Dietary Patterns and Heritability of Food Choice in a UK Female Twin Cohort

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To examine the contribution of genetic factors to food choice, we determined dietary patterns from food frequency questionnaires in 3262 UK female twins aged 18 to 79 years. Five distinct dietary patterns were identified (fruit and vegetable, high alcohol, traditional English, dieting, low meat) that accounted for 22% of the total variance. These patterns are similar to those found in other singleton Western populations, and were related to body mass index, smoking status, physical activity and deprivation scores. Older subjects had higher scores on the fruit and vegetable and traditional English patterns, while lower social deprivation was associated with higher scores for fruit and vegetable, and lower scores for traditional English patterns. All 5 patterns were heritable, with estimates ranging from 41% to 48%. Among individual dietary components, a strongly heritable component was identified for garlic (46%), coffee (41%), fruit and vegetable sources (49%), and red meat (39%). Our results indicate that genetic factors have an important influence in determining food choice and dietary habits in Western populations. The relatively high heritability of specific dietary components implicates taste perception as a possible target for future genetic studies.

There is a growing body of evidence demonstrating that diet modifies the risk of chronic disease, for example, cardiovascular disease (Kris-Etherton et al., 2005; Voutilainen et al., 2006), arthritis (Choi, 2005), respiratory conditions (Wickens et al., 2005), cancer (Colomer & Menendez, 2006; Vainio & Weiderpass, 2006) and inflammatory disorders (Calder, 2006). However, reducing the occurrence of disease through dietary modification is not easy, as the factors influencing an individual's choice of diet are manifestly complex.

While social and environmental factors have a well-established and important influence in determining an individual's dietary pattern, there is increasing awareness of the contribution of genetic factors. Two studies of twins have indicated that these may account for up to 50% of total variance in dietary behaviours in US populations (Gunderson et al., 2006; van den Bree et al., 1999). These studies are important in providing an understanding of the etiological determinants of food choice. Establishing the extent to which genetic factors explain variation in dietary patterns might provide an indication of the most appropriate measures for population-based intervention strategies to improve human health.

The aim of the present study was to carry out a comprehensive investigation of the dietary patterns of twins enrolled on the Twins UK Registry, using data derived from food frequency questionnaires (FFQs), in order to determine the relative genetic and environmental influences on food choices and nutrient intake. This approach focuses on dietary patterns, which have been studied extensively in the United States, and to a lesser extent in Europe (Fung et al., 2001; Hu, 2002; Osler et al., 2001); there is also a scarcity of data from twin studies. Dietary patterns better represent the long-term, complex, and often subtle interactive effects of multiple dietary exposures, and hence the effect of overall dietary intake (Hu, 2002; Jacques & Tucker, 2001; Newby et al., 2003), than measures of nutrient intake alone.

Materials and Methods

Study Population

The study participants were twins enrolled on the Twins UK Registry. This is a national sample of adult twin volunteers assembled through successive media campaigns aimed at recruiting healthy individuals for medical research (Spector & Williams, 2006). The twins were not selected for disease-specific studies. Initial recruitment into the Registry focused on female pairs, and there has been an emphasis on recruiting

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DZ twins for genetic studies. Zygosity was derived by questionnaire and confirmed by multiplex DNA fingerprinting (PE Applied Biosystems, Foster City, CA). Ethical approval for this study has been obtained from St. Thomas' Hospital Research Ethics committee and informed consent was obtained from all subjects.

Twins included in this sample were female UK residents aged 18 to 80 years without metabolic illnesses likely to affect food intake or require dietary modification. All completed a FFQ and attended clinical assessment at St Thomas' Hospital between 1996 and 2000. Participants also completed lifestyle questionnaires that included questions on smoking and physical activity.

Food Frequency Questionnaire Data Processing

Subjects completed a 131-item FFQ previously used in the EPIC study (Bingham et al., 2001), which has been validated against urinary biomarkers and plasma ascorbic acid levels (Bingham et al., 1997). An established nutrient database was used to derive nutrient intake. The 131 food items were aggregated into 54 food groups, defined by similarity in nutrient content and culinary use. Frequency of intake for a food group was calculated as the sum of the servings per week for the individual food items. For the heritability analyses, 24 custom food types were also defined (shown in Appendix A). These were compiled by a further grouping of food information obtained from the FFQ questionnaires. These larger groups were based on common tastes and nutrient content.

Subjects were excluded from the analysis for the following reasons: answers for more than 10 food items were left blank; the ratio of the FFQ derived estimate of total energy intake to the subject's estimated basal metabolic rate (based on the Harris-Benedict equation [Frankenfield et al., 1998]) was outside two standard deviations from the mean of that ratio (< 0.52 or > 2.58); the subject's twin had not completed an eligible FFQ.

Covariates

Area-based deprivation scores were derived for all subjects with valid UK postcodes. Ninety-three per cent of participants lived in England, where the Index of Multiple Deprivation (Office of the Deputy Prime Minister, 2004) has been calculated for small areas of about 1500 residents. It is made up of seven domains: income; employment; health; education; barriers to services; environment; crime. Similar deprivation scores were used for residents in Scotland, Wales and Northern Ireland. Smoking status was defined as currently smoking, former smoker, or never smoked. Physical activity, based on work, home and leisure activity, was aggregated into three groups: sedentary, moderately active, and active. BMI was calculated using the Quetelet index, with categories based on WHO criteria (WHO, 1998). Vitamin supplementation was recorded as yes or no.

Statistical Analyses

Dietary Patterns

Principal components analysis (PCA) was used to identify patterns of dietary consumption. For each food group, the frequency of intake (servings/week) was adjusted for total energy intake, using the residual method (Willet & Stampfer, 1986). The energy-adjusted intakes were then standardized to z scores, and these were used in the PCA.

The PCA ignored the twin-pair structure, and the use of related individuals may have affected the results. To test this, an estimate of the sampling distribution of the components in unrelated individuals was generated using bootstrap techniques. For 10,000 bootstrap replications, the PCA was carried out on subsamples in which one twin from each pair was selected at random. The loadings for the PCA on the full dataset were compared to a 95% confidence interval derived from the 2.5% and 97.5% percentiles of this empirical distribution. Although in PCA the choice of sign for contrasting elements within a component is arbitrary, there were food items that were always in opposition to each other, so that signs could be allocated consistently between iterations.

Differences between MZ and DZ means for age, BMI, macronutrient intakes and dietary pattern scores were analyzed using t tests. Differences in variances were tested using a clustered version of Levene's test for homogeneity of variances (Iachine et al., 2004). Differences in smoking status, deprivation, and physical activity were investigated using chi-squared tests. Relationships between dietary pattern scores and lifestyle variables were analysed using one-way ANOVA.

Heritability

The heritability of the scores for the first 5 dietary components and for the energy-adjusted food type intakes was investigated. First, these were residual-adjusted for age. Box-Cox power transformations were then applied to these measures to obtain variables with zero skewness. Linear structural equation modeling was used to estimate the genetic and environmental components of variance in the transformed pattern scores and food type intakes. Univariate ACE and ADE models that decompose the phenotypic variance into that due to additive genetic effects (A), dominant genetic effects (D), environmental effects shared in common (C), and nonshared environmental effects (E) were considered. ACE models assume that additive genetic effects are completely correlated in MZ twins and have a correlation of .5 in DZ twins. ADE models assume that dominant genetic effects have a correlation of .5 in MZ twins and .25 in DZ twins. Both assume that the shared environment contributes equally to the correlations for MZ and DZ twins. Non-nested submodels were assessed using Akaike's information criterion (AIC) as a measure of parsimony and goodness-of-fit. The best fitting model was defined as having the lowest AIC. Maximum likelihood parameter estimates for the best fitting model for each variable, together with goodness-of-fit statistics, are presented in the results section. The models used assume that phenotypic variances in MZ and DZ twins are the same. This was tested by a likelihood ratio test (on 1 *df*), examining the change in fit produced by scaling the covariance matrix in one of the zygosity groups, so that the MZ and DZ variances were equal. Where this test was significant at 5%, the scaling parameter was included in the model. This test for the necessity of using a variance scaling parameter differs from the more general test for homogeneity of clustered variances (Iachine et al., 2004) described earlier, as it enables the unequal variances to be addressed directly in Mx.

Statistical analyses were carried out using Stata version 9.2 (StataCorp, 2006) and with the Mx software package (Neale et al., 2002). Model fitting in Mx was carried out on raw data, with goodness-of-fit statistics calculated as the difference between the model fitted and the fully saturated model.

Results

Characteristics of Sample

Dietary data were available for 498 MZ twin pairs and 1133 DZ twin pairs ($n = 3262$; Table 1). Three hundred and thirty-five individuals were not included in the analysis because we did not have data from their twin. The mean and variance of dietary measures were similar in the MZ and DZ groups, although the two types of twin differed in their distributions of age and BMI. Their dietary intakes were similar to those reported in UK nontwin samples. Mean energy intake was 8446 kJ/d, which is similar to the estimated average requirement for adult women (8100 kJ for ages 19 to 50 years, and 8000 kJ for 50 to 59 years; COMA, 1991). Energy intake was comparable to that found in the EPIC study (Bingham et al., 2001; 8080kJ), which used a similar FFQ, but approximately 20% higher than the energy intake figures recorded in the National Diet and Nutrition Survey (Henderson et al., 2004), which used a seven day diet record. Macronutrient intakes were also consistent with those found in EPIC (32% for total fat, 17% for protein, and 47% for carbohydrate). The rates of smoking and physical activity were similar to those reported in other national studies (Goddard, 2006; Sproston & Primatesta, 2004). Vitamin supplementation levels were very similar to those in NDNS (Henderson et al., 2004). More participants were in the least deprived categories for deprivation, compared to national rates.

Dietary Patterns

The scree plot of the first 20 components from the PCA (Figure 1) shows elbows after the first and fifth components. As components 2 to 5 are interpretable in terms of plausible dietary patterns, these were retained. The total variance explained by the first 5 components was 22%. Their loadings are shown in Table 2. The 5 patterns identified were:

Fruit and vegetable. Frequent intakes of fruit, allium and cruciferous vegetables; low intakes of fried potatoes.

High alcohol. Frequent intakes of beer, wine and allium vegetables; low intakes of high fiber breakfast cereals and fruit.

Traditional English. Frequent intakes of fried fish and potatoes, meats, savoury pies and cruciferous vegetables.

Dieting. Frequent intakes of low-fat dairy products, low-sugar soda; low intake of butter and sweet baked products.

Low meat. Frequent intakes of baked beans, pizza and soy foods; low intakes of meat, other fish and seafood, and poultry.

There were no significant differences in mean dietary pattern scores between MZ and DZ twins. All loadings lie within the 95% confidence intervals generated from the bootstrapped samples, suggesting that the twin-based results are consistent with those from samples of unrelated individuals.

Reproducibility

A group of 750 respondents completed a second FFQ, at intervals ranging from 6 months to 6 years after their first questionnaire. Test–retest correlation coefficients are shown in Table 3. The reproducibility was higher for the components that explained more of the variation in intake, and did not seem to reduce greatly with a longer interval between measurements.

Nutrient Composition of Patterns

Table 4 shows mean nutrient levels for each tertile of the 5 dietary patterns. Those with higher scores for the healthier patterns (fruit and vegetables, dieting and low meat) generally had more favourable nutrient profiles, while those who scored highly on the less healthy patterns (high alcohol and traditional English) tended to have less favourable nutrient intakes.

Pattern Scores and Covariates

Table 5 shows mean dietary pattern scores by age, BMI, deprivation index, smoking status, and physical activity. The fruit and vegetable score significantly increased with age and physical activity and decreased with BMI. The score on the high alcohol pattern significantly decreased with age, BMI, and physical activity, in contrast with the traditional English pattern score, which showed a significant increase with all three. The dieting pattern score increased with age, decreased with BMI, and increased with physical activity. The low meat pattern score showed a significant decreasing trend with age and physical activity. The fruit and vegetable pattern score decreased with increasing values of the deprivation index, while the traditional English and low meat pattern scores increased with

Table 1

Characteristics of the Study Population and Comparison of Dietary Results by Zygosity

		All subjects (n = 3262)				MZ only (n = 996)		DZ only (n = 2266)			
		Min	Max	Mean	*SD*	Mean	*SD*	Mean	*SD*	*P* (mean)*	*P* (var)*
Age		18	79	48.14	12.80	49.79	13.79	47.41	12.28	†	†
Height		142	191	162.4	6.17	162.1	6.15	162.5	6.17	.057	.142
BMI (kg/m2)		13.92	48.22	25.25	4.47	24.63	4.01	25.38	4.64	†	†
Energy intake (kJ)		2663	19426	8446	2239	8480	2159	8434	2272	.055	.638
Carbohydrates (% of total energy)		23.3	72.2	49.7	6.3	49.82	6.4	49.7	6.2	.317	.612
Protein (% of total energy)		8.17	30.04	16.65	2.78	16.69	2.69	16.63	2.83	.051	.587
Total fat (% of total energy)		9.83	52.75	30.21	5.43	30.23	5.38	30.21	5.45	.943	.921
Saturated fat (% of total energy)		3.05	27.50	11.27	2.84	11.26	2.89	11.28	2.82	.265	.880
Polyusaturated fat (% of total energy)		2.01	17.56	6.70	1.65	6.73	1.65	6.69	1.65	.678	.581
Monosaturated fat (% of total energy)		2.93	20.03	10.07	2.10	10.05	2.05	10.08	2.12	.678	.850
Trans fat (% of total energy)		0.06	2.65	0.87	0.30	0.87	0.30	0.86	0.30	.550	.541
Fruit and veg pattern score		–7.45	23.61	0.00	2.11	0.09	2.09	–0.04	2.12	.911	.188
High alcohol pattern score		–6.86	7.28	0.00	1.44	–0.08	1.41	0.03	1.45	.390	.085
Traditional English pattern score		–5.70	15.69	0.00	1.40	–0.02	1.35	0.01	1.42	.356	.704
Dieting pattern score		–7.50	9.12	0.00	1.32	–0.05	1.27	0.02	1.35	.662	.229
Low meat pattern score		–7.68	10.26	0.00	1.31	–0.03	1.30	0.01	1.31	.928	.415
		%	*n*			%	*n*	%	*n*	*P*	
Smoking status	Current	15.2	218			9.2	29	16.9	189	†	
	Former	30.7	440			24.8	78	32.3	362		
	Never	54.1	777			20.9	208	50.8	569		
National quintile	Quintile 1	6.1	185			4.8	44	6.7	141	.007	
of deprivation index	Quintile 2	13.3	406			11.7	108	14.1	298		
(1=most deprived)	Quintile 3	20.3	619			20.8	192	20.2	427		
	Quintile 4	26.1	793			24.6	227	26.7	566		
	Quintile 5	34.2	1039			38.2	353	32.4	686		
Physical activity	Inactive	37.6	595			33.0	150	39.4	445	.030	
	Moderately active	25.1	397			25.1	114	25.1	283		
	Active	37.3	591			41.9	190	35.5	401		
Vitamin supplementation	Yes	55.2	1412			56.2	533	53.2	1206	.234	
	No	44.8	1739			43.8	415	44.0	997		

Note: **P* values for mean comparison using *t* tests, for variance using a clustered version of Levene's test (except age, where standard Levene with one obs/pair was used)

† $P < .001$

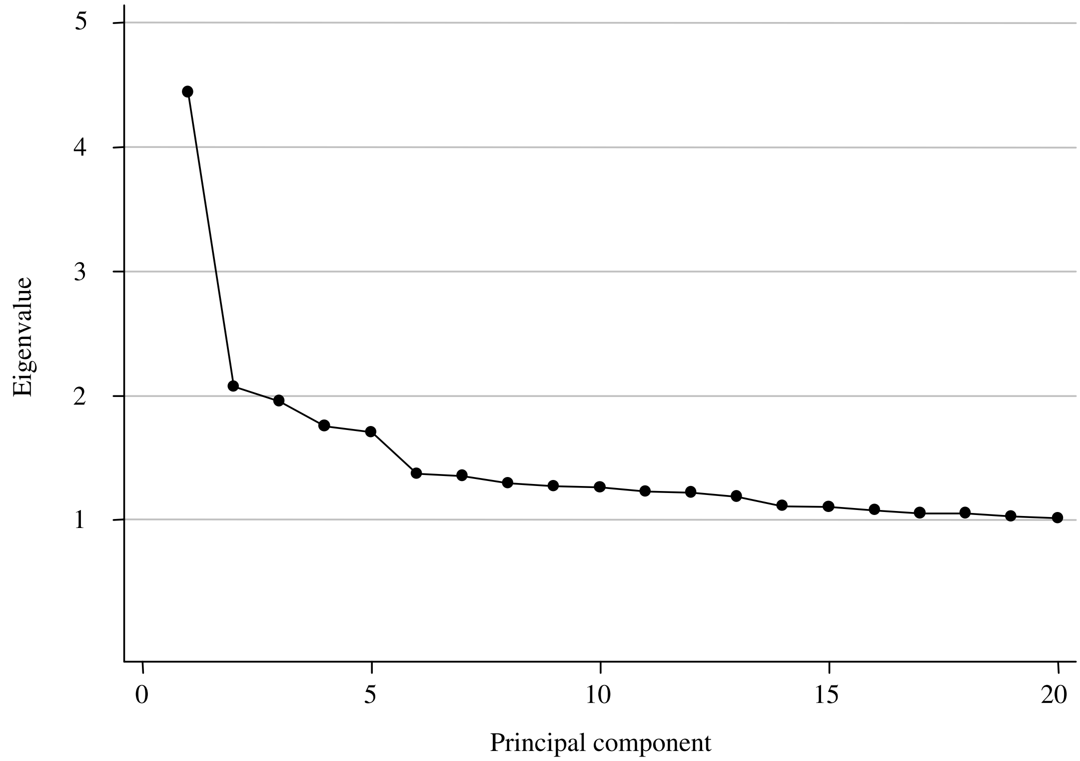

Figure 1

Scree plot of the eigenvalues of the first 20 principal components.

deprivation. Smoking status was related to scores on the first three patterns.

Heritability

Table 6 shows the results of the model fitting for the 5 dietary patterns derived from the PCA and the 24 custom food types (defined in Appendix A). Parameter estimates from the best-fitting model are shown. Additive genetic factors contributed to all models. A contribution from the shared environment was found for the first PCA-derived component ('fruit and vegetable') and for four of the custom food types: 'salad', 'alcohol', 'fast food', and 'fish except fried'. Dominant genetic effects were found only for savoury tastes, fruit juice, and refined grains. The heritability of all 5 dietary patterns exceeded 40%. For the custom food types of fruit and vegetable sources, garlic, fruit, and coffee, additive genetic effects accounted for over 40% of the variance in consumption. The variance scaling parameter was fitted for six of the models. Variance differences do not account completely for the poor fit in some models, as shown by the fact that the fit may remain poor after the variances are scaled to be equal.

Discussion

We found, in a population of twins with comparable population characteristics and energy intakes to both similar UK singleton (Henderson et al., 2004, Sproston & Primatesta, 2004), and US twin populations (van den Bree et al., 1999), 5 distinct dietary patterns that explain 22% of the total variance in the FFQ data. These dietary patterns were similar to those found in other Western populations (Adebamowo et al., 2005; Schulze et al., 2001) and were related to BMI, smoking and physical activity. All 5 patterns are heritable, with additive genetic effects accounting for between 41% and 48% of the variance in all of the first 5 PCA pattern scores. The most heritable foods were garlic, coffee, and fruit and vegetables, where the proportion of variance explained by genetic factors was over 40%.

The representativeness of the study sample is an important factor in all volunteer based studies of twins. We have previously shown that the present sample of female twins is representative of adults in the UK population with respect to the anthropometric characteristics, frequency of disease related traits, lifestyle, and environmental exposures (Andrew et al., 2001). Our analysis of the present data shows that the patterns of food intake in responding pairs in the present twin cohort are broadly comparable to those reported in a number of large-scale population-based studies of nutrition. In the Nurses' Health cohort in the United States (Adebamowo et al., 2005), the two patterns generated were similar to our traditional English and fruit and vegetable patterns. Patterns comparable to our first four patterns were found in the EPIC

Table 2

Food Items (n = 3262): Distribution of Consumption and Factor Loadings for the First 5 Dietary Patterns With Bootstrapped 95% Confidence Intervals*

			Factor loading with bootstrapped 95% CI for the first 5 dietary patterns (% variance explained by each pattern shown next to pattern name)									
Food item	% consuming any	Servings/wk mean (*SD*)	Fruit and vegetable (8.2%)		High alcohol (3.9%)		Traditional English (3.6%)		Dieting (3.3%)		Low meat (3.2%)	
Baked beans	75.5	1.1 (1.3)	–.01	(–.04, .01)	–.07	(–.18, .10)	.17	(–.01, .25)	.10	(–.19, .36)	**.31**	(–.16, .37)
Beefburgers	16.4	0.1 (0.3)	–.14	(–.16,–.13)	.13	(–.11, .23)	.18	(–.02, .25)	.15	(–.02, .23)	.08	(–.18, .19)
Beer	35.7	0.9 (2.7)	–.03	(–.05,–.01)	**.22**	(.07, .26)	.00	(–.18, .17)	.09	(–.03, .16)	.04	(–.12, .14)
Berries	79.4	0.7 (1.0)	.16	(.14, .19)	–.05	(–.11, .04)	–.05	(–.11, .04)	.00	(–.10, .09)	–.05	(–.13, .06)
Butter	47.1	3.1 (6.3)	–.07	(–.09,–.05)	.11	(.00, .19)	–.03	(–.16, .13)	**–.35**	(–.40,–.03)	**–.20**	(–.40, .37)
Citrus fruit	83.5	3.3 (4.3)	.19	(.16, .21)	–.11	(–.16,–.01)	–.01	(–.12, .09)	.08	(–.11, .16)	–.07	(–.15, .06)
Coffee	75.2	11.3 (12.3)	–.01	(–.04, .01)	.17	(.04, .21)	–.01	(–.17, .14)	.13	(–.20, .23)	–.16	(–.25, .06)
Cooked potatoes	96.9	3.6 (2.6)	.03	(.00, .05)	–.19	(–.27, .00)	.19	(–.02, .28)	–.08	(–.17, .08)	–.02	(–.15, .15)
Crisp bread	38.7	1.2 (3.7)	.11	(.09, .14)	–.06	(–.11, .02)	–.03	(–.10, .05)	.03	(–.07, .10)	.02	(–.08, .11)
Dairy products; high fat	97.6	5.4 (5.4)	–.07	(–.09,–.06)	.14	(.00, .20)	–.13	(–.21, .02)	–.12	(–.20, .02)	–.07	(–.18, .16)
Dairy products; low fat	93.6	6.6 (4.6)	.15	(.13, .17)	**–.29**	(–.33,–.06)	–.05	(–.24, .21)	.25	(–.09, .29)	–.02	(–.27, .22)
Drinks; other	73.7	6.1 (9.5)	.04	(.02, .06)	–.07	(–.14, .07)	–.10	(–.17, .02)	.17	(–.01, .23)	.11	(–.19, .23)
Eggs	86.3	1.4 (1.4)	.00	(–.02, .02)	.04	(–.08, .12)	.11	(.01, .17)	–.05	(–.14, .07)	–.06	(–.16, .11)
Fried fish	52.4	0.4 (0.6)	–.11	(–.13,–.09)	–.02	(–.18, .13)	**.21**	(.08, .24)	–.01	(–.11, .10)	.03	(–.07, .13)
Fried potatoes	88.8	1.7 (1.4)	**–.21**	(–.22,–.19)	.09	(–.17, .23)	**.22**	(.04, .27)	.01	(–.12, .17)	.12	(–.05, .19)
Fruit juice	80.0	3.2 (4.1)	.09	(.07, .12)	.06	(–.03, .12)	–.07	(–.14, .03)	.08	(–.08, .13)	–.04	(–.13, .07)
High fat breakfast cereals	70.0	2.8 (3.2)	.06	(.04, .09)	**–.23**	(–.29, .04)	–.14	(–.26, .12)	.13	(–.17, .23)	–.13	(–.27, .08)
Lasagne	43.2	0.3 (0.4)	.01	(–.01, .03)	.13	(.02, .18)	.00	(–.14, .13)	**.25**	(–.00, .31)	.13	(–.27, .29)
Legumes	98.1	3.7 (2.8)	.19	(.16, .21)	.03	(–.24, .23)	**.29**	(.10, .33)	–.16	(–.27, .18)	.13	(–.09, .28)
Low fat breakfast cereals	32.7	1.2 (2.4)	–.07	(–.09,–.05)	–.06	(–.11, .01)	.05	(–.04, .11)	–.05	(–.12, .10)	.07	(–.03, .14)
Low fat spread	27.9	2.3 (6.1)	.02	(–.01, .04)	–.10	(–.14,–.01)	.02	(–.09, .12)	.15	(–.01, .22)	.11	(–.18, .22)
Margarine	26.6	1.5 (4.5)	–.09	(–.11,–.07)	–.01	(–.08, .07)	.07	(–.01, .12)	.00	(–.12, .16)	.13	(–.04, .20)
Meat	87.4	2.2 (1.8)	–.10	(–.12,–.08)	–.02	(–.27, .21)	**.34**	(.11, .41)	.05	(–.35, .31)	**–.32**	(–.39, .02)
Nuts	51.0	0.8 (1.8)	.06	(.02, .09)	.14	(–.02, .24)	–.15	(–.25, .01)	–.12	(–.20, .11)	.07	(–.09, .18)
Oily fish	76.1	0.9 (1.2)	.15	(.12, .19)	.01	(–.04, .07)	–.01	(–.09, .07)	.02	(–.16, .13)	–.12	(–.17, .02)
Other fish and seafood	79.2	1.0 (1.1)	.18	(.16, .21)	.07	(–.03, .13)	.07	(–.06, .18)	–.04	(–.25, .19)	**–.20**	(–.26, .07)
Other fruit	98.3	12.5 (9.9)	**.27**	(.25, .29)	–.21	(–.26, .00)	–.07	(–.21, .13)	.09	(–.06, .14)	–.01	(–.13, .10)
Pizza	63.5	0.6 (0.7)	–.06	(–.08,–.04)	.15	(.02, .22)	–.10	(–.21, .07)	.18	(–.09, .31)	**.22**	(–.20, .32)
Polyunsaturated margarine	57.3	4.7 (7.4)	–.02	(–.04, .00)	–.08	(–.14, .03)	–.06	(–.15, .06)	.07	(–.10, .21)	.18	(–.10, .25)

Note: Figures in bold are loadings ≥ .2 or ≤ –.2

*Bootstrapped confidence interval derived from 10,000 replications using a single, randomly selected member of each twin pair.

(continued over)

Table 2 (continued)

Food Items (n = 3262): Distribution of Consumption and Factor Loadings For the First 5 Dietary Patterns With Bootstrapped 95% Confidence Intervals*

Food item	% consuming any	Servings/wk mean (*SD*)	Factor loading with bootstrapped 95% CI for the first 5 dietary patterns (% variance explained by each pattern shown next to pattern name): Fruit and vegetable (8.2%)		High alcohol (3.9%)		Traditional English (3.6%)		Dieting (3.3%)		Low meat (3.2%)	
Porridge	32.4	0.8 (1.8)	.08	(.06, .10)	–.13	(–.17, –.03)	.05	(–.08, .15)	–.14	(–.20, .05)	.00	(–.15, .17)
Poultry	93.3	1.9 (1.3)	.05	(.03, .07)	–.02	(–.13, .09)	.14	(.01, .25)	.17	(–.30, .32)	**–.25**	(–.33, .04)
Processed meats	89.6	2.6 (2.3)	–.10	(–.12,–.08)	.02	(–.25, .24)	**.32**	(.10, .38)	.13	(–.23, .28)	–.16	(–.27, .06)
Salad dressing high fat	68.8	1.6 (2.2)	.12	(.09, .14)	**.30**	(.08, .34)	–.11	(–.31, .13)	–.02	(–.10, .08)	–.03	(–.10, .07)
Salad dressing low fat	39.4	0.7 (1.5)	.14	(.10, .17)	–.02	(–.13, .11)	.10	(–.03, .19)	.18	(–.03, .27)	.13	(–.20, .25)
Savoury pies	38.6	0.3 (0.5)	–.19	(–.21,–.17)	.03	(–.20, .19)	.24	(.09, .27)	.00	(–.10, .09)	–.01	(–.09, .09)
Savoury snacks	83.0	2.5 (3.4)	–.10	(–.12,–.08)	.12	(.03, .17)	–.03	(–.12, .08)	.04	(–.07, .13)	.09	(–.07, .15)
Seasonings	94.9	3.9 (4.0)	.02	(.00, .05)	.05	(–.05, .11)	.07	(–.04, .14)	.02	(–.15, .23)	.18	(–.06, .25)
Soda; high sugar	38.1	1.0 (3.0)	–.08	(–.10,–.06)	.09	(–.01, .15)	.04	(–.07, .12)	.08	(–.05, .19)	.11	(–.12, .20)
Soda; low sugar	46.6	2.3 (5.3)	.02	(–.01, .04)	.06	(–.05, .14)	.04	(–.10, .18)	**.33**	(–.05, .36)	.08	(–.34, .33)
Soup	68.0	1.0 (1.6)	.12	(.10, .14)	–.03	(–.10, .03)	.03	(–.05, .11)	.05	(–.17, .18)	–.13	(–.20, .02)
Soy and other milk	1.3	0.0 (0.5)	.05	(.03, .08)	.00	(–.06, .08)	–.03	(–.11, .05)	–.15	(–.22, .12)	.08	(–.10, .21)
Soy foods	11.2	0.2 (0.9)	.11	(.07, .14)	.06	(–.06, .17)	–.09	(–.24, .05)	–.15	(–.37, .40)	.38	(.03, .43)
Spirits and liquor	52.0	1.4 (3.2)	.00	(–.02, .02)	**.20**	(.06, .23)	.01	(–.17, .16)	.10	(–.18, .20)	–.13	(–.21, .04)
Sweet baked	95.2	8.9 (9.8)	–.16	(–.17,–.14)	**–.22**	(–.26, .00)	–.10	(–.25, .14)	**–.22**	(–.27, .10)	.00	(–.20, .24)
Sweets and sweet condiments	97.3	12.8 (14.9)	–.17	(–.19,–.15)	–.02	(–.08, .05)	–.01	(–.13, .09)	**–.26**	(–.29, .17)	.09	(–.19, .28)
Tea	86.9	20.4 (14.2)	–.03	(–.05,–.01)	**–.23**	(–.28,–.05)	.08	(–.13, .26)	**–.24**	(–.29, .12)	.02	(–.22, .27)
Vegetables; allium	93.2	4.4 (4.0)	**.23**	(.21, .25)	**.27**	(.04, .30)	.06	(–.18, .23)	–.13	(–.18, .07)	.02	(–.13, .18)
Vegetables; cruciferous	98.1	5.9 (4.7)	**.21**	(.17, .24)	–.03	(–.32, .26)	**.36**	(.14, .39)	–.08	(–.20, .15)	.07	(–.08, .19)
Vegetables; green leafy	95.3	3.3 (2.9)	**.30**	(.28, .32)	.12	(–.04, .17)	.07	(–.06, .15)	–.06	(–.12, .10)	.07	(–.04, .13)
Vegetables; other	98.4	6.6 (5.7)	**.32**	(.30, .33)	.18	(–.09, .26)	.15	(–.05, .25)	–.13	(–.20, .15)	.12	(–.07, .19)
Vegetables; yellow	99.5	6.1 (4.2)	**.30**	(.28, .32)	–.03	(–.17, .13)	.18	(.06, .23)	–.09	(–.15, .11)	.06	(–.07, .15)
White and brown bread, refined grains	98.6	11.3 (9.7)	–.11	(–.13,–.09)	.04	(–.02, .09)	–.03	(–.10, .05)	–.02	(–.14, .17)	.15	(–.04, .22)
Wholemeal bread and grains	79.7	5.3 (7.4)	.15	(.12, .17)	–.11	(–.22, .12)	–.18	(–.23, .00)	–.01	(–.10, .08)	–.01	(–.10, .08)
Wine	74.5	3.0 (5.0)	.08	(.06, .10)	**.33**	(.07, .37)	–.14	(–.35, .14)	.03	(–.25, .21)	**–.22**	(–.27, .02)

Note: Figures in bold are loadings ≥ .2 or ≤ –.2

*Bootstrapped confidence interval derived from 10,000 replications using a single, randomly selected member of each twin pair.

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Table 3

Pearson Correlation (95% CI) Between Successive Estimates of Pattern Scores by Interval Length (y)

Pattern	Length of interval between questionnaires			
	0.5–2 y (*n* = 144)	> 2–3 y (*n* = 289)	> 3–6 y (*n* = 317)	All (*n* = 750)
Fruit and vegetable	.83 (.77, .87)	.82 (.78, .85)	.72 (.67, .77)	.78 (.75, .81)
High alcohol	.70 (.61, .78)	.79 (.74, .83)	.65 (.58, .71)	.73 (.69, .76)
Traditional English	.61 (.50, .70)	.63 (.55, .69)	.56 (.48, .63)	.59 (.54, .64)
Dieting	.66 (.55, .74)	.74 (.68, .79)	.65 (.59, .71)	.69 (.65, .72)
Low meat	.46 (.32, .58)	.71 (.65, .76)	.60 (.52, .66)	.63 (.58, .67)

Potsdam study — a cohort of over 20,000 men and women aged 35 to 64 years (Schulze et al., 2001). Our patterns were also similar to those found in the only two studies of dietary patterns in twins to date. A pattern high in fat, salt, and sugar, similar to our traditional English pattern, and a more healthful pattern, comparable to our fruit and vegetable pattern, were found in a study of US twins aged 50 years and over (van den Bree et al., 1999). A smaller study in an American population (Gunderson et al., 2006) also found two similar healthy and unhealthy patterns.

The 5 patterns reported in the present study explained 22% of the total variance, a finding comparable to those of other studies using PCA to examine FFQ data (Williams et al., 2000; van Dam et al., 2003; Velie et al., 2005). While these patterns from different population groups are similar, differences in highly-loading foods occur, reflecting differences in the availability and consumption of individual foods in different countries.

The dietary patterns of the twins showed a relationship with age, as has been reported in previous studies of singleton populations (Schulze et al., 2001; Williams et al., 2000), with older subjects having higher scores on the fruit and vegetable and traditional English patterns. Participants in less deprived areas had higher scores for fruit and vegetables, and lower scores for traditional English patterns. Deprivation has previously been shown to be associated with both individual educational level and occupational social class, but also to be independently associated with fruit and vegetable consumption (Shohaimi et al., 2004).

The heritability of the principal component scores is compatible with that of similar pattern scores as reported in US populations. Van den Bree et al. (1999) reported that genetic factors accounted for 30 to 40% of variance in food choice in the two dietary patterns they identified; Gunderson et al. (2006) found an almost identical heritability for a healthy pattern score (50%) in a study of 350 twins of a similar age to our study population.

A previous study of the heritability of food preferences in twins aged 4 to 5 years found that the shared environment could account for over 50% of the variance in food choice for some food types (Breen et al., 2006). However, the common environment of the twins in the present study was only shown to have an influence on food consumption for a limited number of food groups. This may reflect the age of the twins included in the sample and the fact that all of the twin pairs lived apart. It is known that children prefer to eat foods familiar to them that are available freely in the home (Birch & Marlin, 1992), and that children's attitudes to food are also shaped by their mother's preferences (Nicklas et al., 2003). Changes in marital status can also affect food behaviour (Blane et al., 2003). Our data suggest that the influence of the family environment decreases with age.

It is widely acknowledged that there are major limitations in the use of FFQs for measuring dietary intake, with instruments such as diet diaries or dietary recalls considered to be more accurate (Olafsdottir et al., 2006). However, while FFQs are not ideal for assessing absolute nutrient intakes, they can be reliably used to rank individuals by intake, and are a more representative tool for assessing dietary intakes over an extended period. Dietary patterns derived from FFQs also reflect habitual intake, accounting for the colinearity of foods consumed together at meals. Dietary patterns obtained from FFQs have been shown to correlate well with patterns derived from dietary records (Hu et al., 1999; Hu, 2002). However, FFQs can only measure food intake over a period of about one year, and may not reflect lifetime dietary habits, which are, of course, very likely to change over time.

One limitation of this study is that that all the participants were female and the results cannot be reliably extrapolated to males. In cohorts including both sexes, women had higher loadings for the healthier patterns (Barker et al., 1990; Williams et al., 2000), suggesting that males and females should be analyzed separately in dietary pattern studies. Additionally, van den Bree et al. (1999) found evidence for sex-specific differences in heritability, with genetic factors seeming to have a greater influence in men than women.

The most heritable food types were garlic, coffee, and fruit and vegetables, and these loaded highly on the majority of the 5 patterns. These findings provide some insight into the possible basis for the genetic contribution of dietary choices, which may be driven primarily by taste perception. Some people are unable

Table 4

Mean (SD) of Total Energy and Energy-Adjusted Nutrient Intakes by Tertile of Dietary Pattern

Nutrient	Fruit and vegetable				High alcohol				Traditional English				Dieting				Low meat			
	Tertile				Tertile				Tertile				Tertile				Tertile			
	1	2	3	*P**	1	2	3	*P**	1	2	3	*P**	1	2	3	*P**	1	2	3	*P**
Total energy	8635	8043	8578	.55	8630	8128	8499	.17	8614	8105	8537	.42	8554	8101	8602	.61	8602	8157	8498	.28
(kj/d)	(2299)	(2147)	(2202)		(2173)	(2184)	(2308)		(2224)	(2203)	(2238)		(2160)	(2131)	(2366)		(2105)	(2173)	(2387)	
Total fat	76.8	70.4	63.9	†	65.8	71.3	74.1	†	67.6	70.9	72.8	†	73.6	70.2	67.4	†	69.6	70.6	71.1	†
(g/d)	(10.8)	(10.1)	(12.0)		(12.0)	(10.8)	(12.3)		(12.8)	(11.2)	(12.0)		(12.0)	(11.0)	(12.8)		(12.7)	(11.3)	(12.5)	
Saturated FA	30.6	26.4	22.0	†	24.9	26.8	27.3	†	25.8	26.5	26.7	†	28.3	26.2	24.5	†	26.5	26.5	26.0	.08
(g/d)	(6.1)	(4.9)	(5.5)		(6.2)	(6.1)	(6.9)		(7.0)	(6.2)	(6.3)		(7.3)	(5.6)	(5.9)		(7.0)	(5.9)	(6.6)	
Mono FA	26.3	23.4	20.8	†	21.8	23.8	24.9	†	22.1	23.7	24.7	†	24.4	23.5	22.6	†	23.2	23.6	23.7	.04
(g/d)	(4.2)	(3.8)	(4.6)		(4.6)	(4.3)	(4.9)		(4.9)	(4.2)	(4.7)		(4.7)	(4.3)	(5.1)		(4.7)	(4.4)	(5.1)	
Poly FA	14.8	15.7	16.2	†	14.3	15.6	16.7	†	14.7	15.6	16.3	†	15.8	15.5	15.3	.01	14.6	15.4	16.5	†
(g/d)	(3.6)	(3.5)	(4.3)		(3.7)	(3.5)	(4.0)		(4.0)	(3.5)	(3.8)		(4.3)	(3.4)	(3.7)		(3.4)	(3.5)	(4.2)	
Trans FA	2.49	2.03	1.58	†	2.03	2.09	1.99	.26	1.91	2.07	2.13	†	2.12	2.04	1.95	†	1.91	2.05	2.15	†
(g/d)	(0.67)	(0.53)	(0.56)		(0.78)	(0.63)	(0.67)		(0.69)	(0.67)	(0.71)		(0.74)	(0.62)	(0.71)		(0.63)	(0.63)	(0.80)	
Carbohydrate	250.5	257.8	266.9	†	278.3	259.9	237.0	†	267.0	257.9	250.3	†	257.9	257.9	259.5	.29	246.1	260.8	268.4	†
(g/d)	(31.3)	(30.5)	(35.9)		(28.3)	(25.7)	(31.8)		(35.8)	(30.0)	(31.7)		(32.2)	(31.5)	(36.0)		(34.7)	(29.9)	(31.2)	
Sucrose	53.7	50.3	51.0	†	57.4	52.5	45.0	†	53.2	51.9	49.8	†	55.5	51.0	48.5	†	48.7	52.9	53.3	†
(g/d)	(19.2)	(15.0)	(14.5)		(15.8)	(15.1)	(15.8)		(17.4)	(15.7)	(15.9)		(18.7)	(14.9)	(14.5)		(15.9)	(15.7)	(17.2)	
NSP	15.8	19.9	25.3	†	22.3	20.1	18.6	†	20.1	19.9	21.0	†	20.2	20.1	20.8	.02	19.9	20.1	21.0	†
(g/d)	(3.8)	(3.9)	(6.3)		(6.5)	(5.6)	(5.9)		(6.1)	(5.5)	(6.9)		(6.6)	(5.5)	(6.3)		(6.1)	(5.4)	(6.9)	
Protein	82.2	85.3	88.8	†	88.0	86.4	81.9	†	79.1	85.2	92.1	†	81.7	85.9	88.7	†	90.7	85.5	80.2	†
(g/d)	(13.8)	(12.3)	(14.7)		(14.2)	(13.4)	(13.3)		(13.4)	(11.6)	(13.4)		(13.5)	(13.0)	(14.1)		(14.3)	(11.8)	(13.3)	
Alcohol	7.6	10.2	11.7	†	3.7	7.3	18.4	†	12.5	9.6	7.3	†	8.2	10.2	11.1	†	14.6	8.3	6.5	†
(g/d)	(12.6)	(12.8)	(14.6)		(4.8)	(7.4)	(18.6)		(16.3)	(12.3)	(10.5)		(12.0)	(13.2)	(14.8)		(17.8)	(10.3)	(9.2)	
Cholesterol	245	236	226	†	232	238	237	.07	203	238	266	†	238	235	234	.16	269	236	202	†
(mg/d)	(68)	(60)	(72)		(67)	(63)	(72)		(58)	(59)	(68)		(71)	(63)	(68)		(69)	(54)	(61)	

Note: *P-value for trend using significance of coefficient for tertile numbers (1–3) fitted as the predictor in a linear regression.

† $P < .001$

(continued over)

Table 4 (continued)

Mean (*SD*) of Energy-Adjusted Nutrient Intakes by Tertile of Dietary Pattern

Nutrient	Fruit and vegetable				High alcohol				Traditional English				Dieting				Low meat			
	Tertile				Tertile				Tertile				Tertile				Tertile			
	1	2	3	*P**	1	2	3	*P**	1	2	3	*P**	1	2	3	*P**	1	2	3	*P**
Carotene	3438	4548	6629	†	5114	4845	4655	†	4065	4761	5788	†	5329	4771	4514	†	4759	4736	5118	.01
(Ìg/d)	(2019)	(2070)	(3647)		(3027)	(2795)	(3135)		(2447)	(2462)	(3655)		(3542)	(2610)	(2683)		(2662)	(2799)	(3450)	
Vitamin D	2.63	2.81	2.91	†	2.99	2.79	2.57	†	2.66	2.81	2.89	†	2.62	2.83	2.91	†	2.95	2.75	2.66	†
(Ìg/d)	(1.15)	(1.14)	(1.40)		(1.40)	(1.16)	(1.10)		(1.31)	(1.26)	(1.13)		(1.21)	(1.14)	(1.34)		(1.38)	(1.09)	(1.22)	
Vitamin E	10.4	11.8	13.2	†	11.9	11.7	11.8	.81	12.1	11.7	11.6	†	11.9	11.8	11.7	.04	11.3	11.7	12.4	†
(mg/d)	(2.7)	(2.5)	(3.1)		(3.0)	(2.8)	(3.2)		(3.3)	(2.7)	(3.0)		(3.4)	(2.8)	(2.8)		(2.9)	(2.7)	(3.3)	
Thiamin	1.6	1.774	1.93	†	1.93	1.80	1.62	†	1.71	1.77	1.87	†	1.74	1.77	1.83	†	1.77	1.78	1.80	.11
(mg/d)	(0.34)	(0.32)	(0.38)		(0.38)	(0.33)	(0.33)		(0.37)	(0.35)	(0.37)		(0.38)	(0.33)	(0.39)		(0.37)	(0.34)	(0.39)	
Riboflavin	2.44	2.52	2.63	†	2.77	2.58	2.25	†	2.53	2.52	2.55	.61	2.45	2.55	2.59	†	2.54	2.56	2.49	.16
(mg/d)	(0.70)	(0.66)	(0.76)		(0.69)	(0.72)	(0.63)		(0.79)	(0.67)	(0.68)		(0.69)	(0.68)	(0.76)		(0.68)	(0.64)	(0.81)	
Folate	337	389	466	†	419	400	374	†	382	390	420	†	405	392	396	.08	385	393	414	†
(Ìg/d)	(100)	(95)	(135)		(117)	(124)	(125)		(118)	(114)	(133)		(131)	(109)	(128)		(105)	(107)	(151)	
Vitamin B12	5.96	5.91	6.17	.02	6.22	6.09	5.73	†	5.47	5.99	6.58	†	5.75	5.99	6.30	†	6.68	6.01	5.34	†
(Ìg/d)	(2.44)	(1.87)	(2.24)		(2.16)	(2.05)	(2.34)		(2.03)	(1.96)	(2.43)		(2.13)	(1.92)	(2.48)		(2.45)	(1.96)	(1.94)	
Vitamin C	101	147	218	†	162	153	152	†	152	150	164	†	152	153	162	†	162	152	153	†
(mg/d)	(38)	(43)	(83)		(78)	(69)	(80)		(75)	(69)	(82)		(79)	(70)	(77)		(78)	(67)	(81)	
Potassium	3798	4165	4697	†	4363	4203	4094	†	4081	4203	4377	†	4078	4226	4356	†	4363	4213	4084	†
(mg/d)	(669)	(584)	(728)		(791)	(731)	(729)		(790)	(668)	(783)		(762)	(694)	(791)		(747)	(690)	(808)	
Calcium	1117	1159	1207	†	1249	1174	1059	†	1219	1142	1121	†	1124	1169	1189	†	1128	1167	1188	†
(mg/d)	(319)	(297)	(352)		(345)	(315)	(284)		(400)	(253)	(297)		(339)	(304)	(329)		(306)	(297)	(366)	
Magnesium	324	362	407	†	377	361	355	†	375	361	358	†	351	364	379	†	376	363	354	†
(mg/d)	(55)	(52)	(62)		(69)	(64)	(63)		(71)	(60)	(65)		(67)	(59)	(69)		(65)	(60)	(70)	
Sodium	2206	2307	2409	†	2370	2333	2218	†	2261	2277	2384	†	2263	2286	2373	†	2235	2283	2403	†
(mg/d)	(420)	(443)	(556)		(529)	(460)	(446)		(472)	(451)	(518)		(491)	(442)	(509)		(492)	(445)	(498)	
Iron	11.9	13.1	14.5	†	13.7	13.0	12.8	†	13.3	13.0	13.1	.05	12.6	13.1	13.7	†	13.8	13.0	12.7	†
(mg/d)	(2.7)	(2.7)	(3.2)		(3.5)	(2.8)	(2.8)		(3.2)	(2.9)	(3.1)		(2.8)	(2.7)	(3.5)		(3.3)	(2.7)	(3.0)	
Zinc	9.9	10.3	10.8	†	10.7	10.4	9.9	†	9.8	10.2	11.0	†	9.9	10.4	10.8	†	10.9	10.3	9.8	†
(mg/d)	(1.8)	(1.6)	(1.7)		(1.9)	(1.6)	(1.6)		(1.7)	(1.5)	(1.8)		(1.7)	(1.6)	(1.8)		(1.8)	(1.5)	(1.7)	
Selenium	45.3	51.1	58.2	†	51.7	51.7	51.1	.24	48.1	51.6	54.8	†	49.5	51.6	53.4	†	56.2	50.9	47.4	†
(Ìg/d)	(10.4)	(10.7)	(15.7)		(14.6)	(12.6)	(13.4)		(12.7)	(13.9)	(13.3)		(13.6)	(12.4)	(14.4)		(15.1)	(11.4)	(12.4)	

Note: **P*-value for trend using significance of coefficient for tertile numbers (1–3) fitted as the predictor in a linear regression.

†$P < .001$

Table 5

Dietary Pattern Scores by Covariate Status

Covariate		Dietary pattern														
		Fruit and vegetable			High alcohol			Traditional English			Dieting			Low meat		
		Mean	*SD*	*P**	Mean	*SD*	*P**	Mean	*SD*	*P**	Mean	*SD*	*P**	Mean	*SD*	*P**
Age (years)	18 to 35	–0.53	2.14	†	0.62	1.41	†	–0.23	1.33	†	–0.26	1.39	†	0.69	1.53	†
	36 to 50	–0.19	2.02		0.20	1.46		–0.03	1.42		–0.17	1.30		0.00	1.20	
	51 to 60	0.33	2.10		–0.29	1.32		0.10	1.41		0.08	1.27		–0.25	1.18	
	61 or over	0.38	2.10		–0.55	1.31		0.12	1.39		0.47	1.27		–0.29	1.19	
BMI (kg/m2)	Less than 18.5	–0.96	2.74	.03	0.30	1.56	†	–0.11	1.33	†	0.64	1.41	†	0.52	1.57	.30
	18.5 to 24.9	–0.03	2.18		0.11	1.45		–0.16	1.39		0.12	1.29		0.02	1.29	
	25 to 29.9	0.18	1.20		–0.13	1.42		0.11	1.32		–0.09	1.26		–0.10	1.27	
	30 or above	–0.13	2.05		–0.21	1.38		0.46	1.49		–0.41	1.49		0.09	1.37	
National quintile of deprivation index (1 = most deprived)	Quintile 1	–0.91	2.09	†	0.00	1.51	.10	0.40	1.43	†	–0.02	1.51	.65	0.16	1.30	.003
	Quintile 2	–0.33	2.16		0.13	1.50		0.19	1.48		–0.05	1.37		0.17	1.42	
	Quintile 3	–0.14	1.97		0.05	1.48		–0.03	1.33		–0.06	1.22		0.00	1.18	
	Quintile 4	0.12	2.23		–0.08	1.42		–0.08	1.43		0.07	1.32		0.00	1.34	
	Quintile 5	0.29	2.01		–0.02	1.39		–0.06	1.37		–0.03	1.33		–0.05	1.32	
Smoking status	Current	0.09	1.99	†	–0.23	1.30	†	–0.08	1.32	.01	0.05	1.23	.17	1.25	–0.04	.26
	Former	–0.71	1.79		0.78	1.47		0.21	1.26		–0.09	1.46		1.40	0.10	
	Never	0.58	2.34		0.13	1.45		–0.11	1.53		–0.08	1.36		1.33	–0.07	
Physical activity	Low	–0.32	1.71	†	0.24	1.46	.02	–0.16	1.26	.02	–0.22	1.27	.05	0.05	1.25	.26
	Medium	0.03	2.04		0.13	1.30		–0.03	1.29		–0.03	1.32		0.02	1.19	
	High	0.19	2.10		0.06	1.47		0.02	1.38		–0.07	1.32		–0.03	1.25	
Vitamin supplements	Yes	0.29	2.12	†	–0.05	1.42	.02	–0.14	1.41	†	–0.09	1.30	†	–0.02	1.33	.27
	No	–0.34	2.07		0.07	1.44		0.18	1.39		0.10	1.34		0.03	1.27	

Note: **P*-value for trend, † *P* < .001

Table 6

Intraclass Correlation Coefficients and Maximum-Likelihood Estimates From Structural Equation Modeling of a^2, d^2, c^2 and e^2 with 95% Confidence Intervals and Goodness-of-Fit Statistics for the Best-Fitting Genetic Model for Component Scores and Food Groups, All Variables Adjusted for Age (498 MZ pairs, 1133 DZ pairs)

Variable	Intraclass correlations		Structural equation modelling							
	rMZ	rDZ	a^2	d^2	c^2	e^2	χ^2	*df*	*P*	*AIC*
PCA pattern scores										
Fruit and vegetable	.56 (.49, .62)	.32 (.27, .37)	.43 (.28, .58)		.11 (.00, .23)	.45 (.40, .51)	1.91	3	.59	–4.1
High alcohol	.46 (.39, .53)	.25 (.20, .30)	.48 (.42, .54)			.52 (.46, .58)	2.76	4	.60	–5.2
Traditional English	.42 (.35, .50)	.18 (.12, .24)	.41 (.35, .47)			.59 (.53, .65)	7.61	4	.11	–0.4
Dieting†	.39 (.31, .46)	.22 (.17, .28)	.41 (.34, .47)			.59 (.53, .66)	3.10	3	.38	–2.9
Low meat	.40 (.33, .48)	.24 (.18, .29)	.43 (.37, .49)			.57 (.51, .63)	16.07	4	.00	8.1
Food types										
Fruit juice	.31 (.23, .39)	.05 (.00, .11)	.00 (.00, .16)	.70 (.63, .78)		.30 (.11, .37)	13.10	3	.00	7.1
Fruit and vegetable sources	.49 (.42, .55)	.26 (.21, .31)	.49 (.43, .54)			.51 (.46, .57)	3.71	4	.45	–4.3
Coffee	.41 (.34, .49)	.19 (.13, .25)	.41 (.35, .47)			.59 (.53, .65)	2.91	4	.57	–5.1
Savoury tastes†	.33 (.25, .40)	.10 (.04, .16)	.07 (.00, .31)	.68 (.60, .76)		.25 (.00, .40)	12.17	2	.00	8.2
Root vegetables	.37 (.30, .45)	.17 (.11, .22)	.36 (.29, .42)			.64 (.58, .71)	1.88	4	.76	–6.1
Wholemeal grains	.32 (.24, .40)	.11 (.06, .17)	.29 (.22, .35)			.71 (.65, .78)	2.08	4	.72	–5.9
Eggs†	.32 (.24, .40)	.12 (.06, .18)	.29 (.23, .36)			.71 (.64, .77)	8.32	3	.04	2.3
Garlic†	.44 (.37, .51)	.24 (.19, .30)	.46 (.40, .51)			.54 (.49, .60)	7.21	3	.07	1.2
Refined grains	.29 (.21, .37)	.09 (.04, .15)	.08 (.00, .30)	.71 (.63, .79)		.21 (.00, .37)	0.18	3	.98	–5.8
Fruit	.40 (.32, .47)	.22 (.16, .27)	.40 (.34, .46)		.00 (.00, .00)	.60 (.54, .66)	6.81	4	.15	–1.2
Low-fat dairy/dieting	.36 (.29, .44)	.18 (.12, .24)	.36 (.30, .42)			.64 (.58, .70)	1.34	4	.85	–6.7
Red meat	.38 (.30, .45)	.20 (.14, .26)	.39 (.32, .45)			.61 (.55, .68)	2.98	4	.56	–5.0
Brassica	.32 (.25, .40)	.16 (.10, .22)	.32 (.25, .38)			.68 (.62, .75)	3.31	4	.51	–4.7
Salad	.45 (.38, .52)	.29 (.23, .34)	.35 (.18, .51)		.11 (.00, .23)	.54 (.48, .61)	19.04	3	.00	13.0
Sweet tastes†	.30 (.22, .38)	.14 (.08, .20)	.30 (.23, .36)			.70 (.64, .77)	0.55	3	.91	–5.5
Tea	.36 (.28, .44)	.20 (.14, .26)	.38 (.31, .44)			.62 (.56, .69)	1.69	4	.79	–6.3
Allium	.36 (.29, .44)	.21 (.15, .26)	.38 (.32, .44)			.62 (.56, .68)	0.93	4	.92	–7.1
Alcohol	.40 (.32, .47)	.26 (.20, .31)	.28 (.10, .45)		.12 (.00, .25)	.61 (.54, .68)	10.67	3	.01	4.7
Fast food	.38 (.30, .45)	.24 (.18, .29)	.26 (.08, .43)		.11 (.00, .24)	.63 (.56, .71)	12.05	3	.01	6.0
Legumes — earthy	.29 (.21, .37)	.15 (.09, .21)	.30 (.23, .36)			.70 (.64, .77)	5.23	4	.26	–2.8
Nuts†	.31 (.23, .39)	.18 (.12, .23)	.32 (.26, .38)			.68 (.62, .74)	28.81	3	.00	22.8
Poultry	.29 (.21, .37)	.16 (.10, .21)	.29 (.23, .36)			.71 (.64, .77)	2.05	4	.73	–6.0
High-fat dairy†	.23 (.15, .32)	.13 (.08, .19)	.24 (.18, .31)			.76 (.69, .82)	17.92	3	.00	11.9
Fish (except fried)†	.30 (.22, .38)	.22 (.16, .27)	.17 (.00, .36)		.13 (.00, .27)	.70 (.62, .78)	6.29	2	.04	2.3
Dieting	.20 (.11, .28)	.15 (.09, .20)	.24 (.17, .31)			.76 (.69, .83)	11.67	4	.02	3.7

Note: a^2, d^2, c^2 and e^2 are estimates of the proportion of the variance explained by additive genetic, dominant genetic, shared environmental and nonshared environmental factors respectively, calculated for the model best fitting the data. A small c^2 for the degrees of freedom (*df*) and a high *P* value indicate a good agreement between the model and the observed data. AIC is Akaike's Information Criterion.

†Variance scaling parameter used

to taste bitter substances, such as phenylthicarbamide and 6-n-propylthiouracil, and this inability is genetically determined. It has been shown that these people also have a heightened ability to taste artificial sweeteners, and show a preference for sweet tastes, fatty foods, and alcohol (Duffy, 2004). Further work has shown that children with an inability to taste these bitter substances consumed more vegetables, especially those that were bitter tasting (Bell & Tepper, 2006).

In conclusion, we found 5 dietary patterns that were associated with age, BMI, deprivation, and smoking, and related to specific nutrients of interest. We also found that these 5 patterns were heritable. Genetic effects explained over 40% of the variance in all of the patterns, and in the garlic, coffee, and fruit and vegetable food types. The relatively high heritability of specific dietary components implicates taste perception as a possible target for future genetic studies.

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Appendix A

Definition of Custom Food Types Used in Heritability Analysis

Food type	Food items included
Fruit and vegetable sources	Berries, citrus fruit, other fruit, parsnips, turnips, swedes, beetroot, carrots, onions, leeks, broccoli, spring greens, kale, Brussels sprouts, cabbage, cauliflower, coleslaw, watercress, green lettuce, cucumber, celery, sweet pepper, avocado, tomatoes, dried lentils, green beans, runner beans, bean sprouts, peas
Garlic	Garlic
Alcohol	Wine, beer, spirits and liquor
Fruit	Berries, citrus fruit, other fruit
Coffee	Coffee
Red meat	Beef (inc. roast, steak, mince, stew or casserole), pork (roast, chops, stew or slices), lamb (roast, chops or stew)
Fish (other than fried)	Mackerel, kippers, tuna, salmon, sardines, herring, white fish, shellfish, fish roe, taramasalata
Tea	Tea
Root vegetables	Parsnips, turnips, swedes, beetroot, carrots
Allium	Onions, leeks
Brassica	Broccoli, spring greens, kale, Brussels sprouts, cabbage, cauliflower, coleslaw, watercress
Low-fat dairy/ dieting	Skimmed milk, semi-skimmed milk, low-fat yoghurt or fromage frais, cottage cheese, low-fat soft cheese, low-sugar soda, low-fat spread, very low-fat spread, low-fat salad cream.
Wholemeal grains	Wholemeal bread and rolls, brown rice, wholemeal pasta, crispbread, porridge, high fiber breakfast cereals
Salad	Green lettuce, cucumber, celery, sweet pepper, avocado, tomatoes, watercress, mayonnaise, salad cream, low fat salad cream, French dressing, other oil and vinegar dressing
Nuts	Peanuts or other nuts, peanut butter
Sweet tastes	Sweet biscuits (chocolate and plain), cakes, buns and pastries, fruit pies, tarts and crumbles, sponge puddings, jam, marmalade, honey, sugar added to tea/coffee/cereal, sweets, toffees, mints, chocolate bars/single squares, high-sugar soda, hot chocolate, Horlicks, Ovaltine, fruit squash or cordial
Legumes — earthy	Dried lentils, green beans, runner beans, bean sprouts, peas
Eggs	Eggs
Savoury tastes	Marmite, Bovril, pickles, chutney, tomato ketchup, gravy, white sauce
Poultry	Chicken or other poultry
Refined grains	White/brown bread and rolls, white rice, white or green pasta, noodles, spaghetti, low fiber breakfast cereals
Fast food	Bacon, ham, sausage, luncheon meat, liver, liver pate, liver sausages, meat pies, pork pies, pasties, steak and kidney pies, sausage rolls, fish fried in batter as fish and chips, fish fingers, fish cakes, chips, roast potatoes, potato salad, crisps, cream crackers, beef burgers
Fruit juice	Fruit juice
High-fat dairy	Full-fat milk, butter, single or sour cream, double or clotted cream, full-fat or Greek yoghurt, cheese (cheddar, brie, edam), dairy desserts, milk puddings (rice pudding, custard trifle), icecream, coffee whitener