the present study include its large sample of community-dwelling subjects and its prospective design. There are indeed very few epidemiological data on the association between intake of food and nutrients and hearing function. Dietary data reflected midlife exposure because they were collected when the participants were aged 45–60 years, which was 13 years before the assessment of auditory function. The use of repeated 24 h dietary records resulted in relatively accurate dietary data, especially concerning nutrient intake in well-educated subjects[38]. In the present study, hearing function was assessed using standardised audiometric methods. Finally, the exclusion of subjects with personal or family history of hearing impairment allowed us to more accurately identify subjects with age-related hearing loss. It is important to note that the level of sensitivity to nutrition and the type of food involved in hearing protection might differ according to the pathogenesis of hearing loss.

The main limitation of the present study was the absence of audiometric assessment at baseline. Further, generalisability of the findings is somewhat limited as we selected a subsample of the SU.VI.MAX2 cohort with no personal or family history of hearing loss. These results should therefore be confirmed in other populations. In addition, participants in a long-term cohort initially recruited for a randomised controlled trial are likely to be particularly health conscious and to have high functional capacity levels. The relatively young age of the

population was another limitation potentially leading to an underestimation of the association between diet and HL. Finally, although a wide range of covariates was assessed during follow-up, we cannot exclude the possibility that other important confounders were omitted, such as ototoxic medication, habitual noise exposure at work, medical conditions other than those taken into account and genetic factors.

Conclusion

The present study documented a long-term association between diet in midlife and HL assessed 13 years after baseline. Intake of retinol and vitamin B_{12} tended to be associated with a better HL in women. In addition, intake of food groups known to be significant sources of these two micronutrients (i.e. meat as a whole, red meat and organ meat) was also associated with a better HL in women. The associations were less significant in men in whom only intake of seafood, particularly shellfish, tended to be associated with a better HL. Several direct or indirect mechanisms are likely to be involved in the association between diet and hearing function. Further research is required to confirm these results and to better elucidate the mechanisms behind the link between diet and hearing.

Acknowledgements

We thank all scientists, dietitians, technicians and assistants who helped carry out the SU.VI.MAX 2 study. We especially thank N. Arnault, who coordinated data management and performed the analyses, R. Mehroug, who coordinated operational aspects of the study and G. Monot, who coordinated the computing aspects. We are grateful to the volunteers and clinicians who carried out the clinical examinations. S. P. conducted the literature review and drafted the manuscript. E. K.-G., C. J., P. D., V. A. A., S. H. and P. G. were involved in interpreting results and editing and critically reviewed the manuscript. E. K.-G., P. G. and S. H. were responsible for developing the design and protocol of the study. The SU.VI.MAX2 study was supported by the Agence Nationale de la Recherche (ANR-05-PNRA-010), Direction Générale de la Santé (Ministry of Health), Médéric, Sodexo, Ipsen, Mutuelle Générale de l'Education Nationale and Pierre Fabre. Mederic and Mutuelle Générale de l'Education Nationale are French health insurance organisations complementary to the national health insurance system. Ipsen and Pierre Fabre are private pharmaceutical companies. Sodexo is a food-catering company that sponsored events between the researchers and study participants. S. P., C. J., P. D., V. A. A., P. G. and E. K.-G. report no conflicts of interest. S. H. participated in the examiner board of the Union Pour la Promotion des Industries Conserve Appertisée.

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APPENDIX 1
Members (City) of the Research Group SU.VI.MAX 2 Study

Luc Vogt (Agen); Michèle Escande (Allauch); Jean-Marie Sérot (Amiens); Emmanuel Vasseur (Angers); Matthieu Debray (Annecy); Chantal Hussonnois (Auxerre); Martine Iehl-Robert (Besançon); Myriam le Sommer (Bordeaux); Thierry Boge (Bourg en Bresse); Josiane Rajaonarivo (Bourges); Jean Jouseau (Bourges); Monique Frison (Brest); Armelle Gentric Brest); Fabienne Leenaert (Caen); Bernard Bascou (Carcassonne); Jean-Paul Lemaire (Cavaillon); Nathalie Baptiste (Champcueil); Marie-France Maugourd (Champcueil); Anne Gibelain (Chartres); Roland Lopitaux (Clermont-Ferrand); Jacques Hild (Colmar); Henri Nachar (Avignon); Géraldine Soulié (Dax); Francine Clémenti (Dax); Patrick Friocourt (Blois); Alain Sagnier (Chambéry); Philippe Schiano (Hyères); Andréa Collet (Port-Louis Riantec); Dominique Richard (Dijon); Françoise Zandi (Gradignan); Pascal Couturier (Grenoble); Agathe Raynaud-Simon (Ivry); Pierre Lermite (La Roche sur Yon); Michel Alix (La Rochelle); Emmanuel Alix (Le Mans); François Puisieux (Lille); Cédric Gaxatte (Lille); Thierry Dantoine (Limoges); Pierre livet (Lyon); Gilles Albrand (Lyon); Pierre Haond (Lyon); Pascal Ménecier (Macon); François Pinoche (Malestroit); Sylvie Bonin Guillaume (Marseille); Marc Heim (Marseille); André Wang (Metz); Claude Jeandel (Montpellier); Yves Passadori (Mulhouse); Athanase Benetos (Nancy); Catherine Couturier (Nantes); Gilles Berrut (Nantes); Sylvie Sacher-Huvelin (Nantes); Henri Patouraux (Nevers); Patrice Brocker (Nice); Olivier Guérin (Nice); Denise Strubel (Nîmes); Florence Dupriez (Orléans); Jean-Bernard Gauvain (Orléans); Yves Wolmark (Paris); Olivier Hanon (Paris); Bernard Cassou (Paris); Philippe Déjardin (Paris, Troyes); François de la Fournière (Pau); Frédéric Woné (Périgueux); Claudine Buj-Hardy (Perpignan); Marc Paccalin (Poitiers); Bertrand Placines (Pontacq-Nay); Jean-Luc Novella (Reims); Pierre Jouanny (Rennes); Florence Martin (Rodez, Toulouse); Philippe Chassagne (Rouen); Isabelle Landrin (Rouen); Chantal Girtanner (St-Etienne); Régis Gonthier (St-Etienne); Claudie Troadec (St-Brieuc); Christophe Dourthe (Saintes); Eric Bonnin (Saintes); Jean-Paul Marot (St-Nazaire); Sylvie Rossignol (Sens); Georges Sebbane (Sevran); Pierre-Yves Cornu (Sevran); Jean-Jacques Monsuez (Sevran); Isabelle Périllat (Sevran); Robert Ratiney (Sevran); Georges Kaltenbach (Strasbourg); Yves Rolland (Toulouse); Thierry Constans (Tours); Gisèle Coz (Tréguier); Monique Ferry (Valence); Jean Pierre Aquino (Versailles); Odile Cézard (Voiron).