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Can nutrient profiling help to identify foods which diet variety should be encouraged? Results from the Whitehall II cohort

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Abstract

Higher variety of recommended foods, identified arbitrarily based on dietary guidelines, has been associated with better health status. Nutrient profiling is designed to identify objectively, based on nutrient content, healthier foods whose consumption should be encouraged. The objective was to assess the prospective associations between total food variety (food variety score, FVS) and variety from selected recommended and non-recommended foods (RFV and NRFV, respectively) and risk of chronic disease and mortality. In 1991–3, 7251 participants of the Whitehall II study completed a 127-item FFQ. The FVS was defined as the number of foods consumed more than once a week. (N)RFV(Ofcom) and (N)RFV(SAIN,LIM) were similarly derived selecting healthier (or less healthier) foods as defined by the UK Ofcom and French SAIN,LIM nutrient profile models, respectively. Multi-adjusted Cox regressions were fitted with incident CHD, diabetes, CVD, cancer and all-cause mortality (318, 754, 137, 251 and 524 events, respectively – median follow-up time 17 years). RFV and NRFV scores were mutually adjusted. The FVS (fourth *v.* first quartile) was associated with a 39 and 26 % reduction of prospective CHD and all-cause mortality risk, respectively. The RFV(Ofcom) (third *v.* first quartile) was associated with a 27 and 35 % reduction of all-cause mortality and cancer mortality risk, respectively; similar associations were suggested, but not significant for the RFV(SAIN,LIM). No prospective associations were observed with NRFV scores. The results strengthen the rationale to promote total food variety and variety from healthy foods. Nutrient profiling can help in identifying those foods whose consumption should be encouraged.

Key words: **Food variety: Nutrient profiling: Whitehall II cohort: Proportional hazards regression**

Several approaches have been used for the identification of dietary patterns linked to improved health status of individuals[1–4]. Indicators of total food variety have been associated with improved nutritional status, particularly in developing countries[5–9], and higher food variety has been associated with reduced diabetes and colorectal cancer prevalence[10–12]. In developed countries, it has been suggested that specific variety from healthy or recommended foods is protective against all-cause mortality and chronic disease[3,13–16]. An objective identification of such healthier foods whose consumption should be recommended could assist in the development of food-based dietary guidelines that implicitly include dietary variety as a parameter[17–20].

Nutrient profiling is defined by the WHO as 'the science of classifying or ranking foods according to their nutritional composition for reasons related to preventing disease and promoting health'[21]. A nutrient profile model developed for the UK regulator for broadcast media (Ofcom) is being used for regulatory purposes in its original or adapted version in the UK, the Republic of Ireland, and Australia and New Zealand[22–24]. The SAIN,LIM nutrient profile model[25,26] is developed for the French food safety agency as an answer to the European Union regulation on food labelling[27]. Other governments and commercial companies around the world have or are proposing to use different models[28].

Selecting healthier foods as defined by nutrient profile models would provide a robust basis to assess the impact on health of an increased variety from selected healthier foods, and to compare with the health effect of an increased

Abbreviations: FVS, food variety score; ICD, International Classification of Disease; MAR, mean adequacy ratio; MER, mean excess ratio; NRFV, non-recommended food variety scores; Ofcom, UK Ofcom nutrient profiling model; RFV, recommended food variety scores; SAIN,LIM, score for the nutritional adequacy of individual foods, score for disqualifying nutrients.

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total food variety. The use of longitudinal data would allow assessing prospective associations with chronic disease risk and mortality events, ensuring the temporality of the associations. The aim of the present study was to assess, within the British Whitehall II cohort, the associations between total food variety and variety from selected healthier foods identified using the UK Ofcom and French SAIN,LIM nutrient profile models and prospective risk of coronary events and diabetes, and mortality.

Subjects and methods

The Whitehall II cohort

The target population of the Whitehall II study was all civil servants aged 35–55 years working in the London offices of twenty Whitehall departments in 1985–8. A response rate of 73 % led to the recruitment of 10 308 participants, invited to the research clinic at 5-year intervals and receiving a postal questionnaire between clinic phases[29]. The last completed clinical phase ended in December 2009. The study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects were approved by the University College London Research Ethics Committee. Written informed consent was obtained from all subjects and renewed at each contact.

Dietary assessment and baseline covariates

Detailed dietary assessments were introduced between 1991 and 1993, the baseline for the present analysis. Dietary intakes were reported in a validated 127-item FFQ[30,31]. The FFQ was completed by 7935 respondents. For all items in the FFQ, participants were asked to report their frequency of eating a common unit or portion size during the previous year in nine predefined categories ranging from ‘never or less than once per month’ to ‘6 + /d’.

Clinical examinations were conducted by trained staff at the study clinic or at home. As described in full elsewhere[29,32], height, weight, blood pressure and serum lipids were collected following standard procedures. Employment grade within the British Civil Service (six levels) was used as the measure of adult socio-economic position. Ethnicity (white, South Asian, Afro-Caribbean or other), marital status (married, single, widowed or divorced), smoking habit (never, ex-smoker or current), leisure-time physical activity (hours mild, moderate and vigorous activity per week), prevalence of longstanding illness and medication use were self-reported in the general health questionnaire.

BMI was calculated as the ratio between weight (kg) and height squared (m^2); subjects were classified as overweight/obese if their BMI was $\geq 25{\cdot}0\,kg/m^2$. Hypertension was defined as systolic or diastolic blood pressure ≥ 140 or ≥ 90 mmHg, respectively, or by the use of hypertensive drugs[33]. Dyslipidaemia was defined as serum LDL-cholesterol $\geq 4{\cdot}1$ mmol/l, or serum HDL-cholesterol $\leq 0{\cdot}9$ mmol/l (men) or ≤ 1 mmol/l (women), or serum TAG $\geq 1{\cdot}7$ mmol/l, or by the use of lipid-lowering drugs[34,35].

Outcomes follow-up

Mortality data (median follow-up 17·7 years, range 0·08–18·4 years), including the cause of death, were available through the National Health Service Central Registry until 31 January 2010. Death certificates were coded using the 9th or 10th revision of the International Classification of Disease (ICD). A total of 915 incident deaths were recorded within the 171 267 person-years of follow-up (mean 16·8 (SD 2·67) years per person). Of these, 419 were attributable to cancer (ICD-9 codes 140–209 except 173 and ICD-10 codes C00–C97 except C44), 259 to CVD (ICD-9 codes 390–458 and ICD-10 codes I00–I99) and 143 to CHD (ICD-9 codes 410–414 and ICD-10 codes I20–I25).

Potential cases of non-fatal myocardial infarction up to 30 December 2009 have been ascertained by questionnaire items on chest pain[36], doctors’ diagnoses and hospitalisations (NHS Hospital Episode Statistics database), as described in full elsewhere[4]. Myocardial infarction was defined as negative when self-reported only. A total of 416 incident fatal CHD and non-fatal myocardial infarction cases were identified in the 140 641 person-years of follow-up (mean 14·5 (SD 5·24) years per person).

Incident cases of diabetes up to 30 December 2009 have been identified by self-report of doctor’s diagnosis, diabetic medication and 2 h 75 g oral glucose tolerance test in clinical phases, according to the 1999 WHO classification[37], as described previously[4]. A total of 927 incident cases of diabetes were identified with a mean follow-up of 13·9 (SD 4·27) years per person (total 114 209 person-years).

The UK Ofcom and SAIN,LIM nutrient profile models

The UK Ofcom nutrient profile model is a two-category model, scoring food and drinks separately, but using the same basic algorithm – a semi-continuous score based on nutrient and ingredient content – as a basis to define products that are ‘healthier’ and ‘less healthy’. The detailed algorithm has been presented elsewhere[38]. The Ofcom model incorporates on a single scale the following components per 100 g of food: saturated fats, Na, total sugar and energy as the negative components; and protein, fibre and fruit, vegetable, and nut content as the positive components.

The SAIN,LIM nutrient profile model was proposed by the French Food Safety Agency[25,26]. It is based on two sub-scores: the SAIN that includes eight positive nutrients (protein, fibre, vitamin C, Ca, Fe, and the optional vitamin D, vitamin E and α-linolenic acid) calculated per 418 kJ (100 kcal) of food; and the LIM that includes three negative nutrients calculated per 100 g of food (saturated fats, free sugars and Na). Thresholds are defined for each of these sub-scores to define four healthiness classes, with foods from the first class being the ‘healthiest’ since having a SAIN and a LIM, respectively, higher and lower than the related thresholds, and those in the fourth class being the ‘least healthy’.

The Ofcom and SAIN,LIM nutrient profile models were applied to all the items of the FFQ, using the respective nutrient content information. The Ofcom and SAIN,LIM models identified sixty-one and forty-nine healthy items, and fifty-three and thirty-nine unhealthy items, respectively. Alcoholic drinks were excluded from the analyses.

Food variety scores

Five variety scores were calculated for each individual. The food variety score (FVS) was simply the number of FFQ items reported to be consumed more than once a week[6]. The recommended food variety scores (RFV(Ofcom) and RFV(SAIN,LIM)) were derived similar to the FVS, counting only the foods identified as 'healthier' and 'healthiest' by the Ofcom and SAIN,LIM models, respectively. In addition, to adjust the variety of recommended foods for the variety from less healthy foods, the non-recommended food variety scores (NRFV(Ofcom) and NRFV(SAIN,LIM)) were computed similar to the RFV selecting foods identified as 'less healthy' and 'least healthy' by the Ofcom and SAIN,LIM models, respectively.

Statistical analyses

Spearman rank correlations were assessed between the five variety scores. Baseline participant characteristics were tested for heterogeneity across quartiles of all variety scores using one-way ANOVA or χ^2 tests. Nutrients and food groups intakes were expressed in density, i.e. on a constant energy basis.

To assess the overall nutritional status, the variety scores were tested against the mean adequacy ratio (MAR) and the mean excess ratio (MER), which do not include variety in their algorithm. The MAR was used to assess average nutritional adequacy for nineteen micronutrients (Ca, Mg, P, Na, K, Cl, Fe, Zn, Cu, I and vitamins A, B_1, B_2, B_3, B_6, B_9, B_{12}, C and D); it was calculated as follow[39]:

$$\mathrm{MAR} = \sum_{1}^{19} \frac{\mathrm{intake}_i}{\mathrm{DRV}_i} * \frac{100}{19},$$

where intake_i is the daily intake of nutrient i and DRV_i the respective British Dietary Reference Value[40], taking into account the age and sex of each individual. If $\mathrm{intake}_i/\mathrm{DRV}_i > 1$, then $\mathrm{intake}_i/\mathrm{DRV}_i = 1$.

The MER represented a mean percentage of intakes above maximal recommended amounts for saturated fats, Na and free sugars and was calculated as follows[41]:

$$\mathrm{MER} = \left(\sum_{1}^{3} \frac{\mathrm{intake}_j}{\mathrm{MRV}_j} * \frac{100}{3} \right) - 100,$$

where intake_j is the daily intake of either saturated fats, Na or free sugars, and MRV_j the respective maximum recommended value (22 g, 3153 mg and 50 g, respectively). If $\mathrm{intake}_j/\mathrm{MRV}_j < 1$, then $\mathrm{intake}_j/\mathrm{MRV}_j = 1$

Cox proportional hazard regressions[42] were fitted between quartiles of the variety scores and prospective outcomes, using follow-up time in years as time variable. Prevalent cases at baseline were excluded from the analyses. The FVS was assessed individually. To assess independently the effect of healthier and less healthy food variety, the RFV and NRFV scores linked to the same nutrient profile model were mutually adjusted following the approach of Kaluza *et al.*[16] and Michels *et al.*[14] Base models were adjusted for age, sex, ethnicity and total energy intake. Further adjustment included marital status, employment grade, smoking status, physical activity level, alcohol intake, BMI categories and prevalence of longstanding illness. Proportional hazard assumption was tested using scaled Schoenfeld residuals[43]. Linear trend was assessed by including quartiles of variety scores as continuous variables. All analyses were conducted on a complete case dataset (*n* 7251) to allow comparison between different levels of adjustment, using the SAS version 9.3 software (SAS Institute, Inc.).

In order to take some account of reporting bias and reverse causality, Cox regressions were conducted excluding either low- and high-energy reporters identified using Goldberg cut-off values[44], or individuals that declared a prevalent longstanding illness or the use of anti-hypertensive or lipid-lowering medication at baseline.

The Ofcom score includes fruit, vegetable and nut content as a positive component in its algorithm. Multi-adjusted Cox regressions further including fruit, vegetable, and nut intake as covariate were conducted to assess the contribution of fruit and vegetable intake on the overall results.

Results

Total food variety was positively correlated with variety of both healthier and less healthy foods (Table 1). RFV and NRFV scores derived from the same nutrient profile model were moderately correlated; correlations were highest between the two RFV scores and the two NRFV scores. Since the main objective of the present study was to compare the effects between increased total variety and increased variety from selected healthier foods, results for the NRFV score are presented in online Supplementary Tables S1–S7.

Baseline characteristics

For all variety scores, a positive association was observed with high employment grade, and inverse associations with current smoking, physical inactivity and being single (Table 2 and online Supplementary Table S1). Men were more likely to have a higher FVS and NRFV scores, but lower RFV scores; age was positively associated with the RFV scores, and negatively with the NRFV scores. The FVS and RFV (Ofcom) scores were positively associated with prevalent overweight or obesity (i.e. BMI $\geq$25 kg/m^2). Higher prevalence of longstanding illness was associated with higher RFV scores.

The five variety scores were associated with increased energy intake, the trend being strongest for the NRFV scores and the FVS (Table 3 and online Supplementary Table S2). The FVS was positively associated with the intake – in g/MJ – of salted snacks and sweets, fish and shellfish, fruit and nuts, and vegetables. The FVS was inversely associated with the intake of dairy products and breads; no association was observed for other food groups. The two RFV scores were positively associated with the consumption of breakfast

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Table 1. Descriptive statistics and Spearman's correlations between the five variety scores (*n* 7251)

	FVS	RFV(Ofcom)	NRFV(Ofcom)	RFV(SAIN,LIM)	NRFV(SAIN,LIM)
Mean	43·1	25·6	14·7	17·6	10·9
SD	11·5	7·40	5·50	6·00	4·70
Median	43	25	14	18	11
Range	0–99	0–51	0–42	0–38	0–32
Spearman correlations					
FVS	1				
RFV(Ofcom)	0·86	1			
NRFV(Ofcom)	0·72	0·32	1		
RFV(SAIN,LIM)	0·78	0·95	0·25	1	
NRFV(SAIN,LIM)	0·69	0·33	0·91	0·23	1

FVS, food variety score (total food variety); RFV, recommended food variety score (healthier food variety); NRFV, non-recommended food variety score (less healthy food variety); Ofcom, UK Ofcom nutrient profiling model[38]; SAIN,LIM, score for the nutritional adequacy of individual foods, score for disqualifying nutrients[26].

cereals and other starches, fish and shellfish, fruit and nuts, and vegetables, and inversely with the intake of breads, and salted snacks and sweets (Table 3). Consumption of dairy products was not associated with the RFV scores. The two NRFV scores were inversely associated with the intake of all food groups except salted snacks and sweets (online Supplementary Table S2).

The FVS and RFV scores were positively associated with overall nutritional adequacy of the diet as indicated by the MAR (Table 3). The FVS and the NRFV scores were positively associated with the MER. The RFV (Ofcom) was weakly, but positively, associated with the MER; there was no association with the RFV(SAIN,LIM). All scores were inversely associated with energy misreporting (both low and high energy reporting). Most associations between the variety scores and macro- and micronutrients intake followed the trends highlighted by the MAR and MER (online Supplementary Table S3).

Survival analyses

The FVS was linearly associated with prospective risk reduction of fatal and non-fatal CHD and all-cause mortality in the base models (Table 4). Further adjustment attenuated the linear trend estimates, which indicated a borderline significant risk reduction of 11 and 8 % for CHD and all-cause mortality, respectively; the hazard ratio estimates for the fourth quartile (*v.* first) of FVS indicated risk reductions of 39 and 26 % for CHD and all-cause mortality, respectively. A protective association was also suggested for cancer mortality, but estimates were not significant.

A protective effect of the RFV(Ofcom) on prospective all-cause and cancer mortality was observed in the base and fully adjusted models, significant estimates indicating an approximate 30 % risk reduction for the second and third quartiles (*v.* first; Table 4). Similar protective effects were suggested for the RFV(SAIN,LIM) second, third and fourth quartiles (*v.* first), but were not robust to multi-adjustment. For both RFV scores, there was no association with CHD risk. Overall, a higher variety of unhealthy foods, as measured by the NRFV scores, was not associated with prospective risk of CHD, and cancer and all-cause mortality (online Supplementary Table S4).

Similar trends were observed for CVD mortality risk, although the small number of cases led to wider CI and non-significant results (online Supplementary Table S5). No robust association could be observed between the variety scores and diabetes risk (online Supplementary Table S5). Prospective associations were investigated with diet-related cancer mortality (seventy-five cases), but no associations could be observed (data not shown).

Post hoc *analyses: diet misreporting and reverse causation*

The exclusion of low and high energy reporters (*n* 1387 and 545, respectively) attenuated most associations observed between the variety scores and the risk of CHD (models M2-rep in online Supplementary Table S6); the risk reductions obtained with the full sample with the FVS remained suggested, but estimates were non-significant. The protective effect of the FVS on cancer mortality risk was reinforced but with wider CI. The cancer and all-cause mortality risk reductions previously observed with the RFV(Ofcom) were confirmed.

Excluding individuals who reported a prevalent illness (*n* 2427; models M2-ill in online Supplementary Table S6) confirmed the protective effect of the FVS on both CHD and all-cause mortality risk. The protective association between the RFV scores and all-cause mortality were equally confirmed. No significant estimates were observed for the NRFV scores. Excluding individuals who reported the use of anti-hypertensive or lipid-lowering drug, and those for whom follow-up time was less than 2 years, led to similar conclusions (data not shown).

Further adjusting the Cox regression for fruit, vegetable and nut intake did not modify the overall conclusions (online Supplementary Table S7). Associations with cancer mortality were slightly attenuated; the protective effect of total variety on fatal and non-fatal CHD was confirmed.

Discussion

The present study assessed the prospective associations between both total food variety and variety from recommended – or healthier – foods (FVS and RFV scores, respectively) and adverse health outcomes over a long follow-up period. In contrast to previous investigations[14,16], the recommended foods included in the RFV scores were based on validated nutrient profile models. In multi-adjusted survival analyses, total food variety was protective against the risk of fatal and non-fatal CHD, and all-cause mortality. Similar associations were suggested for cancer and CVD mortality risk, but estimates were not significant. Middle quartiles (*v.* first) of the RFV(Ofcom) were associated with cancer and all-cause mortality risk reduction. Similar risk reductions were suggested for the RFV(SAIN,LIM), but were not robust to adjustment. Higher variety of non-recommended foods (NRFV scores) was not associated with prospective health status. *Post hoc* analyses did not alter conclusions, including when adjusting for fruit, vegetable and nut intake.

Table 2. Baseline sociodemographic and risk factor characteristics across variety score quartiles
(Mean values with their standard errors; number of subjects and percentages, *n* 7251)

Score quartiles...	1		2		3		4		
	% or Mean	*n* or SE	% or Mean	*n* or SE	% or Mean	*n* or SE	% or Mean	*n* or SE	*P**
FVS		1640		1969		1650		1992	
Range	0–34		35–42		43–49		50–99		
Sex (% men)	64·8	1063	68·6	1350	71·0	1172	72·5	1444	<0·001
Age									0·412
Mean	49·7		49·7		49·5		49·4		
SE	0·15		0·14		0·15		0·14		
Ethnicity (% white)	84·1	1380	92·3	1818	93·8	1548	94·2	1876	<0·001
Grade (% high)	10·2	168	15·6	307	19·8	326	23·7	473	<0·001
% Single	21·6	354	14·4	283	11·2	185	11·3	225	<0·001
% Current smoker	18·4	301	14·8	291	11·0	181	10·6	211	<0·001
% Inactive	73·6	1207	67·8	1335	64·1	1058	59·7	1190	<0·001
BMI (kg/m^2)	25·2	0·10	25·1	0·08	25·1	0·09	25·4	0·08	0·075
% Overweight/obese	44·8	735	45·5	896	46·5	767	49·4	984	0·025
% Hypertension	20·1	330	19·7	387	20·8	343	20·8	414	0·786
% Dyslipidaemia	66·8	1096	68·0	1339	65·2	1076	67·7	1348	0·294
% Longstanding illness	32·2	528	33·5	659	33·9	560	34·1	680	0·624
RFV(Ofcom)		1528		1749		2148		1826	
Range	0–19		20–24		25–30		31–51		
Sex (% men)	75·5	1153	70·7	1237	68·2	1465	64·3	1174	<0·001
Age									0·009
Mean	49·2		49·5		49·8		49·8		
SE	0·15		0·14		0·13		0·14		
Ethnicity (% white)	89·0	1360	91·1	1594	93·4	2006	91·0	1662	<0·001
Grade (% high)	11·5	176	15·9	278	19·3	415	22·2	405	<0·001
% Single	22·3	340	15·0	263	12·0	258	10·2	186	<0·001
% Current smoker	19·3	295	14·4	251	11·9	256	9·97	182	<0·001
% Inactive	71·7	1096	69·0	1207	64·4	1384	60·4	1103	<0·001
BMI (kg/m^2)	25·1	0·10	25·1	0·09	25·2	0·08	25·5	0·09	0·004
% Overweight/obese	44·2	675	46·5	814	46·2	992	49·3	901	0·026
% Hypertension	19·4	296	19·8	347	20·6	442	21·3	389	0·517
% Dyslipidaemia	67·7	1035	68·8	1203	65·7	1412	66·2	1209	0·175
% Longstanding illness	30·8	470	33·7	589	33·0	708	36·1	660	0·011
RFV(SAIN,LIM)		1508		2091		1764		1888	
Range	0–12		13–17		18–21		22–38		
Sex (% men)	77·7	1172	71·3	1490	68·7	1211	61·2	1156	<0·001
Age									<0·001
Mean	48·8		49·4		49·8		50·2		
SE	0·15		0·13		0·15		0·14		
Ethnicity (% white)	91·1	1374	91·1	1904	92·9	1638	90·4	1706	0·052
Grade (% high)	12·1	183	16·1	337	18·8	331	22·4	423	<0·001
% Single	21·6	326	14·2	297	12·4	218	10·9	206	<0·001
% Current smoker	19·5	294	13·4	281	12·1	214	10·3	195	<0·001
% Inactive	71·4	1077	69·4	1452	64·4	1136	59·6	1125	<0·001
BMI (kg/m^2)	25·2	0·10	25·1	0·08	25·1	0·08	25·4	0·09	0·083
% Overweight/obese	45·3	683	46·8	978	45·6	804	48·6	917	0·192
% Hypertension	19·0	287	19·7	412	21·0	370	21·5	405	0·262
% Dyslipidaemia	68·4	1031	68·5	1432	65·0	1147	66·2	1249	0·069
% Longstanding illness	31·7	478	31·9	668	34·1	602	36·0	679	0·019

FVS, food variety score (total food variety); RFV, recommended food variety score (healthier food variety); Ofcom, UK Ofcom nutrient profiling model[38]; SAIN,LIM, score for the nutritional adequacy of individual foods, score for disqualifying nutrients[26].
* Test for heterogeneity across quartiles, based on ANOVA for continuous variables, χ^2 test for categorical variables.

Consistent with previous observations[5–9,13,14,16], Whitehall II participants with higher FVS and RFV scores had a higher nutritional adequacy and a higher energy intake. They were also more likely to have a higher employment grade and to be more active, and less likely to be current smokers. These results strengthen previous evidence that diet variety, especially from recommended foods, is associated with healthier behaviours[13,14,16] and further explain the protective effect of dietary variety on prospective mortality and CHD risk. However, participants with higher FVS and RFV scores were more likely to be

Table 3. Baseline dietary characteristics across variety score quartiles
(Mean values with their standard errors)

Score quartiles…	1		2		3		4		
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	*P**
FVS									
Energy (MJ)	7·41	0·06	8·85	0·05	9·67	0·06	11·5	0·07	<0·001
Food groups (g/8·4 MJ)									
Meat products and eggs	127	1·95	126	1·39	125	1·44	126	1·20	0·853
Fish and shellfish	32·0	0·84	32·3	0·61	32·2	0·57	34·6	0·51	0·007
Breads	94·1	1·59	90·3	1·25	86·7	1·27	78·7	1·03	<0·001
Breakfast cereals	35·8	1·22	37·1	0·90	38·5	0·95	36·3	0·74	0·224
Other starches	173	2·18	177	1·64	173	1·61	174	1·43	0·373
Dairy products	501	11·1	455	8·78	431	8·55	416	7·39	<0·001
Salted snacks and sweets	73·1	1·29	79·4	1·13	79·3	1·11	88·9	1·00	<0·001
Fruit and nuts	236	6·01	232	4·45	257	4·92	257	3·64	<0·001
Vegetables	215	3·68	230	2·92	244	3·08	248	2·38	<0·001
MAR	92·4	0·23	97·8	0·08	99	0·05	99·7	0·02	<0·001
MER	22·7	0·74	32·7	0·73	38·9	0·83	58·7	0·98	<0·001
Acceptable reporters†									<0·001
n	888		1478		1371		1582		
%	54·1		75·1		83·1		79·4		
RFV(Ofcom)									
Energy (MJ)	7·99	0·06	9·04	0·06	9·62	0·06	10·8	0·07	<0·001
Food groups (g/8·4 MJ)									
Meat products and eggs	128	1·91	126	1·48	126	1·30	124	1·34	0·388
Fish and shellfish	27·3	0·70	30·1	0·61	33·9	0·58	38·9	0·62	<0·001
Breads	92·7	1·59	89·8	1·33	87·8	1·13	79·2	1·14	<0·001
Breakfast cereals	33·4	1·14	37·6	0·99	37·5	0·82	38·5	0·88	0·001
Other starches	166	2·06	172	1·74	175	1·54	183	1·54	<0·001
Dairy products	454	10·2	445	9·12	449	8·27	450	8·59	0·917
Salted snacks and sweets	88·2	1·41	82·8	1·15	78·4	0·99	74·5	1·03	<0·001
Fruit and nuts	177	4·89	213	4·47	260	4·17	317	4·82	<0·001
Vegetables	174	2·95	215	2·77	246	2·66	291	3·00	<0·001
MAR	93·1	0·24	97·3	0·11	98·8	0·06	99·5	0·04	<0·001
MER	32·2	0·89	37·9	0·92	39·0	0·78	45·7	0·97	0·006
Acceptable reporters†									<0·001
n	928		1284		1704		1403		
%	60·7		73·4		79·3		76·6		
RFV(SAIN,LIM)									
Energy (MJ)	8·18	0·07	9·09	0·06	9·71	0·06	10·6	0·07	<0·001
Food groups (g/8·4 MJ)									
Meat products and eggs	125	1·84	127	1·39	127	1·42	125	1·36	0·758
Fish and shellfish	27·0	0·64	30·5	0·57	34·0	0·62	39·1	0·66	<0·001
Breads	93·4	1·59	90·2	1·21	85·8	1·24	80·0	1·14	<0·001
Breakfast cereals	32·6	1·09	36·6	0·87	37·4	0·97	40·1	0·89	<0·001
Other starches	170	2·04	174	1·61	174	1·66	179	1·57	0·004
Dairy products	450	10·2	446	8·43	442	8·94	459	8·55	0·579
Salted snacks and sweets	90·6	1·42	82·3	1·06	78·2	1·05	72·8	1·03	<0·001
Fruit and nuts	166	4·72	216	3·91	260	4·64	328	4·87	<0·001
Vegetables	163	2·65	217	2·50	246	2·82	301	3·07	<0·001
MAR	93·3	0·24	97·4	0·10	98·8	0·06	99·4	0·04	<0·001
MER	34·2	0·94	37·4	0·83	39·7	0·84	43·8	0·96	0·555
Acceptable reporters†									<0·001
n	928		1543		1417		1431		
%	61·5		73·8		80·3		75·8		

FVS, food variety score (total food variety); MAR, mean adequacy ratio[39]; MER, mean excess ratio[41]; RFV, recommended food variety score (healthier food variety); Ofcom, UK Ofcom nutrient profiling model[38]; SAIN,LIM, score for the nutritional adequacy of individual foods, score for disqualifying nutrients[26].
* Test for heterogeneity across quartiles, based on ANOVA for continuous variables, χ^2 test for categorical variables.
† Acceptable energy reporters identified using Goldberg cut-off values[44].

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Table 4. Hazard ratio (HR) estimates across variety score quartiles for the risk of fatal and non-fatal CHD, all-cause mortality and cancer mortality (Hazard ratios and 95 % confidence intervals)

	Fatal and non-fatal CHD (*n* 318 cases/7174)				All-cause mortality (*n* 524/7242)				Cancer mortality (*n* 251/7235)			
	Model 1*		Model 2		Model 1		Model 2		Model 1		Model 2	
Score quartiles/trend	HR	95 % CI	HR	95 % CI	HR	95 % CI	HR	95 % CI	HR	95 % CI	HR	95 % CI
FVS												
1	Ref		Ref		Ref		Ref		Ref		Ref	
2	0·70	0·52, 0·96	0·74	0·54, 1·01	0·75	0·59, 0·95	0·80	0·63, 1·02	0·75	0·54, 1·06	0·75	0·53, 1·06
3	0·84	0·61, 1·16	0·90	0·65, 1·25	0·75	0·58, 0·97	0·82	0·63, 1·06	0·68	0·47, 1·00	0·68	0·46, 1·00
4	0·56	0·39, 0·81	0·61	0·42, 0·89	0·67	0·50, 0·88	0·74	0·56, 0·99	0·75	0·50, 1·11	0·73	0·49, 1·10
Trend†	0·86	0·77, 0·97	0·89	0·79, 1·00	0·89	0·81, 0·97	0·92	0·84, 1·01	0·91	0·79, 1·03	0·90	0·79, 1·03
RFV(Ofcom)												
1	Ref		Ref		Ref		Ref		Ref		Ref	
2	0·79	0·57, 1·09	0·82	0·59, 1·14	0·68	0·53, 0·87	0·72	0·55, 0·92	0·65	0·45, 0·93	0·66	0·45, 0·95
3	0·79	0·58, 1·09	0·88	0·63, 1·21	0·67	0·53, 0·86	0·73	0·57, 0·94	0·64	0·45, 0·92	0·65	0·45, 0·93
4	0·92	0·66, 1·29	1·03	0·73, 1·46	0·81	0·63, 1·05	0·88	0·68, 1·16	0·81	0·56, 1·17	0·79	0·54, 1·16
Trend†	0·98	0·87, 1·09	1·02	0·91, 1·14	0·94	0·86, 1·02	0·96	0·88, 1·05	0·93	0·82, 1·06	0·93	0·82, 1·06
RFV(SAIN,LIM)												
1	Ref		Ref		Ref		Ref		Ref		Ref	
2	0·93	0·68, 1·26	0·99	0·72, 1·35	0·78	0·61, 0·99	0·83	0·65, 1·06	0·74	0·52, 1·05	0·76	0·53, 1·08
3	0·93	0·67, 1·28	1·03	0·74, 1·43	0·76	0·59, 0·99	0·84	0·64, 1·09	0·78	0·54, 1·12	0·79	0·55, 1·15
4	0·81	0·57, 1·14	0·91	0·64, 1·30	0·79	0·61, 1·03	0·87	0·66, 1·13	0·76	0·52, 1·10	0·75	0·51, 1·10
Trend†	0·94	0·84, 1·05	0·98	0·87, 1·09	0·93	0·86, 1·02	0·96	0·88, 1·05	0·93	0·82, 1·05	0·92	0·81, 1·05

FVS, food variety score (total food variety); Ref, reference; RFV, recommended food score (healthier food variety); Ofcom, UK Ofcom nutrient profiling model[38]; SAIN,LIM, score for the nutritional adequacy of individual foods, score for disqualifying nutrients[26].

* Model 1 adjusted for age, sex, ethnicity and energy intake; Model 2 further adjusted for marital status, employment grade, smoking status, physical activity level, alcohol intake, BMI categories and prevalence of longstanding illness. Models including the RFV were further adjusted for variety of less healthy foods.

† Linear trend was assessed using quartiles as continuous variable.

obese or overweight. These associations were weak but significant (except for RFV(SAIN,LIM)) and had not previously observed in Swedish and North-American women[13,14], may be explained by socio-demographic characteristics of Whitehall II participants. In the UK, the prevalence of overweight or obesity is higher in men and in men with lowest income households, i.e. closer to the profile of participants with higher FVS[45]. In line with observations made in the USA[13], age was positively associated with RFV scores, which would have explained the association between RFV scores and the prevalence of overweight and obesity.

A strength of the present study was the use of the Whitehall II cohort, in which participants have well-characterised health status and precisely determined socio-economic characteristics through repeated questionnaires and clinical examinations[29]. Dietary intakes have been reported in a validated FFQ[31], and dietary patterns identified either with cluster analysis or the Alternative Healthy Eating Index have been associated with the prospective risk of CHD, diabetes and mortality outcomes[4,46]. However, the Whitehall II sample size was smaller compared with previous examinations assessing health effects of recommended and non-recommended food variety[14,16], resulting in a lower statistical power and wider CI. The exclusion of energy misreporters and individuals with reported prevalent longstanding illness further reduced the sample size, not allowing for robust conclusions despite the strength of the suggested associations.

A limitation of the present study was in the definition of the variety scores since they were very dependent on the FFQ tool itself. The Whitehall II FFQ put more emphasis on fruit and vegetables (thirty-four items) compared with meat and fish products (16), dairy products (13) or snack foods (12). Hereby, participants with higher FVS or RFV scores were mechanically more likely to have a varied and increased intake of fruit and vegetables. Nevertheless, *post hoc* analyses adjusted for fruit and vegetable intake did not alter the conclusions. The use of alternative dietary assessment methods with no pre-defined list of food items such as dietary records or 24 h recalls could help in overcoming such limitation. Latest national dietary surveys in the UK, USA and France used such dietary assessment methods[47–49]; however, these rarely include follow-up for incident chronic disease and/or mortality. In addition, all variety scores had a minimum of zero. These very low scores could be explained by either a very high dietary variety (i.e. more foods consumed less than once a week) or by underreporting. Sensitivity analyses excluding 1 % of participants at the extremes of the variety score distributions did not alter the conclusions (data not shown), and Cox models excluding energy misreporters did not alter the conclusions from this report (*post hoc* analysis).

The stronger effects observed with the RFV scores compared with the NRFV scores, in particular, the cancer and all-cause mortality risk reduction observed with the middle quartiles of RFV(Ofcom), supported the rationale to promote higher variety of healthier foods and the move of Dietary Guidelines for Americans from the 'Eat a variety of food message' in 1995[50] to the 'Eat a variety of vegetables' and 'Choose a variety of protein foods' messages in 2010[20]. As recently illustrated, individuals tend to focus more on less healthy foods when thinking of healthy diets[51]. The present results, which would need confirmation in larger data sets and using alternative nutrient profile models, therefore, suggest that more focus should be put on promoting healthier foods and total food variety.

In the present study and unlike previous observations, the significant protective associations of the RFV(Ofcom) score were observed in the middle quartiles, suggesting that intermediate variety of healthier foods may be more favourable than higher variety of such foods. In previous studies, the 'Recommended' foods were defined on an *a priori* basis using food-based dietary guidelines[14,16,52], i.e. essentially linked to the identification of healthier dietary patterns rather than foods *per se*, which may have led to the stronger and linear protective effects. As an example, in the recent study by Larsson *et al.*[52], all fruit and vegetables and all fish products, but no meat or poultry products often associated with Western style dietary patterns, were included in the recommended food score. In addition, both the UK Ofcom and SAIN,LIM models were virtually across-the-board, i.e. they scored almost all foods using a similar algorithm. Such approach, although allowing to better align classification of foods with existing dietary guidelines, may not be the most appropriate to identify healthier dietary patterns[53]. Conducting similar analyses using category-specific models would allow assessing whether the present results could be explained by the choice of nutrient profile models.

Previous results regarding the association between increased variety of non-recommended foods and prospective health outcomes have not been consistent. No association has been found with all-cause mortality risk in a cohort of Swedish women[14]; however, a positive association was observed with the risk of stroke in the same population[52]. A positive association with all-cause mortality risk was observed in Swedish men[16]. In addition, dietary variety of sweets, snacks, condiments, carbohydrates and entrées was associated with increased body fatness in a small US population[54]. No robust associations could be identified in the present study.

The use of nutrient profiling to identify the recommended (or healthier) and non-recommended (or less healthy/unhealthy) foods was another strength of the present analysis since no previous assumption was made on the healthiness of particular foods. The stronger associations observed with the UK Ofcom nutrient profile model indicated that it may be a more adequate model to identify dietary patterns predictive of improved health status, compared with the SAIN,LIM. This result may be explained by the fact that the SAIN,LIM model was more restrictive when selecting healthier foods. As opposed to the RFV(Ofcom), foods such as pears, grapes, wholemeal bread, brown rice, boiled potatoes or vegetable soups were not included in the RFV(SAIN,LIM). In contrast, full-fat milk products were considered healthier by the SAIN,LIM and not by the UK Ofcom model. However, Darmon *et al.*[26] have indicated that the SAIN,LIM did identify 'most unrefined starches and grains' as healthier in a French database. Differences in food composition database may explain these diverging classifications of foods, as well as the fact the Whitehall II FFQ items were calculated as weighted average of several individual foods, i.e. not reflecting the true nutrient content of specific foods. In addition, the SAIN,LIM was developed and validated using French data; an adaptation of criteria and target values may be needed when implementing the model on foreign data. The inclusion in the UK Ofcom algorithm of fruit, vegetable and nut content as a positive nutritional component could have explained the stronger associations; however, analyses adjusted for fruit, vegetable and nut intake did not alter the conclusions.

To the best of our knowledge, only one study has linked a nutrient profile model, the US Overall Nutrition Quality Index (ONQI), to prospective risk of chronic disease and mortality[55]. A diet index based on the ONQI was associated with modest reduced risk of total chronic disease, CVD, diabetes and total mortality in the US Nurses' Health study and Health Professionals Follow-up Study datasets. Unlike the RFV scores, the ONQI diet index did not account for diet variety. Cross-validation of the present results with the ONQI model and in the two US data sets would strengthen the nutrient profiling rationale.

The results from the present analysis strongly support the inclusion of messages recommending increased overall diet variety and variety from healthier foods in public health recommendations. In this respect, nutrient profiling could become the most adequate tool to help identify healthier foods; however, more research is needed to assess nutrient profile models and their ability to predict prospective health in various populations. The consistency with previous results with regard to the association between food variety and nutritional adequacy would support the generalisability of the present findings. The use of alternative datasets, and more particularly alternative dietary assessment tools, should therefore confirm the beneficiary health effects of total food variety and variety of healthier food options.

Supplementary material

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S000711451500094X

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