British Journal of Nutrition (2001), **86**, 405–414
DOI: 10.1079/BJN2001414

Dietary assessment in Whitehall II: comparison of 7 d diet diary and food-frequency questionnaire and validity against biomarkers

Eric Brunner[1]*, Daryth Stallone[1], Maneesh Juneja[1], Sheila Bingham[2] and Michael Marmot[1]

[1]*International Centre for Health and Society, Department of Epidemiology and Public Health, University College London Medical School, 1–19 Torrington Place, London WC1E 6BT, UK*
[2]*MRC Dunn Human Nutrition Unit, Wellcome Trust/MRC Building, Hills Road, Cambridge CB2 2XY, UK*

(Received 14 April 2000 – Revised 18 April 2001 – Accepted 1 May 2001)

The aim of the present cross-sectional study was to examine the agreement and disagreement between a 7 d diet diary (7DD) and a self-administered machine-readable food-frequency questionnaire (FFQ) asking about diet in the previous year, and to validate both methods with biomarkers of nutrient intake. The subjects were an age- and employment-grade-stratified random subsample of London-based civil servants (457 men and 403 women), aged 39–61 years, who completed both a 7DD and a FFQ at phase 3 follow-up (1991–1993) of the Whitehall II study. Mean daily intakes of dietary energy, total fat, saturated, monounsaturated and polyunsaturated fatty acids, linoleic acid, total carbohydrate excluding fibre, sugars, starch, dietary fibre, protein, vitamin C, vitamin E (as α-tocopherol equivalents), folate, carotenes (as total β-carotene activity), Fe, Ca, Mg, K and alcohol were measured. Serum cholesteryl ester fatty acids (CEFA), plasma α-tocopherol and β-carotene were also measured as biomarkers. Estimates of mean energy intake from the two methods were similar in men, and some 10 % higher according to the FFQ in women. Compared with the 7DD, the FFQ tended to overestimate plant-derived micronutrient intakes (carotenes from FFQ *v.* 7DD men 2713 (SD 1455) *v.* 2180 (SD 1188) μg/d, women 3100 (SD 1656) *v.* 2221 (SD 1180) μg/d, both differences $P<0{\cdot}0001$) and to underestimate fat intake. Against plasma β-carotene/cholesterol, carotene intake was as well estimated by the FFQ as the 7DD (Spearman rank correlations, men 0·32 *v.* 0·30, women 0·27 *v.* 0·22, all $P\leq0{\cdot}0001$, energy-adjusted data). Ranking of participants by other nutrient intakes tended to be of the same order according to the two dietary methods, e.g. rank correlations for CEFA linoleic acid against FFQ and 7DD estimates respectively, men 0·38 *v.* 0·41, women 0·53 *v.* 0·62, all $P\leq0{\cdot}0001$, energy-adjusted % fat). For α-tocopherol there were no correlations between plasma level and estimated intakes by either dietary method. Quartile agreement for energy-adjusted nutrient intakes between the two self-report methods was in the range 37–50 % for men and 32–44 % for women, and for alcohol, 57 % in both sexes. Disagreement (misclassification into extreme quartiles of intake) was in the range 0–6 % for both sexes. The dietary methods yielded similar prevalences (about 34 %) of low energy reporters. The two methods show satisfactory agreement, together with an expected level of systematic differences, in their estimates of nutrient intake. Against the available biomarkers, the machine-readable FFQ performed well in comparison with the manually coded 7DD in this study population. For both methods, regression-based adjustment of nutrient intake to mean dietary energy intake by gender appears on balance to be the optimal approach to data presentation and analysis, in view of the complex problem of low energy reporting.

Diet surveys: Bias: Dietary fats: Micronutrients: Research methodology

The measurement of nutrient intake in large survey samples is a methodological challenge. Diaries are probably the most accurate of the self-report methods in motivated groups (Bingham & Day, 1997), but present a considerable burden to respondent and researcher alike. A less laborious approach is to use a machine-readable pre-coded

Abbreviations: CEFA, cholesteryl ester fatty acids; FFQ, food-frequency questionnaire; LER, low energy reporter; PUFA, polyunsaturated fatty acid; 7DD, 7 d diet diary.

* **Corresponding author:** Dr Eric Brunner, fax +44 20 7813 0242, email e.brunner@ucl.ac.uk

questionnaire. Such methods allow for a large sample size, with a trade-off in the form of reduced accuracy of the food and nutrient intake estimates (Willett, 1998).

The Whitehall II study utilised both types of dietary method at the time of the second medical examination. The estimated 7 d diet diary (7DD) (Braddon *et al.* 1988) was coded in a subsample of 865 respondents, and validation of these results against biomarkers has been published (Stallone *et al.* 1997). The machine-readable food-frequency questionnaire (FFQ), adapted from the Willett form (Willett *et al.* 1985), was also completed and nutrient analysis conducted for all respondents. The methods are similar to those used in the UK arm of the EPIC study (Bingham *et al.* 1997), although the Whitehall II diary contained black and white rather than colour portion-size photos.

In the present paper we compare the estimated nutrient intakes obtained from the two methods with one another, and with biomarkers of fatty acid and anti-oxidant vitamin intake. As before (Stallone *et al.* 1997), we examine three statistical approaches to the problem of low energy reporting, utilising: (1) all complete records, regardless of reported energy intake; (2) excluding those with implausibly low reported energy intake (less than 1·2 times calculated BMR); (3) all complete records, with adjustment for energy intake. Adjustment of nutrient intake to the mean gender-specific energy intake produces an estimate of dietary composition, rather than of absolute intake. It provides an assessment of nutrient intake independent of body size and activity level, as well as of energy intake itself. The purpose of the comparison is to evaluate the accuracy of the FFQ against that of the 7DD, and to quantify the extent to which the two dietary methods produce similar rankings of study participants according to the intake of individual nutrients. The last question is important for future epidemiological analyses of dietary effects on health (Brunner, 1997).

Methods

Sample

Participants were drawn from the Whitehall II longitudinal study of British civil servants (Marmot *et al.* 1991). The Whitehall II cohort comprises 10 308 male and female civil servants who at the time of recruitment (1985–1988, phase 1) were working in the London offices of twenty departments. Participants completed a self-administered health questionnaire and attended a health screening clinic. All non-industrial civil servants working in these offices were invited to participate. The overall response rate was 73 %, although the true response was probably higher, as investigations in one department showed that 4 % of those invited to participate had moved before the study began, and were therefore ineligible for inclusion. During phase 3 (September 1991 – May 1993) 8826 participants (86 % of the cohort) completed a follow-up questionnaire and/or attended the screening clinic (Brunner *et al.* 1997).

7 d diet diary

Participants attending the phase 3 screening clinic were asked to take home and complete an open-ended estimated 7DD (Braddon *et al.* 1988). Participants were given a pre-paid envelope to return the completed diary, and 83 % did so. The diet-diary booklet contained instructions, four pages to record foods eaten during seven time periods (before breakfast, breakfast, mid-morning, lunch, tea, evening meal, later evening) for each of 7 d (twenty-eight pages in total) and fifteen sets of black and white food photographs. Each set of photographs depicted three portion choices for a common food item. The instructions indicated that the respondent should record the food brand, portion size, and name and daily dose of any vitamin, mineral or food supplements taken each day. General questions, for example, on the type of milk and spreadable fat usually consumed, were asked at the end of the diary. The resources necessary for coding made it feasible to code only a subsample of the returned 7DD (*n* 865, 13 %). Stratified random sampling was used to select the diaries for coding, to ensure a more equal distribution of diaries across gender, employment-grade and age-group categories than exists overall in the target Whitehall II population (Stallone *et al.* 1997).

Food-frequency questionnaire

Participants invited to the phase 3 clinic were sent a machine-readable FFQ based on that used in the US Nurses Health study (Willett *et al.* 1985, 1998), and 8360 participants completed the questionnaire, a response rate of 95 %. The food list (127 items) in the FFQ was anglicised, and foods commonly eaten in the UK were added (Bingham *et al.* 1997). A common unit or portion size for each food, e.g. one egg or one slice of bread was specified, and participants were asked how often, on average, they had consumed that amount of the item during the previous year. The nine responses ranged from 'never or less than once per month' to 'six or more times per day'. We also enquired about types of fat or oil used for frying and baking, and about regular use of dietary supplements over the last 5 years. Nutrient intake was computed by multiplying the frequency of food consumption by the nutrient content of the specified standard portion, as described later.

Nutrient analysis

Nutrient analyses were carried out using a computerised system developed for the Whitehall II dietary data. The system's database contains nutritional information for 2533 food items and 374 nutrient supplements based on the 4th and 5th editions of *McCance and Widdowson's The Composition of Foods* and supplementary tables (Paul & Southgate, 1978; Holland *et al.* 1988, 1989, 1991*a*,*b*, 1992*a*,*b*, 1993; Chan *et al.* 1994, 1995). Nutrient supplement information was obtained from manufacturers and added to the database. For the 7DD, daily nutrient intake values were calculated as the average of nutrient values over the 7 d of recording. Only diaries with all 7 d of intake recorded by participants were used in the analyses. Dietary supplements were excluded from analysis because

the 7DD and FFQ questions referred to different time periods.

Nutrients used in this analysis were dietary energy, total fat, saturated, monounsaturated fatty acids and polyunsaturated fatty acids (PUFA), linoleic acid, total carbohydrate excluding fibre, sugars (intrinsic plus extrinsic), starch, Southgate fibre, protein, vitamin C, vitamin E (as α-tocopherol equivalents), folate, carotenes (as total β-carotene activity), Fe, Ca, Mg, K and alcohol.

Blood collection and analysis

The protocol for the phase 3 examination has been published (Beksinska *et al.* 1995). Blood samples were collected following either an 8 h fast (participants presenting to the clinic in the morning), or at least 4 h after a light fat-free breakfast (subjects presenting in the afternoon). Venepuncture of the left antecubital vein was performed with tourniquet. Blood was collected into plain, heparin, citrate and fluoride Sarstedt monovettes. After centrifugation, lithium heparin plasma for β-carotene and α-tocopherol analysis was frozen immediately on dry ice and transferred to a −80°C freezer. Samples were stored at −80°C for a maximum of approximately 12 months before analysis. Serum for lipid analysis was refrigerated at −4°C after processing and analysed on the following working day. Serum for cholesteryl ester fatty acids (CEFA) was stored at −80°C prior to analysis.

Plasma concentrations of β-carotene and α-tocopherol (μmol/l) were determined by HPLC using a concurrent method (Buttriss & Diplock, 1984) (Armstrong *et al.* 1997). Plasma vitamins were analysed statistically as absolute concentration or as concentration/mmol per litre serum total cholesterol. CEFA were measured as methyl esters by GC on approximately half of the participants (*n* 216) selected for 7DD coding. The same random sampling method was used, with stratification by gender, age and employment grade (Stallone *et al.* 1997). Serum CEFA fractions were analysed statistically as % total measured CEFA.

Anthropometry

Weight was measured to the nearest 0·1 kg using an electronic scale with participants dressed in a cloth gown and underclothes. Height was measured to the nearest centimetre using a stadiometer, with participants barefoot and their head tilted to the Frankfurt plane position.

Low energy reporters

The energy intake:calculated BMR ratio (Schofield *et al.* 1985) was used as a measure of the degree of energy underreporting within each dietary method. Low energy reporters (LER) were defined as individuals with reported energy intakes of less than 1·2 times their BMR (Black *et al.* 1991).

Statistical analysis

Nutrient intakes were expressed three ways: as absolute intakes using available data, after exclusion of LER, and as energy-adjusted intakes, using all available data. Energy-adjusted nutrient intake was calculated as the residual from a regression model with absolute nutrient intake the dependent variable and total energy intake the independent variable (Willett & Stampfer, 1986). The energy-adjusted intake is the sum of the residual and the expected intake of the given nutrient at the mean energy intake of the study sample by gender, according to each dietary method. Indicator variables were created to identify LER records according to the 7DD and FFQ methods. These records were omitted from the 'LER excluded' analyses. Difference between means was tested using the paired *t* test. Associations between biomarker and nutrient intakes, and between nutrient intakes from each method, were measured using Spearman rank correlation, partialled for potential confounders age and employment grade. For the correlations with CEFA, dietary fatty acid intakes were analysed both as absolute amount (mg/d) and as % total dietary fatty acids. The energy-adjusted intake values used in the correlations were the residuals obtained from a regression model as above, utilising either absolute or % intake as dependent variable. Individuals were ranked into quartiles on the basis of nutrient intakes from both the dietary methods and biomarker concentrations. Method agreement and disagreement is expressed as the proportion of participants classified respectively into the same and extreme (top and bottom) quartiles of the distribution for a given nutrient intake. Relationships between low energy reporting and relative weight, and employment grade, were assessed using the Mantel Haenszel test for trend. Statistical analyses were performed using SAS (Statistical Analysis Systems Inc., Cary, NC, USA).

Results

Data were combined from those with a coded 7DD (*n* 865) and those with a completed FFQ (*n* 8360) to give a maximum sample size of 860 for these analyses. All tables show results for men and women separately. Tables 1–5 present results in three ways: (1) all observations; (2) with LER (energy intake: BMR<1·2) excluded; (3) adjusted for reported energy intake.

Table 1 shows the mean values and standard deviations for reported daily intakes of energy and eighteen nutrients obtained from the 7DD and the FFQ. The table shows tests for difference of the mean derived from each dietary method, according to the three data presentation approaches. Among men, mean energy intake from the two dietary methods is similar, while among women estimated energy intake from the FFQ is some 10 % higher than from the 7DD. The observed distribution of energy intake, and of nutrient intake in general, tended to be wider according to the FFQ than the 7DD. Intake distributions were narrower after energy adjustment than in the unadjusted data. Differences in mean intakes were statistically significant at the 0·01 % level in the majority of comparisons. In some cases the mean difference is substantial but this is not true for all nutrients. The method difference for carotenes is about 28 % in men and 40 % in women (FFQ>7DD), and while the difference was about 25 % for total carbohydrate among women, it was only some 14 % among men. In both sexes the 7DD yielded higher

Table 1. Comparison of daily intakes of energy and eighteen nutrients from the 7 d diet diary and food-frequency questionnaire† (Mean values and standard deviations)

	7 d diet diary						Food-frequency questionnaire					
	All results		LER excluded		Energy-adjusted		All results		LER excluded		Energy-adjusted	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Men												
n	457		311		457		457		280		457	
Energy (MJ)	9·7‡	2	10·8***	1·4	–		9·6	3·0	11·3	2·3	–	
Total fat (g)	97****	26	109****	22	97****	14	83	33	99	28	83	15
Saturated fat (g)	38****	13	43****	12	38****	9	33	14	39	13	33	8
Monounsaturated fat (g)	34****	10	38****	9	34****	6	27	10	32	9	27	5
Polyunsaturated fat (g)	18‡	7	20*	6	18‡	5	18	9	22	9	18	6
Protein (g)	86‡	18	93***	15	86‡	12	88	28	101	25	88	15
Total carbohydrate (g)	267****	65	295****	54	267****	37	295	94	347	74	295	40
Sugars (g)	113****	41	128****	37	113****	29	125	49	148	45	125	33
Starch (g)	152****	39	164****	37	152****	29	168	60	196	50	168	36
Southgate fibre (g)	22***	7	24****	7	22****	6	28	12	32	11	28	9
Vitamin C (mg)	81****	46	88****	47	81****	44	142	78	160	78	142	71
Vitamin E (mg)	6·5****	2·6	7·4*	2·5	6·5****	2·2	5·8	2·7	6·8	2·6	5·8	2·1
Folate (μg)	266****	85	290****	84	266****	72	351	123	400	109	351	82
Carotenes (μg)	2181****	1197	2279****	1192	2180****	1188	2713	1530	3012	1515	2713	1455
Iron (mg)	14‡	4	15‡	3	14‡	3	14	5	16	4	14	3
Calcium (mg)	979****	307	1074****	285	979****	228	863	350	1012	336	863	230
Magnesium (mg)	334****	93	364****	88	334****	69	364	125	424	107	364	76
Potassium (mg)	3377****	798	3671****	695	3377****	588	3652	1090	4177	933	3651	629
Alcohol (g)	14‡	15	16*	15	14‡	14	14	16	16	17	14	15
Women												
n	403		261		403		403		279		403	
Energy (MJ)	7·7****	1·7	8·6****	1·3	–		8·4	2·5	9·6	2·1	–	
Total fat (g)	77****	24	88*	21	77*	11	71	26	82	23	71	13
Saturated fat (g)	30*	11	35‡	11	30*	7	28	12	32	11	28	8
Monounsaturated fat (g)	27****	9	31****	8	27****	5	23	8	26	7	23	4
Polyunsaturated fat (g)	14*	5	16*	5	14*	4	15	7	17	7	15	5
Protein (g)	72****	16	78****	14	72****	11	83	26	93	24	83	15
Total carbohydrate (g)	208****	51	231****	43	208****	30	257	82	293	69	257	35
Sugars (g)	97****	33	109****	31	97****	24	118	45	134	42	118	31
Starch (g)	110****	29	119****	27	110****	22	138	54	159	50	138	33
Southgate fibre (g)	19****	6	20****	6	19****	5	27	11	30	10	27	8
Vitamin C (mg)	94****	49	102****	50	94****	47	185	89	200	85	185	82
Vitamin E (mg)	6·0‡	2·5	6·8‡	2·5	6·0‡	1·9	6·2	2·7	6·8	2·7	6·2	2·2
Folate (μg)	229****	68	249****	67	229****	58	339	123	375	121	339	91
Carotenes (μg)	2221****	1230	2405****	1245	2221****	1180	3100	1741	3361	1732	3100	1656
Iron (mg)	12****	3	13****	3	12****	2	13	4	14	4	13	3
Calcium (mg)	830*	249	915‡	237	831*	201	875	401	982	404	875	323
Magnesium (mg)	285****	73	310****	66	285****	56	350	113	392	103	350	68
Potassium (mg)	3021****	677	3250****	601	3021****	525	3700	1125	4084	1065	3700	689
Alcohol (g)	10****	11	12*	13	10****	10	8	10	9	10	8	10

LER, low energy reporter.
Mean values were significantly different from those of the food-frequency questionnaire: * $P<0·05$, *** $P<0·001$, **** $P<0·0001$ (paired *t* test).
† For details of subjects and procedures, see p. 406.
‡ Not significant.

Table 2. Spearman rank correlations between nutrient intakes and biomarkers of nutrient status (adjusted for age and employment grade)‖

		All results				LER excluded				Energy-adjusted			
		7DD		FFQ		7DD		FFQ		7DD		FFQ	
Biomarker	Nutrient	Crude intake[1]	% of fat[2]	Crude intake[1]	% of fat[2]	Crude intake[1]	% of fat[2]	Crude intake[1]	% of fat[2]	Crude intake[1]	% of fat[2]	Crude intake[1]	% of fat[2]
Men													
CEFA			*n* 115			*n* 92		*n* 78			*n* 115		
Saturated	Saturated fat	−0·04	0·23‡	−0·01	0·16	0·11	0·07	0·14	0·24	0·23‡	0·26‡	0·25‡	0·17
Polyunsaturated	Polyunsaturated	0·36§	0·37§	0·33*	0·43†	0·31*	0·32*	0·31‡	0·55†	0·46†	0·41†	0·40†	0·43†
P:S ratio	P:S ratio	0·26*	–	0·33§	–	0·22	–	0·42§	–	0·31*	–	0·33§	–
Linoleic (*n*-6)	Linoleic	0·46†	0·39†	0·37§	0·38†	0·35*	0·35*	0·40*	0·47†	0·45†	0·41†	0·38†	0·38†
EPA (*n*-3)	EPA	0·25‡	0·28*	0·45†	0·54†	0·31*	0·34*	0·45§	0·56†	0·24‡	0·19	0·50†	0·53†
Plasma vitamins			*n* 356			*n* 249		*n* 216			*n* 356		
β-Carotene	Carotenes	0·23†		0·22†		0·28†		0·24§		0·23†		0·25†	
β-Carotene/cholesterol	Carotenes	0·29†		0·28†		0·34†		0·27†		0·30†		0·32†	
α-Tocopherol	Vitamin E	−0·01		−0·07		0·02		−0·11		−0·02		−0·07	
α-Tocopherol/cholesterol	Vitamin E	0·01		−0·02		0·06		−0·07		−0·01		−0·03	
Women													
CEFA			*n* 71			*n* 42		*n* 50			*n* 71		
Saturated	Saturated fat	0·08	0·15	0·05	0·26‡	0·03	0·10	0·04	0·29	0·25	0·16	0·23	0·26‡
Polyunsaturated	Polyunsaturated	0·56†	0·49†	0·45§	0·50†	0·77†	0·56§	0·64†	0·51§	0·48†	0·51†	0·33*	0·41§
P:S ratio	P:S ratio	0·37*	–	0·40*	–	0·38‡	–	0·35‡	–	0·37*	–	0·37*	–
Linoleic (*n*-6)	Linoleic	0·67†	0·61†	0·51†	0·57†	0·84†	0·80†	0·63†	0·56†	0·60†	0·62†	0·46§	0·53†
EPA (*n*-3)	EPA	0·38*	0·36*	0·13	0·23	0·37‡	0·37‡	0·14	0·25	0·42§	0·38*	0·18	0·23
Plasma vitamins			*n* 309			*n* 211		*n* 220			*n* 309		
β-Carotene	Carotenes	0·16*		0·20§		0·14‡		0·23§		0·18*		0·26†	
β-Carotene/cholesterol	Carotenes	0·20§		0·21§		0·16‡		0·21*		0·22†		0·27†	
α-Tocopherol	Vitamin E	−0·04		−0·07		−0·10		−0·07		−0·03		−0·07	
α-Tocopherol/cholesterol	Vitamin E	−0·01		−0·07		−0·08		−0·06		0·01		−0·03	

LER, low-energy reporters; 7DD, 7 d diet diary; FFQ, food-frequency questionnaire; CEFA, serum cholesteryl ester fatty acids (analysed as g/100 g total fatty acids in CEFA fraction); P:S ratio, polyunsaturated:saturated fatty acid ratio in CEFA or in dietary intake; EPA, eicosapentaenoic acid (20 : 5*n*-3).

† $P<0{\cdot}0001$, § $P<0{\cdot}001$, * $P<0{\cdot}01$, ‡ $P<0{\cdot}05$.

[1] Intake analysed as amount, e.g. mg/d.

[2] Fatty acid intake analysed as percentage a total dietary fatty acids.

‖ For details of subjects and procedures. See pp. 406–407.

Table 3. Agreement (%) between quartiles of nutrient intake and biomarker concentrations*†

		All results		LER excluded		Energy-adjusted	
Biomarker	Nutrient	7DD	FFQ	7DD	FFQ	7DD	FFQ
Men							
CEFA							
Saturated	Saturated fat	33	28	29	36	32	25
Monounsaturated	Monounsaturated	30	29	33	27	34	30
Polyunsaturated	Polyunsaturated	35	40	32	44	40	40
P:S ratio	P:S ratio	28	36	31	40	32	36
Linoleic	Linoleic	35	40	35	44	33	36
EPA	EPA	32	38	29	32	27	38
Plasma vitamins							
β-Carotene	Carotenes	31	28	30	31	30	33
β-Carotene/cholesterol	Carotenes	35	33	36	30	35	34
α-Tocopherol	Vitamin E	24	23	20	19	20	19
α-Tocopherol/cholesterol	Vitamin E	25	23	32	20	27	24
Women							
CEFA							
Saturated	Saturated fat	37	38	21	33	32	38
Monounsaturated	Monounsaturated	21	25	18	22	21	26
Polyunsaturated	Polyunsaturated	43	35	50	33	41	29
P:S ratio	P:S ratio	38	40	37	38	37	38
Linoleic	Linoleic	49	48	42	49	51	43
EPA	EPA	32	30	34	38	30	30
Plasma vitamins							
β-Carotene	Carotenes	32	29	28	32	28	32
β-Carotene/cholesterol	Carotenes	35	29	31	28	32	33
α-Tocopherol	Vitamin E	20	21	19	24	24	25
α-Tocopherol/cholesterol	Vitamin E	23	21	23	22	29	23

LER, low energy reporters; 7DD, 7 d diet diary; FFQ, food-frequency questionnaire; CEFA, serum cholesteryl ester fatty acids (analysed as g/100 g total fatty acids in CEFA fraction); P:S, polyunsaturated:saturated fatty acid ratio in CEFA or in dietary intake; EPA, eicosapentaenoic acid (20:5*n*-6).
* For details of subjects and procedures, see p. 406.
† Fatty acid intakes analysed as a proportion of total dietary fatty acids.

Table 4. Spearman rank correlations between 7 d diet diary intake and food-frequency questionnaire intake†‡

	Men			Women		
	All results	LER excluded	Energy-adjusted	All results	LER excluded	Energy-adjusted
n	457	225	453	402	207	400
Energy (MJ)	0·30	0·21*	–	0·38	0·22*	–
Total fat (g)	0·32	0·27	0·42	0·41	0·32	0·43
Saturated fat (g)	0·43	0·44	0·52	0·56	0·51	0·58
Monounsaturated fat (g)	0·36	0·30	0·41	0·39	0·34	0·42
Polyunsaturated fat (g)	0·36	0·45	0·49	0·32	0·35	0·36
Protein (g)	0·30	0·35	0·37	0·29	0·32	0·34
Total carbohydrate (g)	0·40	0·36	0·53	0·48	0·37	0·46
Sugars (g)	0·48	0·46	0·48	0·43	0·41	0·48
Starch (g)	0·37	0·42	0·43	0·46	0·39	0·35
Southgate fibre (g)	0·50	0·54	0·62	0·51	0·46	0·60
Vitamin C (mg)	0·44	0·41	0·46	0·41	0·42	0·45
Vitamin E (mg)	0·30	0·30	0·41	0·22	0·31	0·33
Folate (μg)	0·42	0·36	0·45	0·42	0·41	0·51
Carotenes (μg)	0·34	0·40	0·35	0·37	0·36	0·37
Iron (mg)	0·36	0·36	0·58	0·40	0·27	0·53
Calcium (mg)	0·40	0·43	0·48	0·40	0·41	0·44
Magnesium (mg)	0·48	0·48	0·63	0·40	0·38	0·62
Potassium (mg)	0·37	0·39	0·48	0·33	0·36	0·50
Alcohol (g)	0·78	0·79	0·78	0·85	0·86	0·83

LER, low-energy reporters.
All correlations are significant to $P \leq 0{\cdot}0001$, unless indicated otherwise: * $P \leq 0{\cdot}05$.
† For details of subjects and procedures, see p. 406.
‡ Results adjusted for age and employment grade.

Table 5. Agreement and disagreement between 7 d diet diary and food-frequency questionnaire estimates of intake*†

	All results		LER excluded		Energy-adjusted	
	Same quartile	Extreme quartile	Same quartile	Extreme quartile	Same quartile	Extreme quartile
Men						
Energy (MJ)	36	6	26	8	–	–
Total fat (g)	38	5	30	8	38	4
Saturated fat (g)	40	5	39	5	39	3
Monounsaturated Fat (g)	37	5	38	7	39	5
Polyunsaturated fat (g)	36	6	36	4	41	4
Protein (g)	36	7	37	5	37	4
Total carbohydrate (g)	39	5	32	6	40	2
Sugars (g)	42	4	37	4	38	4
Starch (g)	38	6	36	5	42	3
Southgate fibre (g)	43	3	40	4	47	2
Vitamin C (mg)	40	4	38	5	38	3
Vitamin E (mg)	35	6	34	6	38	5
Folate (μg)	34	5	32	5	40	4
Carotenes (μg)	35	7	34	5	38	6
Iron (mg)	37	4	35	5	39	1
Calcium (mg)	41	5	37	4	41	4
Magnesium (mg)	42	4	37	3	50	1
Potassium (mg)	35	6	34	5	41	3
Alcohol (g)	56	0	59	0	57	0
Women						
Energy (MJ)	38	5	32	8	–	–
Total fat (g)	37	5	35	6	39	5
Saturated fat (g)	41	2	36	4	44	2
Monounsaturated fat (g)	37	5	33	4	35	4
Polyunsaturated fat (g)	32	7	31	6	36	6
Protein (g)	35	8	31	7	39	6
Total carbohydrate (g)	40	4	39	4	37	4
Sugars (g)	38	6	35	6	41	4
Starch (g)	36	4	32	4	33	6
Southgate fibre (g)	38	3	40	3	43	1
Vitamin C (mg)	39	6	40	5	40	6
Vitamin E (mg)	33	8	33	7	34	7
Folate (μg)	36	5	34	6	43	4
Carotenes (μg)	33	6	29	5	33	5
Iron (mg)	35	5	31	8	40	3
Calcium (mg)	36	5	35	5	32	3
Magnesium (mg)	39	4	36	8	44	2
Potassium (mg)	36	7	35	6	41	5
Alcohol (g)	64	0	65	0	57	0

LER, low-energy reporters.
* For details of subjects and procedures, see p. 406.
† Values are the classification of individuals (%) into the same and extreme quartiles of nutrient intake.

estimated intakes of total fat, saturated and monounsaturated fatty acids, whereas estimates tended to be higher from the FFQ for protein, total carbohydrate, sugars, starch, fibre, vitamin C, folate, carotenes, Mg and K. The two methods produced similar estimated mean intakes of PUFA and Fe in both sexes.

Rank correlations of biomarkers with intakes obtained from the 7DD and FFQ are shown in Table 2. Correlations for linoleic and eicosapentaenoic acid are shown since they were respectively the main components of the *n*-6 and *n*-3 CEFA fractions. For comparison, coefficients for the three approaches to data presentation and analysis are shown side by side. There was no association between intake of monounsaturated fatty acids from either dietary method, and CEFA monounsaturated fatty acids (results not shown). Correlations for total PUFA, the PUFA:saturated fatty acid ratio and linoleic acid were in the range 0·3–0·5 for men and 0·4–0·7 for women for all methods of data presentation. As a guide for comparing coefficients, the standard error (estimated as $(1-r^2)/n$) for r 0·5, n 100 is 0·08. Correlations between plasma β-carotene and carotene intakes were about 0·2, while those for vitamin E were not significant. The standard error for r 0·2, n 300 is 0·06. In the case of eicosapentaenoic acid the FFQ correlation for men is numerically higher in several cells than that for the 7DD, but in general the 7DD tends to be higher. The correlation coefficients for eicosapentaenoic acid may be imprecise, given their low level in CEFA (mean value for eicosapentaenoic acid 11·4 (SD 8·9) *v.* linoleic acid 471 (SD 163) mg/ml).

Table 3 shows the level of agreement between reported nutrient intake and biomarker concentrations as % in the same quartile. Validity of the two dietary methods appears to be similar in both sexes. For fatty acids but not carotenes, agreement between biomarkers and each dietary method tends to be better among women than men.

Table 6. Low energy reporting according to the two dietary methods*

	FFQ					
	No		Yes		Total	
	n	%	*n*	%	*n*	%
Men						
7DD						
No	225	49·2	86	18·8	311	68·0
Yes	55	12·0	91	19·9	146	32·0
Total	280	61·3	177	38·7	457	100
Women						
7DD						
No	207	51·4	54	13·4	261	64·8
Yes	72	17·9	70	17·4	142	35·2
Total	279	69·2	124	30·8	403	100

FFQ, food-frequency questionnaire; 7DD, 7 d diet diary.
* For details of subjects and procedures, see p. 406.

Table 7. Odds ratios for being a low energy reporter according to BMI and employment grade*†

	Men (*n* 457)		Women (*n* 403)	
	7DD	FFQ	7DD	FFQ
BMI (kg/m^2)				
<20	1	1	1	1
20–24·9	1·58	0·49	1·38	1·44
25–29·9	3·45	0·95	3·41	1·82
30+	4·45	2·93	3·45	3·26
P value	<0·0001	<0·0001	<0·0001	<0·005
Employment grade				
1 (high)	1	1	1	1
2	1·89	0·90	1·70	1·69
3	1·67	1·57	1·01	0·99
4	2·44	2·26	1·84	1·32
5	1·60	2·04	4·25	2·00
6 (low)	3·94	2·20	4·26	2·41
P value	<0·0001	<0·0005	<0·0001	<0·05

7DD, 7 d diet diary; FFQ, food-frequency questionnaire.
* For details of subjects and procedures, see p. 406.
† χ^2 tests for trend.

Rank correlations between the two dietary methods are shown in Table 4. Correlations are in the range 0·33–0·62 for energy-adjusted nutrient intakes, and higher for alcohol (men 0·78, women 0·83). There is no clear difference in the magnitude of correlations for men and women. Table 5 shows the quartile agreement of reported nutrient intake according to the two self-report methods, and the percentage of observations falling into extreme quartiles of intake. Agreement tended to be higher, and disagreement lower, in the energy-adjusted data compared with the alternative methods of data analysis. Quartile agreement between the two methods was in the range 37–50 % for men and 32–44 % for women, and for alcohol 57 % in both sexes. Quartile disagreement was in the range 0–6 % for both sexes.

Table 6 cross-tabulates LER according to the dietary methods. The dietary methods yielded similar LER prevalences of about 34 % in both sexes. Table 7 shows the odds of being a LER according to BMI category and employment grade. The employment grade gradient in LER was largely unaffected when BMI was controlled for in the logistic regression model (results not shown).

Discussion

The FFQ has been described by its originators as a semiquantitative method of dietary assessment (Willett *et al.* 1985). In the present study sample, nutrient intakes estimated by the FFQ method proved to be well correlated with biomarker levels and with intake estimates from the generally more accurate 7DD, collected at the same study phase. While the estimated 7DD method is itself not a primary standard, the correlation of about 0·5 for most nutrients and 0·8 for alcohol between methods is good evidence that the FFQ has the ability to rank individuals, albeit imperfectly, according to nutrient intake. Further, the correlations among men and women are similar to those obtained for the same FFQ against weighed records in a validation sample of women in Cambridge, UK (50–65 years, *n* 156) (Bingham *et al.* 1997). This indicates that the FFQ is a useful dietary assessment tool in both sexes in the Whitehall II cohort.

Against biomarkers, the validity of the 7DD was similar to that of the FFQ in our present study sample. Fatty acid intakes appeared to be better measured in women than men by both dietary methods, but this did not reflect a clear gender difference in the quality of responses as the correlations for carotenes tend to be higher in men. LER was high on both dietary methods in both men and women, at approximately 34 %. Biomarkers are useful in assessing validity because errors of measurement are likely to be weakly correlated with those for self-reporting dietary methods. Low correlations are to be expected, since biomarker levels are subject to laboratory error and are not influenced by diet alone. The correlations obtained for the FFQ are similar to or better than those previously seen (Willett, 1998), i.e. of the order of 0·3 for CEFA linoleic acid and 0·2 for plasma β-carotene. The FFQ correlations tended to be higher than those for the 7DD for β-carotene in women, and PUFA: saturated fatty acid ratio among men. Conversely, in women, correlations with linoleic acid and PUFA, expressed as % fat intake, tended to be higher for the 7DD (0·5–0·8) than the FFQ (0·4–0·6). While the 7DD estimates produced remarkably good agreement with CEFA polyunsaturates (*r* 0·84 for linoleic acid intake among women) it appears that the two methods each contribute useful information about nutrient intakes.

The systematic differences in results from the two methods reflect the complexity of dietary assessment. Relative to the 7DD, the FFQ overestimates intakes of vitamin C, carotenes and folate, and underestimates total fat and monounsaturated fatty acids, whereas there is broad agreement between the two methods for energy, PUFA and protein. The upward bias in plant-derived micronutrient estimates from the FFQ has been observed before (Bingham *et al.* 1997) and is at least partly explained by the presence of multiple items for reporting vegetable intake (*n* 23). A seasonal effect may also operate. In epidemiology the primary need is often to place individuals in correct rank

order, rather than to make accurate estimates of absolute intake. In the case of carotenes, the balance between capturing between-person variation in nutrient intakes utilising a long food list, and obtaining an unbiased mean intake with a shorter food list is appropriately tilted towards correct ranking.

The advantages and disadvantages of the two dietary methods used in Whitehall II have been extensively reviewed (Bingham, 1991; Willett, 1998). Both the 7DD and FFQ are self-administered methods utilising, in Whitehall II, a common nutrient database system to derive energy and nutrient intakes. Respondent burden is considerably greater with the 7DD method, since for 1 week the diary must be filled in every time food or drink is consumed. Further, the financial cost of the 7DD method is substantially more, because trained coders are needed for manual data entry. The FFQ, in contrast, involves automated data capture using an optical scanner, and precoded foods and portion sizes (plus manual coding of dietary supplement information, not used in this analysis). Speed of completing and processing the FFQ is thus obtained putatively at the cost of the accuracy of the information obtained (Smith, 1993).

Whereas the 7DD is open-ended and involves portion size estimation for each item consumed, the FFQ respondent must estimate usual dietary intake in terms of given portions and a fixed set of single or closely related foods. In comparison, the strength of the open-ended 7DD is that a report of the entire diet can be captured, at least for a period of 7 d. This approach, in common with other diet record methods, has recognised weaknesses, in the form of conscious or unconscious biases. Respondents may change their intake during the diary period (observation bias), and may provide incomplete or false information (response bias).

One important type of response bias in the two methods is LER. Both FFQ and 7DD yielded some 34 % LER overall. These individuals are reporting energy intakes of less than 1·2 times their calculated BMR, and are thus unlikely to be reporting their usual diet (Goldberg *et al.* 1991). LER appears to be a property both of the individual and the dietary method. In our study sample, some 60 % of the LER group under-reported on both methods, while the remainder did so only on one of them. As we have previously shown (Stallone *et al.* 1997), overweight and obesity, and lower employment grade are each linked with probability of under-reporting dietary intake. Considering the respondent burden inherent in the two methods, it might be expected that the FFQ would perform better than the 7DD. There is a suggestion that this is so in relation to employment grade in both sexes, and to relative weight in men.

An important question addressed here concerns the way in which the nutrient data are best presented and analysed. Of the three approaches examined, energy adjustment using regression has several theoretical advantages. First, energy adjustment, unlike the nutrient density method (Kipnis *et al.* 1993), eliminates confounding due to total energy intake when epidemiological effects are analysed (Willett & Stampfer, 1986). Second, energy adjustment reduces bias due to LER, which tends to confound associations between socioeconomic measures and nutrient intake. Third, it permits all data to be used in analyses, in contrast with the method where LER status is used to exclude records (Pryer *et al.* 1995). On the down side, energy adjustment cannot correct intake data for differential reporting bias, and further it may obscure diet–disease relationships if absolute intake rather than nutritional composition is the operative effect (Stallone *et al.* 1997). Empirically, the validity of the energy-adjusted data, compared with the unadjusted and LER-excluded data, supports the use of the energy adjustment method for dietary analyses. The dietary methods are designed to capture differing aspects of diet, and so this is true despite the fact that energy adjustment does not produce consistently better agreement between 7DD and FFQ estimates of intake than the other two methods of analysis.

While the 7DD was found to be superior to the FFQ when evaluated against weighed records and biomarkers in the UK arm of the EPIC study (Bingham *et al.* 1997), the evidence from Whitehall II suggests that the relative performance of the two instruments may depend on the study population and method of nutrient analysis. Given the considerably greater resources needed to employ the 7DD it appears that there could be circumstances when the FFQ method is the preferred approach. In view of the moderate agreement between methods, and the similarity of the respective biomarker correlations, it may be that a combination of intake estimates from both methods has better predictive power for nutritional effects on health and disease than 7DD estimates alone.

Acknowledgements

The Whitehall II study is supported by grants from the Medical Research Council; British Heart Foundation; Health and Safety Executive; Department of Health; National Heart Lung and Blood Institute (HL36310), US, NIH: National Institute on Aging (AG13196), US, NIH; Agency for Health Care Policy Research (HS06516); and the John D. and Catherine T. MacArthur Foundation Research Networks on Successful Midlife Development and Socio-economic Status and Health. M.M. is supported by an MRC Research Professorship. E.B. is supported by the BHF. We also thank all participating civil service departments and their welfare, personnel, and establishment officers; the Occupational Health and Safety Agency; the Council of Civil Service Unions; all participating civil servants in the Whitehall II study; and all members of the Whitehall II study team. The diet component of this study was supported by DH/MRC Nutrition Programme (SPG 9324537) and the Ministry of Agriculture, Fisheries and Food.

References

Armstrong NC, Paganga G, Brunner EJ, Miller JN, Nanchahal K, Shipley MJ, Rice-Evans CA, Marmot MG & Diplock AT (1997) Reference values for α-tocopherol and β-carotene in the Whitehall II Study. *Free Radical Research* **27**, 207–219.

Beksinska M, Yea L & Brunner EJ (1995) *Whitehall II Study Manual for Screening Examination 1991–93*, London: UCL, Department of Epidemiology and Public Health.

Bingham SA (1991) Limitations of the various methods for collecting dietary intake data. *Annals of Nutrition and Metabolism* **35**, 117–127.
Bingham SA & Day NE (1997) Using biochemical markers to assess the validity of prospective dietary assessment methods and the effect of energy adjustment. *American Journal of Clinical Nutrition* **65**, 1130S–1137S.
Bingham SA, Gill C, Welch A, Cassidy A, Runswick SA, Oakes S, Lubin R, Thurnham DI, Key TJA, Roe L, Khaw K & Day NE (1997) Validation of dietary assessment methods in the UK arm of EPIC using weighed records, and 24-hour urinary nitrogen and potassium and serum vitamin C and carotenoids as biomarkers. *Epidemiology* **26**, S137–S151.
Black AE, Goldberg GR, Jebb SA & Prentice AM (1991) Evaluating dietary surveys against energy requirements. *Proceedings of the Nutrition Society* **50**, 33A.
Braddon FEM, Wadsworth MEJ, Davies JMC & Cripps HA (1988) Social and regional differences in food and alcohol consumption and their measurement in a national birth cohort. *Journal of Epidemiology and Community Health* **42**, 341–349.
Brunner EJ (1997) Inequalities in diet and health. In *Diet, Nutrition and Chronic Disease: Lessons from Contrasting Worlds*, 1st ed., [P Shetty and K McPherson, editors]. Chichester: Wiley.
Brunner EJ, Marmot MG, Nanchahal K, Shipley MJ, Stansfeld SA, Juneja M & Alberti KGMM (1997) Social inequality in coronary risk: central obesity and the metabolic syndrome. Evidence from the Whitehall II study. *Diabetologia* **40**, 1341–1349.
Buttriss JL & Diplock AT (1984) High-performance liquid chromatography methods for vitamin E in tissues. *Methods in Enzymology* **105**, 131–138.
Chan W, Brown J & Buss DH (1994) *Miscellaneous Foods. Fourth Supplement to the 5th Edition of McCance and Widdowson's The Composition of Foods*. Cambridge: Royal Society of Chemistry.
Chan W, Brown J & Lee SM (1995) *Meat, Poultry and Game. Supplement to the 5th Edition of McCance and Widdowson's The Composition of Foods*. Cambridge: Royal Society of Chemistry.
Goldberg GR, Black A, Jebb E, Cole TJ, Murgatroyd PR, Coward WA & Prentice AM (1991) Critical evaluation of energy intake data using fundamental principles of energy physiology: 1. Derivation of cut-off limits to identify under-recording. *European Journal of Clinical Nutrition* **45**, 569–591.
Holland B, Brown J & Buss DH (1993) *Fish and Fish Products. Third Supplement to the 5th Edition of McCance and Widdowson's The Composition of Foods*. Cambridge: Royal Society of Chemistry.
Holland B, Welch AA & Buss DH (1988) *Cereals and Cereal Products. Third Supplement to the 4th Edition of McCance and Widdowson's The Composition of Foods*. Cambridge: Royal Society of Chemistry.
Holland B, Welch AA & Buss DH (1989) *Milk Products and Eggs. Fourth Supplement to the 4th Edition of McCance and Widdowson's The Composition of Foods*. Cambridge: Royal Society of Chemistry.
Holland B, Welch AA & Buss DH (1991*b*) *Vegetables, Herbs and Spices. Fifth Supplement to the 4th Edition of McCance and Widdowson's The Composition of Foods*. Cambridge: Royal Society of Chemistry.
Holland B, Welch AA & Buss DH (1992*a*) *Fruit and Nuts. First Supplement to the 5th Edition of McCance and Widdowson's The Composition of Foods*. Cambridge: Royal Society of Chemistry.
Holland B, Welch AA & Buss DH (1992*b*) *Vegetable Dishes. Second Supplement to the 5th Edition of McCance and Widdowson's The Composition of Foods*. Cambridge: Royal Society of Chemistry.
Holland B, Welch AA, Unwin ID, Buss DH, Paul AA & Southgate DAT (1991*a*) *McCance and Widdowson's The Composition of Foods*, 5th ed. Cambridge: Royal Society of Chemistry.
Kipnis V, Freedman LS, Brown CC, Hartman A, Schatzkin A & Wacholder S (1993) Interpretation of energy adjustment models for nutritional epidemiology. *American Journal of Epidemiology* **137**, 1376–1380.
Marmot MG, Davey Smith G, Stansfeld SA, Patel C, North F, Head J, White I, Brunner EJ & Feeney A (1991) Health inequalities among British Civil Servants: the Whitehall II study. *Lancet* **337**, 1387–1393.
Paul AA & Southgate DAT (1978) *McCance and Widdowson's The Composition of Foods*, 4th ed. London: H.M. Stationery Office.
Pryer JA, Brunner EJ, Elliott P, Nichols R, Dimond H & Marmot MG (1995) Who complied with COMA 1984 dietary fat recommendations among a nationally representative sample of British adults in 1986–7 and what do they eat? *European Journal of Clinical Nutrition* **49**, 718–728.
Schofield WN, Schofield C & James WPT (1985) Basal metabolic rate. *Human Nutrition: Clinical Nutrition* **39C**, Suppl. 1, 1–96.
Smith AF (1993) Cognitive psychological issues of relevance to the validity of dietary reports. *European Journal of Clinical Nutrition* **47**, Suppl. 2, S6–S18.
Stallone DD, Brunner EJ, Bingham SA & Marmot MG (1997) Dietary assessment in Whitehall II. The influence of reporting bias on apparent socioeconomic variation in nutrient intakes. *European Journal of Clinical Nutrition* **51**, 815–825.
Willett W (1998) *Nutritional Epidemiology*, 2nd ed. New York, NY: Oxford University Press.
Willett WC, Sampson L, Stampfer MJ, Rosner B, Bain C, Witschi J, Hennekens CH & Speizer FE (1985) Reproducibility and validity of a semiquantitative food frequency questionnaire. *American Journal of Epidemiology* **122**, 51–65.
Willett WC & Stampfer MJ (1986) Total energy intake: implications for epidemiologic analyses. *American Journal of Epidemiology* **124**, 17–27.