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Reproducibility of the online Food4Me food-frequency questionnaire for estimating dietary intakes across Europe

Article

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Title

Reproducibility of the online Food4Me food frequency questionnaire for estimating dietary intakes across Europe[1,2,3]

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Abbreviations

Food frequency questionnaire (FFQ); Limits of agreement (LOA); Monounsaturated fatty acid (MUFA); Omega-3 fatty acid (n-3 FA); Pearson's correlation coefficient (PCC); Physical activity level (PAL); Polyunsaturated fatty acid (PUFA); Randomized controlled trial (RCT); Saturated fatty acid (SFA); Sedentary behavior (SB); Spearman's correlation coefficient (SCC, rho)

Abstract

Background: Accurate dietary assessment is key to understanding nutrition-related outcomes and is essential for estimating dietary change in nutrition-based interventions.

Objective: The objective of this study was to assess the pan-European reproducibility of the Food4Me FFQ in assessing the habitual diet of adults.

Methods: Participants were included from the Food4Me study, a 6-mo, internet-based, randomized controlled trial of personalized nutrition conducted in the UK, Ireland, Spain, the Netherlands, Germany, Greece and Poland. Screening and baseline data (both prior to commencement of the intervention) were used in the present analyses and participants were only included if they completed FFQs at screening and at baseline within a one-month timeframe prior to the commencement of the intervention. Socio-demographic (e.g. sex and country) and lifestyle (e.g. BMI and physical activity) characteristics were collected. Linear regression, correlation coefficients, concordance (%) in quartile classification and Bland-Altman plots for daily intakes were used to assess reproducibility.

Results: 567 participants (age 38.7 ± 13.4 y; 59% female; BMI 25.4 ± 4.8 kg/m^2) completed both FFQs within one-month (mean 19.2 ± 6.2 d). Exact plus adjacent classification of total energy intake in participants was highest in Ireland (94%) and lowest in Poland (81%). Spearman Correlation Coefficients (rho) in total energy intake between FFQs ranged from 0.50 for obese participants to 0.68 and 0.60 in normal and overweight participants respectively. Bland-Altman plots showed a mean difference between FFQs of 210 kcal/d, with the agreement deteriorating as energy intakes increased. There was little variation in reproducibility of total energy intakes between sex and age groups.

Conclusions: The online Food4Me FFQ was shown to be reproducible across 7 European countries when administered within a one month period to a large number of participants. The results support the utility of the online Food4Me FFQ as a reproducible tool across multiple European populations.

Trial registration – Clinicaltrials.gov NCT01530139

Key words: Food frequency questionnaire; reproducibility; online; dietary intakes; European

Introduction

Given that poor diet is a predominant cause of the growing burden of non-communicable diseases, more effective strategies for improving diet are of increasing importance (1) . In tandem, accurate dietary assessment tools are essential for evaluating the efficacy of lifestyle interventions (2) but all current methods of assessing habitual dietary intakes (including weighed-dietary intakes, 24-hour dietary recall and food frequency questionnaires (FFQ)) are subjective (3). Although weighed dietary recalls are considered the most accurate of the three (4), retrospective recalls (24-hour recalls and FFQs) offer the advantages of lower costs and lower-respondent burden (5) and are therefore widely used in large scale epidemiological and intervention studies.

With more than 70% of Europeans now Internet users (6), Internet-based diet and lifestyle interventions, including Internet-based FFQs, are an attractive, cost-effective and scalable alternative to face-to-face interventions (7). However, self-reported dietary assessment is prone to respondent bias (8), which may limit reproducibility of the FFQ, resulting in poor measures of dietary change and in chance associations with disease outcomes (9, 10). It is therefore essential to evaluate the measurement error and reproducibility of FFQs to ensure confidence in the precision of any diet-related outcomes.

The online Food4Me FFQ used in this study was validated previously against a weighed food record over a 4-wk period (n=49) and showed moderate agreement (correlation coefficient 0.47) for assessing energy and nutrient intake (11), and a good agreement (0.60) against the EPIC-Norfolk printed FFQ (n=113) (12). Furthermore the reproducibility of the online Food4Me FFQ was assessed in the UK (n=100) and showed good agreement, with mean cross-classification into "exact agreement plus adjacent" at 92% for both nutrient and food group intakes (11). The aim of our present investigation was to verify that the online

Food4Me FFQ was reproducible across 7 European countries by comparing estimated intakes of foods, energy and nutrients between screening and baseline in the Food4Me study.

Methods

Study design

The Food4Me study was a 6-mo, internet-based, randomized controlled trial (RCT) of personalized nutrition designed to improve diet and PA behaviors, which was conducted across 7 European countries (n=1607). Recruitment was via the Food4Me website (13) from the following sites: University College Dublin (Ireland), Maastricht University (The Netherlands), University of Navarra (Spain), Harokopio University (Greece), University of Reading (United Kingdom, UK) and National Food and Nutrition Institute (Poland), Technical University of Munich (Germany). Individuals with ill-health, food intolerances, or special nutritional requirements (e.g. pregnancy) were ineligible to participate. Body mass index (BMI) was estimated from self-reported body weight and height (14). Participants self-reported smoking habits and occupation. Physical activity level (ratio between total energy expenditure and basal metabolic rate; PAL) and sedentary behavior (SB; min/d) were estimated from tri-axial accelerometers (TracmorD, Philips Consumer Lifestyle, The Netherlands). The Research Ethics Committees at each University or Research Centre granted ethical approval for the study. All participants signed online consent forms. The Food4Me trial was registered as a RCT (NCT01530139) at Clinicaltrials.gov. Full details on the study design are available elsewhere (14).

Food4Me FFQ

The Food4Me FFQ is an online, semi-quantitative FFQ, which was administered to individuals at screening, baseline and at follow-up timepoints following randomization. For the purposes of this reproducibility study, screening and baseline were used, as no change in diet was expected. FFQs were available in the language of the country, with respondents asked to report mean consumption over the previous month for 157 items in the UK and Ireland (based on the 130-item printed EPIC-Norfolk FFQ (version CAMB/PQ/6/1205) (12, 15)), with additional country-specific foods added to capture intakes in the other 5 recruitment countries (e.g. "stroopwafels" was added to the Dutch FFQ). A total of 11 food categories were included: 1) cereal, 2) bread and savory biscuits, 3) potatoes, rice and pasta, 4) meat and fish, 5) dairy products, 6) fats and spreads, 7) sweets and snacks, 8) soups, sauces and spreads, 9) drinks, 10) fruit and 11) vegetables (Table S1). Frequency of consumption of each food item was estimated by selecting one of the following options: never or less than once/mo, 1-3 times/mo, once/wk, 2-4 times/wk, 5-6 times/wk, once/d, 2-3 times/d, 5-6 times/d or >6 times/d. The online Food4Me FFQ included photographs of the foods and participant selected the appropriate portion size from the following options: very small, small, small/medium, medium, medium/large, large or very large. Food intake (g/d) was then calculated by multiplying portion size by frequency of consumption. For the purpose of comparing food group intakes, the 11 food categories were subdivided into 35 food groups based on previous validation by Forster *et al*. (12). Further details on the Food4Me FFQ are provided elsewhere (14).

Statistical Analysis

Statistical analysis was performed using STATA (version 12; StataCorp, College Station, TX, USA) and MedCalc Statistical Software (version 12.2.1.0; Medcalc, Mariakerke, Belgium).

ANOVA (continuous data) and logistic regression (categorical) tested for overall differences in anthropometric and socio-demographic characteristics (dependent variable) between countries (independent variable) and were adjusted for age and sex. Post hoc Tukey's tests and logistic regression (adjusted for age and sex) investigated differences in characteristics (dependent variable) between a given country and the overall mean for all countries (independent variable) (**Table 1**). FFQ reproducibility was determined by comparing dietary intakes at screening and baseline (mean 2.7 ± 0.9 wk apart). As the FFQ was designed to assess dietary intakes over a 1-month period, participants were excluded from the current analysis if the time period between completion of FFQs was > 1 month (16). Participants with implausible energy intakes were excluded based on the upper limit of sustained energy expenditure defined by the Scientific Advisory Committee for Nutrition: energy intake > 2.5 x Basal Metabolic Rate (17). Multiple linear regression was used to determine differences in total energy, nutrient and food group intakes (dependent variable) between FFQs (independent variable) and were adjusted for age, sex, country, time of FFQ completion and total energy intake at screening. Normality of data was assessed using the Shapiro-Wilk test and, depending on the outcome, comparison of energy, nutrients and food group intake was assessed using Pearson's product moment correlation coefficients (PCC) or Spearman's correlation coefficient (SCC, rho). Energy-adjusted correlation coefficients were estimated using the residual method (18). Briefly, residuals from the regression analysis (energy intake as independent variable and nutrient intake as dependent) were added to the expected nutrient value for the mean energy intake of the sample (**Table 2** and **Table 3**). The coefficient of reproducibility between methods was calculated (19). Concordance (%) in quartile classification estimated the relative agreements between FFQs. Quartiles of intakes of nutrients and food groups were used to determine changes in classification between timepoints. The percentages of participants classified into the correct quartile (exact classification), adjacent quartile (exact classification plus adjacent), two quartiles apart (misclassification) or three quartiles apart (extreme misclassification) were estimated (**Supplemental Table 2 and Supplemental Table 3**). Bland-Altman plots determined clinical relevance of any difference in total energy and nutrients between methods based on the mean difference between methods (bias), trends, variability and widths of the limits of agreement (LOA; **Figure 1**). Reproducibility of total energy intakes was assessed according to age (<45 y and ≥45 y), sex, country, completion period between FFQs (short: 0-15.6 d; medium: 15.6-22.6 d; long: 22.6-31 d) and BMI at screening (underweight: BMI <18.5 kg/m^2; normal weight: 18.5 to 24.9 kg/m^2; overweight: 25 to 29.9 kg/m^2; obese: ≥30 kg/m^2) using regression analyses, SCC and concordance (%) in quartile classification (**Supplemental Table 4**).

Sensitivity analysis

Sensitivity analyses excluded participants who over- or under-reported energy intakes (**Supplemental Fig. 1**). Under-reporting was operationalized as an energy intake < 1.1 multiplied by predicted basal metabolic rate (using the Henry equation (20)) (21), and energy intakes > 4500 kcal/d were classified as over-reporting (22).

Results

Of the 1607 randomized participants, 1480 completed the FFQ at screening and at baseline and 665 completed the FFQs within one month of each other. Spain was excluded from all analyses due to insufficient numbers completing the FFQs within the 1-month timeframe (n=5). A further 93 participants were excluded based on implausible energy intakes.

Individuals from Greece had higher BMI, WC, more participants in routine and manual work, less students and more participants not currently working than the overall mean across all countries. Less Polish participants were in routine and manual employment and more Polish participants were females, while more Dutch were leaner, than the overall mean. Less participants from the United Kingdom were Caucasian, while there were less female participants from Ireland than the overall mean. No significant differences in PAL, BW or SB were identified (Table 1).

Reproducibility of nutrient intakes

Total energy intakes and intakes of protein, carbohydrate, total fat, saturated (SFA), mono- (MUFA) and polyunsaturated fatty acids (PUFA), omega-3 (n-3 FA), sugar, salt, calcium, folate, iron, carotene, riboflavin, fiber, sodium and vitamins B-6, C, A, D and E were lower at baseline than at screening ($P<0.05$; Table 2). There were no significant differences between timepoints for percentage energy intakes from total fat, MUFAs, PUFAs, protein, carbohydrate and sugars or for intakes of alcohol, vitamin B-12, thiamine and retinol. Shapiro-Wilk tests revealed that data were not normally distributed therefore SCC was used to examine correlations. Unadjusted SCCs ranged from 0.59 for total fat (g/d) to 0.89 for alcohol (mean 0.67; $P<0.001$), while energy adjusted SCCs ranged from 0.59 for total fat to 0.89 for alcohol (0.69; $P<0.001$; Table 2).

The percentage of participants whose dietary intakes were classified exactly at baseline, compared with screening, ranged from lowest for total fat to highest for alcohol (mean 50%; Supplemental Table 2). In total, 88% of participants were classified into the same or adjacent quartile, 10% were misclassified and 2% were extremely misclassified.

Bland-Altman plots comparing intakes of energy, total fat, protein and carbohydrate between timepoints are shown in Figure 1. The bias (mean difference) for total energy, carbohydrate, protein and fat intake was 210 kcal/d, 11.4%, 9.1% and 9.0% respectively. A positive trend indicated a lower agreement in intakes between timepoints for those who reported higher energy intakes (>4500 kcal/d) and who were classified as over-reporters in the sensitivity analyses. The amount consumed did not affect the agreement between intakes of carbohydrate, protein and fat.

Reproducibility of food group intakes

Reported intakes of wholemeal bread, biscuits, other fruits, meat products and soups, sauces and miscellaneous foods were lower at baseline compared with screening (*P*<0.05; Table 3). Unadjusted SCC ranged from 0.42 for tinned fruit or vegetables to 0.89 for alcoholic beverages (mean 0.71, *P*<0.001), while energy adjusted SCCs ranged from 0.45 for rice, pasta, grains and starches to 0.87 for alcoholic beverages (mean 0.69; *P*<0.001).

As shown in Supplemental Table 3, the percentage of participants correctly classified into the same quartile for food group intakes was lowest for rice, pasta, grains and starches and highest for alcoholic beverages. For all food groups, the mean percentages of participants who were misclassified and extremely misclassified were 8% and 2% respectively.

Sub group analysis: reproducibility of total energy intakes

As summarized in Supplemental Table 4, energy intake was lower at baseline than at screening for Greece, Poland and Germany. Correlations in energy intakes between timepoints were highest for the Netherlands and lowest for Greece, while the percentage energy intakes correctly classified was lowest in Germany and the United Kingdom and highest in the Netherlands. Energy intake was lower at baseline compared with screening for those with short and medium time between assessments but not for the longest. For participants with the longest period of time between completing FFQs, SCC of energy intakes were poorest (Table S3). Energy intake was lower at baseline than at screening for normal and overweight participants but not for obese participants. SCCs were lower and the percentage of individuals misclassified was higher in overweight and obese participants than normal weight participants (Table S3). Energy intake was lower at baseline than at screening for participants both ≥ and < 45 y. SCCs for energy intakes between timepoints were higher for participants ≥ 45 y, with similar proportions of individuals correctly classified and extremely misclassified. Energy intakes at baseline were lower than at screening for both male and females. Although more females than males were correctly classified into the same quartile, more females than males were misclassified (Table S3).

Sensitivity Analysis

Analyses were repeated in valid reports (n=437) after the removal of over- (n=8) and under-reporters (n=122). Supplemental Fig. 1 summarizes the delta between timepoints for percentage energy from fat, carbohydrates and protein in the total cohort and in valid reporters. This difference between timepoints is consistently smaller for the valid reporters in comparison with the whole cohort. After exclusion of mis-reporters, differences between timepoints in reported intakes of total fat, SFAs, MUFAs, PUFAs, n-3 FA, protein, calcium, carotene, riboflavin and vitamins C, A, biscuits, other fruits and soups, sauces and miscellaneous foods were not significant. For nutrients, SCC ranged from 0.60 for total fat and SFA g/day to 0.91 for alcohol and for food groups from 0.52 for rice, pasta, grains and starches to 0.91 for alcoholic beverages (P<0.001). Bland-Altman analysis on valid reports produced a higher agreement between timepoints for total energy intake (bias reduced from 210 kcal/d to 88.5 kcal/d), carbohydrate (11.4% to 5.3%), protein (9.2% to 2.3%) and fat (9.5% to 2.4%). The coefficient of reproducibility in valid reports was reduced by 780kcal/d for energy intake, 14.4% for percentage energy from carbohydrate, 12.7% for protein intake and 13.3% for fat intake.

Discussion

Main findings

Our main findings indicate that the online Food4Me FFQ is reproducible for estimation of nutrient and food group intakes by adults across 7 European countries.

Comparison with other studies

An earlier study investigated the reproducibility of the online Food4Me FFQ by asking 100 participants within a single country (UK) to complete the FFQ on two occasions 4 wk apart. In that study, Fallaize *et al*. (11) reported higher mean correlation coefficients than in the present study for total energy intake (0.77 vs 0.61), nutrients (0.75 vs 0.67) and food group intakes (0.75 vs 0.71). Cross classification analysis for nutrients was also higher, with 92% of participants classified into the same or adjacent quartile, compared with 88% in the current paper. Bland-Altman analysis indicated a lower mean difference for total energy intake in the study by Fallaize *et al.* (11) compared with ours (135 kcal/d vs 210 kcal/d), however, the removal of mis-reporters lowered the mean difference in the current study to 89kcal/d. In the current study, the online Food4Me FFQ was administered to a much larger and more diverse group of participants across 7 European countries who, in addition to completing the FFQ, were responding to a wider range of questionnaires. Furthermore, FFQ reproducibility in the study by Fallaize *et al.* (11) was assessed in conjunction with validation against a 4-day weighed food diary, which may have increased the participants awareness of their habitual intake and, thus, they may have been more likely to report similar intakes. The observed lower agreement between repeated administrations of the FFQ in the current study may be because the participants were less focused on the FFQ per se. Previous studies of the reproducibility of FFQs have reported correlation coefficients for total energy intake of 0.66 and 0.65 (8, 23, 24), which are very similar to our observations. The much higher correlation of 0.82 reported by Beasley *et al.* (25) was for an internet-based FFQ repeated within a short time interval (one wk) and thus subject to less variation (26). The shortest interval between FFQ administrations in the current study (0-15.65 d) produced a correlation of 0.64, lower than the 0.82 reported by Beasley et al. (25). However reproducibility in Beasley *et al.* (25) was also accompanied by a validation study against a 4-d weighed food diary, which may have improved correlations by increasing the participants awareness of their diet. Cross-classification analyses in the current study showed agreements that were comparable with previous studies for energy, nutrients and food groups (27-29). We observed that reported energy intakes were lower in the second FFQ, which confirms findings from other reproducibility studies (11, 25, 28, 30) and may be attributed to the learning effect of repeated measure. Alternatively, this observation may be due to fatigue caused by overburdening participants who had recently completed the initial FFQ (31). However, when mis-reporters were excluded, most differences between screening and baseline were no longer significant.

Previous FFQ reproducibility studies using repeated assessments within one month have reported coefficient ranges of 0.58-0.86 for energy intake between several countries (11, 23, 25, 28, 29, 32). Inter-country variations in SCCs in the Food4Me FFQ were similar, suggesting that this dietary assessment tool has wide applicability across several European countries. The disparity between the cross-classifications and SCC in the UK may have been due to the presence of dietary mis-reporters and following exclusion of mis-reporters, these measures of reproducibility were more closely aligned. Our gender-dependent findings are consistent with a previous study (33), reporting higher reproducibility for a 240-item FFQ in males than in females (PCC 0.70 and 0.65, respectively). The reproducibility of the online Food4Me FFQ was similar for both older and younger participants. The lower reported energy intake at baseline compared with screening was significant for both normal weight and overweight participants but not for obese participants. This is probably due to a smaller sample size of obese individuals (n=79) compared with normal weight (n=296) and overweight (n=192) individuals as when assessed by SCC, reproducibility was lowest in the obese group. These findings confirm previous results, where obese individuals are more likely to mis-report their dietary intakes (34, 35). Self-administered dietary assessment tools should thus be interpreted with caution when applied to a population of predominantly obese subjects.

Previous studies on the validation and reproducibility of the Food4Me FFQ excluded under- and over-reporters prior to the main analysis (11, 12). The current study included the whole cohort. The percentage of people under-reporting (21.5%) was higher than that of over-reporters (1.4%), a common occurrence that has been previously reported (36). A sensitivity analysis following removal of misreports improved the reproducibility of the Food4Me FFQ.

Strengths and limitations

The main strength of this study is large number of participants from 7 European countries, which enabled stratification according to country, age, sex, obesity status and time interval between FFQs. However, by excluding participants who did not complete FFQs within a 1-month period, we had too few participants from Spain (n=5) to allow comparisons with this country. Nonetheless, another strength of this study is that it was possible to assess the FFQ reproducibility between valid and mis-reporters in a European population. As recommended by Cade *et al*. (16), we applied the cut off of < 1 month between repeated FFQs to avoid confounding by real temporal changes in food intake. With a short time between the FFQs, it is conceivable that participants might remember and, therefore replicate, their previous FFQ responses (16). However, the comprehensive nature of the online Food4Me FFQ would make this unlikely and a 1-month period is considered an optimal time-period to assess reproducibility (16), whilst minimizing any influence of dietary change over time (11).

Conclusion

The Food4Me FFQ is moderately reproducible when administered to a large cohort of European adults. Variations in reproducibility between countries were small, thus providing confidence in the utility of the method for reporting intakes of energy, nutrients and food groups across multiple European countries.

Authors' contributions

The authors' responsibilities were as follows: YM, IT, CAD, ERG, LB, JAL, JAM, WHS, HD, MG and JCM contributed to the research design. JCM was the Proof of Principle study leader. CCM, CFMM, HF, CBO, CW, ALM, RF, SNC, RSC, SK, LT, CPL, MG, AS, MCW, ERG, LB and JCM contributed to the developing the Standardised Operating Procedure for the study. CCM, SNC, RSC, CW, CBO, HF, CFMM, ALM, RF, SK, LT, CPL, MG, AS, MCW and JCM conducted the intervention. CCM, CFMM and WHS contributed to physical activity measurements. SJM and KML drafted the paper and performed the statistical analysis for the manuscript and are joint first authors. All authors contributed to a critical review of the manuscript during the writing process. All authors approved the final version to be published.

Figure Legends

Figure 1. Bland-Altman plots for reproducibility between screening and baseline intakes of A. total energy, B. fat, C. protein and D. carbohydrate (n=567) in European adults. The solid line represents the mean difference, the dashed line represents the limits of agreement and the dotted line represents the trend in agreement.

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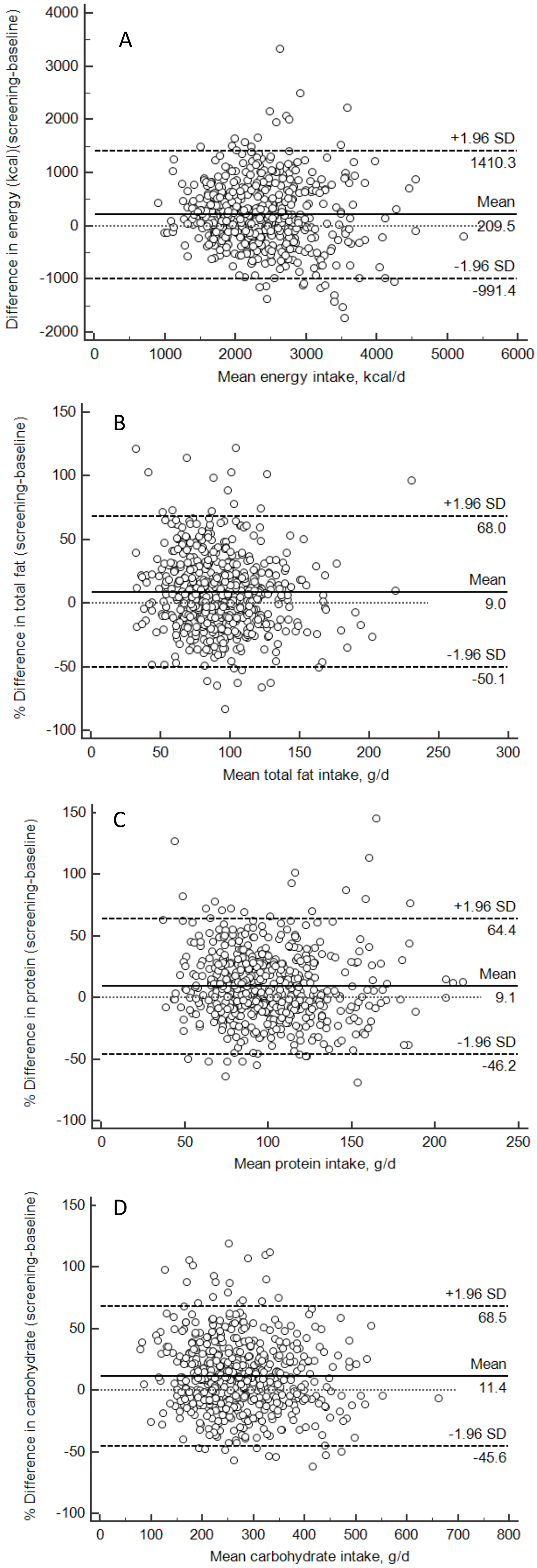

A
Difference in energy (kcal)(screening-baseline)
+1.96 SD
1410.3
Mean
209.5
-1.96 SD
-991.4
Mean energy intake, kcal/d
B
% Difference in total fat (screening-baseline)
+1.96 SD
68.0
Mean
9.0
-1.96 SD
-50.1
Mean total fat intake, g/d
C
% Difference in protein (screening-baseline)
+1.96 SD
64.4
Mean
9.1
-1.96 SD
-46.2
Mean protein intake, g/d
D
% Difference in carbohydrate (screening-baseline)
+1.96 SD
68.5
Mean
11.4
-1.96 SD
-45.6
Mean carbohydrate intake, g/d

Figure 1.

Table 1 Anthropometric and soc

io-demographic characteristics of European adults by country at the time of completing the screening Food4Me food frequency questionnaire[1]

	Total (n=567)	Country						P[2]
		Greece (n=160)	Ireland (n=70)	Netherlands (n=108)	Poland (n=153)	UK (n=49)	Germany (n=27)	
Age, y	38.7 ± 13.4	38.3 ± 11.2	39.6 ± 13.2	42.7 ± 16.6	35.0 ± 12.1	38.4 ± 12.6	43.4 ± 15.4	<0.001
Sex, Female, %	58.9	58.1	41.4*	50.9	70.1*	67.4	59.3	0.03
Ethnicity, Caucasian, %	97.5	99.4	97.1	95.4	100	87.8*	100	0.04
Occupation, %								
Professional and managerial	31.2	31.3	40.0	36.1	19.0	46.9	29.6	0.98
Intermediate occupations	29.1	28.1	21.4	17.6	46.4	12.2	33.3	0.47
Routine and manual	11.6	18.1*	14.3	8.3	5.9*	14.3	7.4	0.02
Student	17.1	7.5*	15.7	24.1	22.9	18.4	14.8	0.048
Not currently working	10.9	15.0*	8.6	13.9	5.9	8.2	14.8	0.04
Anthropometrics								
BMI, kg/m^2	25.4 ± 4.8	26.7 ± 5.5*	26.0 ± 4.6	24.4 ± 3.9*	24.7 ± 4.7	25.3 ± 4.3	24.5 ± 3.0	<0.001
Waist circumference, cm	85.5 ± 14.1	89.3 ± 14.8*	87.5 ± 14.1	84.6 ± 12.5	81.6 ± 14.2	84.2 ± 11.7	85.4 ± 13.0	<0.001
Body weight, kg	75.0 ± 15.4	76.9 ± 15.7	78.3 ± 16.3	74.7 ± 13.5	71.1 ± 16.2	72.7 ± 14.1	75.0 ± 12.1	0.13
Physical activity								
PAL	1.7 ± 0.2	1.7 ± 0.1	1.8 ± 0.2	1.7 ± 0.2	1.7 ± 0.2	1.7 ± 0.2	1.7 ± 0.2	0.07
SB, min/d	745 ± 78.0	744 ± 89.4	755 ± 72.1	753 ± 72.1	741 ± 79.2	725 ± 59.2	762 ± 66.7	0.36

1, Values represent means ± SD or percentages; PAL, physical activity level (ratio between total energy expenditure and basal metabolic rate); SB, sedentary behavior.
2, ANOVA and logistic regression were used to test for significant differences across countries in continuous and categorical variables, respectively. Analyses were adjusted for age and sex; * Post hoc Tukey tests (continuous data) and logistic regression (categorical) were used to test for significant differences between a given country and the overall study mean across all countries, P<0.05.

Table 2 Differences in total energy and nutrient intakes in European adults between screening and baseline as assessed using multiple linear regression and correlation coefficients[1]

	Timepoint[2]		P[3]	Correlation coefficient[4]	
	Screening	Baseline		Crude	Energy adjusted
Total energy, kcal/d	2455 ± 685	2246 ± 730	<0.001	0.61	-
Total fat, g/d	96.4 ± 32.2	89.2 ± 32.8	<0.001	0.59	0.59
Total fat, % energy	35.4 ± 6.2	35.7 ± 5.8	0.423	0.61	0.61
SFA, g/d	38.1 ± 14.6	35.1 ± 14.6	0.001	0.61	0.64
SFA, % energy	13.9 ± 3.2	14 ± 3.1	0.78	0.65	0.65
MUFA, g/d	36.7 ± 13.8	33.9 ± 13.2	<0.001	0.62	0.69
MUFA, % energy	13.5 ± 3.5	13.6 ± 3.2	0.54	0.72	0.71
PUFA, g/d	15.3 ± 5.4	14.3 ± 5.8	0.004	0.67	0.67
PUFA, % energy	5.6 ± 1.3	5.8 ± 1.4	0.13	0.68	0.68
Omega-3 FA, g/d	1.8 ± 0.7	1.7 ± 0.7	0.004	0.65	0.68
Protein, g/d	104 ± 34.3	95 ± 33.1	<0.001	0.63	0.68
Protein, % energy	17.1 ± 3.4	17.2 ± 3.4	0.49	0.71	0.70
Carbohydrate, g/d	288 ± 96.7	259 ± 96.1	<0.001	0.64	0.63
Carbohydrate, % energy	46.8 ± 7.6	46 ± 7.4	0.11	0.65	0.66
Total sugars, g/d	128 ± 47.8	117 ± 48.0	<0.001	0.66	0.72
Total sugars, % energy	21.1 ± 6.1	21 ± 5.9	0.83	0.73	0.73
Fiber, g/d	29.8 ± 12.1	26.8 ± 11.5	<0.001	0.71	0.73
Alcohol, g/d	10.4 ± 12.8	10.3 ± 13.7	0.83	0.89	0.89
Calcium, g/d	1225 ± 478	1111 ± 462	<0.001	0.63	0.69
Folate, μg/d	370 ± 131	338 ± 130	<0.001	0.65	0.70
Iron, mg/d	15.6 ± 5.1	14.2 ± 5	<0.001	0.62	0.63
Carotene, mg/d	6393 ± 5895	5546 ± 4103	0.005	0.7	0.71
Riboflavin, mg/d	2.3 ± 0.9	2.1 ± 0.9	0.001	0.71	0.76
Thiamin, mg/d	2.5 ± 2.3	2.4 ± 2.3	0.34	0.62	0.59
Vitamin B-6, mg/d	2.7 ± 0.9	2.5 ± 0.9	<0.001	0.67	0.69
Vitamin B-12, μg/d	7.7 ± 4.1	7.3 ± 4.1	0.06	0.73	0.75
Vitamin C, mg/d	167 ± 99.7	155 ± 94.3	0.04	0.73	0.76
Vitamin A, mg/d	1658 ± 1083	1506 ± 886	0.008	0.67	0.68
Retinol, μg/d	593 ± 451	582 ± 496	0.65	0.65	0.62
Vitamin D, μg/d	3.8 ± 2.3	3.5 ± 2	0.04	0.67	0.66
Vitamin E, mg/d	11.4 ± 4.3	10.4 ± 4.4	<0.001	0.67	0.70
Salt, g/d	7.2 ± 2.9	6.5 ± 2.7	<0.001	0.65	0.67
Sodium, mg/d	2896 ± 1144	2606 ± 1094	<0.001	0.65	0.67

1, Values represent means ± SD or percentages n=567; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; Omega-3 FA, Omega- 3 fatty acid; RE, retinol equivalents.
2, Mean difference between screening and baseline questionnaires was 2.7 ± 0.9 wk.
3, Multiple linear regression between screening and baseline FFQs adjusted for country, time of FFQ completion, age, sex and total energy at screening.
4, Spearman correlation coefficient (rho) between screening and baseline FFQs. All results were significant to *P*<0.001.

Table 3 Differences in the Food4Me food frequency questionnaire food group intakes (g/d) in European adults between screening and baseline as assessed using multiple linear regression and correlation coefficients[1]

	Timepoint[2]		P[3]	Correlation coefficient[4]	
	Screening	Baseline		Crude	Energy adjusted
Rice, pasta, grains and starches	76.2 ± 57.8	70.2 ± 56.5	0.08	0.52	0.45
Savouries (lasagne, pizza)	36.6 ± 33.3	34.7 ± 35.4	0.34	0.65	0.65
White bread (rolls, tortillas, crackers)	53 ± 95.4	44.2 ± 73.9	0.07	0.76	0.76
Wholemeal, brown breads and rolls	103 ± 131	86.3 ± 102	0.01	0.75	0.69
Breakfast cereals and porridge	56.9 ± 73	52.8 ± 73.4	0.35	0.81	0.80
Biscuits	28.1 ± 46.1	22.4 ± 40.8	0.03	0.61	0.60
Cakes, pastries and buns	15.7 ± 17.4	14.6 ± 16.8	0.34	0.57	0.54
Milk	185 ± 215	170 ± 199	0.21	0.7	0.66
Cheeses	38.5 ± 36.7	35.7 ± 35.5	0.17	0.64	0.67
Yogurts	70.9 ± 89.4	76.6 ± 119	0.27	0.66	0.61
Ice cream, creams and desserts	21.9 ± 22	21.5 ± 25.4	0.74	0.61	0.59
Eggs and egg dishes	30.8 ± 49.4	29.2 ± 41.9	0.55	0.75	0.68
Fats and oils (e.g. butter, low-fat spreads)	19.7 ± 17.3	18.5 ± 15.1	0.16	0.7	0.69
Potatoes and potato dishes	55.4 ± 56.6	53.1 ± 51.5	0.46	0.74	0.71
Chipped, fried & roasted potatoes	14.8 ± 16.8	15.5 ± 17.5	0.49	0.77	0.75
Peas, beans, lentils, vegetable dishes	31.9 ± 33.8	33.1 ± 47.5	0.56	0.79	0.78
Green vegetables	43.6 ± 49.9	38.9 ± 39.5	0.07	0.68	0.70
Carrots	22.6 ± 36.2	19.4 ± 20.5	0.11	0.67	0.66
Salad vegetables (e.g. lettuce)	51.2 ± 57.4	47.5 ± 46.6	0.06	0.77	0.78
Other vegetables (e.g. onions)	55.2 ± 50.2	51.8 ± 47.3	0.24	0.75	0.74
Tinned fruit or vegetables	2.2 ± 8.8	1.9 ± 6.3	0.45	0.42	0.46
Bananas	41.1 ± 50.5	37.6 ± 43.8	0.26	0.81	0.82
Other fruits (e.g. apples pears oranges)	246 ± 214	218 ± 196	0.02	0.8	0.81
Nuts and seeds, herbs and spices	4.8 ± 7.6	4.9 ± 9.4	0.91	0.68	0.67
Fish and fish products/dishes	48.3 ± 40.2	47 ± 42.2	0.60	0.75	0.73
Bacon and ham	18.1 ± 24.9	17.8 ± 27.3	0.81	0.76	0.73
Red meat (e.g. beef, veal, lamb, pork)	38.4 ± 36	36.8 ± 33.4	0.40	0.74	0.73
Poultry (chicken and turkey)	26.2 ± 36.2	22.7 ± 24.5	0.05	0.59	0.58
Meat products (e.g. burgers and sausages)	46 ± 53.1	40 ± 37.8	0.03	0.65	0.64
Alcoholic beverages	134 ± 173	139 ± 207	0.69	0.89	0.87
Sugars, syrups, preserves and sweeteners	4.7 ± 10.3	4.5 ± 9.1	0.66	0.85	0.81
Confectionary and savory snacks	16.7 ± 20.8	15.9 ± 21.7	0.56	0.71	0.64
Soups, sauces and miscellaneous foods	103 ± 80.9	92.7 ± 75.4	0.03	0.71	0.68
Teas and coffees	593 ± 505	579 ± 484	0.67	0.81	0.68
Other beverages (e.g. fruit juices, squash)	238 ± 289	223 ± 277	0.35	0.75	0.74

1, Values represent mean ± SD, n=567.

2, Mean difference between screening and baseline questionnaires was 2.7 ± 0.9 wk.

3, Multiple linear regression between screening and baseline FFQs adjusted for country, time of FFQ completion, age, sex and energy intake at screening;

4, Spearman correlation coefficient (rho) between screening and baseline FFQs. All results were significant to $P<0.001$.

Supplemental Table 1 Food items included within each food category in the Food4Me FFQ

Food category	Number of food items listed within the group	Examples
Cereal	4	Porridge, readybrek Breakfast cereals, wholegrain e.g. branflakes
Bread and savoury biscuits	8	White bread Brown bread and seeded bread
Potatoes, rice and pasta	12	Potatoes - mashed, instant, roast Potatoes - boiled, jacket
Meat and Fish	24	Beef, venison (roast, steak, mince) Pork (roast, chops)
Dairy Products	19	Full-fat/whole milk, buttermilk Low-fat or semi-skimmed milk
Fats and Spreads	7	Butter Block/hard margarine e.g. stork/krona
Sweets and snacks	18	Sweet biscuits, chocolate e.g. digestive, cookies Plain cakes e.g. fruit, sponge, scones, gingerbread
Soups, sauces and spreads	10	Creamy soups e.g. chowder, cream of mushroom Non-creamy soups e.g. minestrone, vegetable
Drinks	15	Tea (black, green, fruit, herbal) Coffee, milky, latte, cappuccino
Fruit	12	Apples Pears
Vegetables	28	Carrots Butternut squash, pumpkin

Supplemental Table 2 Concordance (%) in quartile classification of total energy and nutrient intakes between administration of the Food4Me food frequency questionnaire at screening and baseline[1]

	Exact classification[2]		Exact classification plus adjacent[3]		Misclassification[4]		Extreme misclassification[5]	
	Crude	Energy adjusted	Crude	Energy adjusted	Crude	Energy adjusted	Crude	Energy adjusted
Total energy, kcal/d	44.8	-	86.1	-	10.8	-	3.2	-
Total fat, g/d	43.6	44.6	83.4	85.0	14.1	11.6	2.5	3.4
Total fat, % energy	44.3	46.2	84.7	84.8	13.4	12.9	1.9	2.3
SFA, g/d	47.3	48.0	85.4	87.7	12.5	9.7	2.1	2.6
SFA, % energy	48.7	49.1	86.2	86.7	11.1	11.5	2.6	1.8
MUFA, g/d	45.5	53.3	86.1	89.6	11.8	8.6	2.1	1.8
MUFA, % energy	51.0	50.8	90.3	90.7	8.1	7.9	1.6	1.4
PUFA, g/d	45.9	45.9	86.9	86.9	11.8	11.8	1.2	1.2
PUFA, % energy	47.3	48.1	88.4	88.5	10.1	9.9	1.6	1.6
Omega-3 FA, g/d	50.4	50.1	85.7	89.4	12.2	9.0	2.1	1.6
Protein, g/d	44.3	51.7	86.4	89.1	12.0	8.8	1.6	2.1
Protein, % energy	53.1	51.1	91.0	90.5	7.4	8.3	1.6	1.2
Carbohydrate, g/d	50.8	46.6	85.4	86.6	12.2	11.1	2.5	2.3
Carbohydrate, % energy	49.7	48.7	88.0	88.0	9.3	9.7	2.6	2.3
Total sugars, g/d	48.0	53.3	86.9	89.6	10.8	9.3	2.3	1.1
Total sugars, % energy	52.2	51.9	91.5	91.0	7.2	7.6	1.2	1.4
Fiber, g/d	51.0	55.2	89.6	92.1	9.5	6.3	0.9	1.6
Alcohol, g/d	70.0	66.5	98.1	97.5	1.8	2.5	0.2	0.0
Calcium, mg/d	47.1	48.9	87.3	88.5	9.5	9.2	3.2	2.3
Folate, μg/d	48.7	50.6	86.9	90.7	11.1	7.8	1.9	1.6
Iron, mg/d	46.7	47.3	84.7	87.5	12.7	10.4	2.6	2.1
Carotene, μg/d	52.6	50.8	89.8	89.9	9.3	8.6	0.9	1.4
Riboflavin, mg/d	50.8	56.3	91.0	92.9	7.9	6.3	1.1	0.7
Thiamin, mg/d	49.7	51.7	86.1	85.7	11.1	9.9	2.8	4.4
Vitamin B6, mg/d	47.1	51.7	89.2	91.0	9.2	7.1	1.6	1.9
Vitamin B12, μg/d	55.6	54.1	91.7	91.9	7.4	7.1	0.9	1.1
Vitamin C, mg/d	54.1	54.5	90.5	92.2	8.5	7.1	1.1	0.7
Vitamin A RE, μg/d[1]	52.7	53.4	87.7	88.0	10.9	10.2	1.4	1.8
Retinol, mcg/d	51.7	52.2	87.7	85.7	8.8	10.4	3.5	3.9
Vitamin D, μg/d	50.4	50.6	87.5	89.8	10.8	8.1	1.8	2.1
Vitamin E, mg/d	49.0	52.0	87.7	89.9	10.4	7.8	1.9	2.3
Salt, g/d	47.8	52.7	85.9	88.5	12.7	8.8	1.4	2.6
Sodium, mg/d	47.8	52.0	85.9	87.7	12.7	9.0	1.4	3.3

1, SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; Omega-3 FA, Omega- 3 fatty acid; RE, retinol equivalents. Values represent percentages n=567. Mean difference between screening and baseline questionnaires was 2.7 ± 0.9 wks. The expected value for a 4-category model is 25% exact agreement by chance.

2, Percentage of participants classified into the same quartile.

3, Percentage of participants classified into the same plus the adjacent quartile.

4, Percentage of participants classified two quartiles apart.

5, Percentage of participants classified three quartiles apart.

Supplemental Table 3 Concordance (%) in quartile classification of the Food4Me Food frequency questionnaire food group intakes between screening and baseline[1]

	Exact classification[2]		Exact classification plus adjacent[3]		Misclassification[4]		Extreme misclassification[5]	
	Crude	Energy adjusted	Crude	Energy adjusted	Crude	Energy adjusted	Crude	Energy adjusted
Rice, pasta, grains and starches	45.3	43.0	81.3	79.9	14.5	15.3	4.2	4.8
Savouries (lasagne, pizza)	48.7	46.7	88.7	88.5	9.5	9.9	1.8	1.6
White bread (rolls, tortillas, crackers)	55.0	57.1	91.7	91.5	7.6	7.9	0.7	0.5
Wholemeal, brown breads and rolls	57.0	52.0	91.7	90.1	7.8	8.5	0.5	1.4
Breakfast cereals and porridge	67.4	65.8	93.8	94.9	4.8	3.5	1.4	1.6
Biscuits	50.6	48.7	85.7	85.7	10.9	11.5	3.4	2.8
Cakes, pastries and buns	47.1	47.4	85.0	84.1	11.8	11.6	3.2	4.2
Milk	52.2	49.4	88.5	86.9	10.4	11.8	1.1	1.2
Cheeses	48.5	48.3	86.9	87.1	10.8	11.0	2.3	1.9
Yogurts	53.6	51.5	88.2	86.2	10.1	10.4	1.8	3.4
Ice cream, creams and desserts	47.8	47.3	86.1	85.9	11.5	10.4	2.5	3.7
Eggs and egg dishes	57.5	52.2	93.8	87.8	6.0	10.4	0.2	1.8
Fats and oils (e.g. butter, low-fat spreads)	53.8	52.9	87.3	87.3	11.6	11.1	1.1	1.6
Potatoes and potato dishes	55.6	53.4	91.0	89.9	8.3	8.8	0.7	1.2
Chipped, fried & roasted potatoes	59.6	54.9	93.1	90.8	6.3	9.2	0.5	0.0
Peas, beans, lentils, vegetable dishes	60.8	58.2	92.9	93.8	6.0	5.1	1.1	1.1
Green vegetables	52.4	49.8	88.0	100.0	10.2	0.0	1.8	0.0
Carrots	54.9	52.6	89.1	87.7	9.2	10.1	1.8	2.3
Salad vegetables (e.g. lettuce)	54.9	56.8	93.5	93.1	5.5	5.8	1.1	1.1
Other vegetables (e.g. onions)	53.3	55.0	92.4	90.8	6.9	7.9	0.7	1.2
Tinned fruit or vegetables	54.8	45.9	80.6	81.7	12.9	11.8	5.9	6.5
Bananas	63.7	61.6	95.1	93.5	4.6	5.6	0.4	0.9
Other fruits (e.g. apples pears oranges)	61.9	63.3	94.2	95.4	4.9	3.9	0.9	0.7
Nuts and seeds, herbs and spices	55.9	52.2	87.3	87.1	10.8	11.1	1.9	1.8
Fish and fish products/dishes	53.3	53.8	91.0	90.7	8.5	8.5	0.5	0.9
Bacon and ham	56.1	52.0	93.3	92.1	5.6	7.1	1.1	0.9
Red meat (e.g. beef, veal, lamb, pork)	54.1	54.0	92.1	89.9	7.2	9.3	0.7	0.7
Poultry (chicken and turkey)	53.3	48.7	87.5	83.4	10.4	12.5	2.1	4.1
Meat products (e.g. burgers and sausages)	49.2	50.6	85.5	86.1	12.3	12.7	2.1	1.2
Alcoholic beverages	70.5	64.6	97.9	97.0	1.9	3.0	0.2	0.0
Sugars, syrups, preserves and sweeteners	60.3	60.2	93.3	93.2	5.9	5.6	0.8	1.2
Confectionary and savoury snacks	52.9	49.0	90.8	87.6	7.1	10.4	2.1	2.0
Soups, sauces and miscellaneous foods	51.1	50.6	89.8	89.4	9.0	8.8	1.2	1.8
Teas and coffees	64.6	64.6	94.2	94.2	5.1	5.1	0.7	0.7
Other beverages (e.g. fruit juices, squash)	56.4	56.3	91.7	91.0	6.7	7.8	1.6	1.2

1, Values represent percentages n=567. Mean difference between screening and baseline questionnaires was 2.7 ± 0.9 weeks. The expected value for a 4-category model is 25% exact agreement by chance.
2, Percentage of participants classified into the same quartile.
3, Percentage of participants classified into the same plus the adjacent quartile.
4, Percentage of participants classified two quartiles apart.
5, Percentage of participants classified three quartiles apart.

Supplemental Table 4 Differences in total energy intake between the Food4Me food frequency questionnaire at screening and baseline, Spearman correlation coefficients (SCC, rho) and cross-classifications of quartiles by subgroup[1]

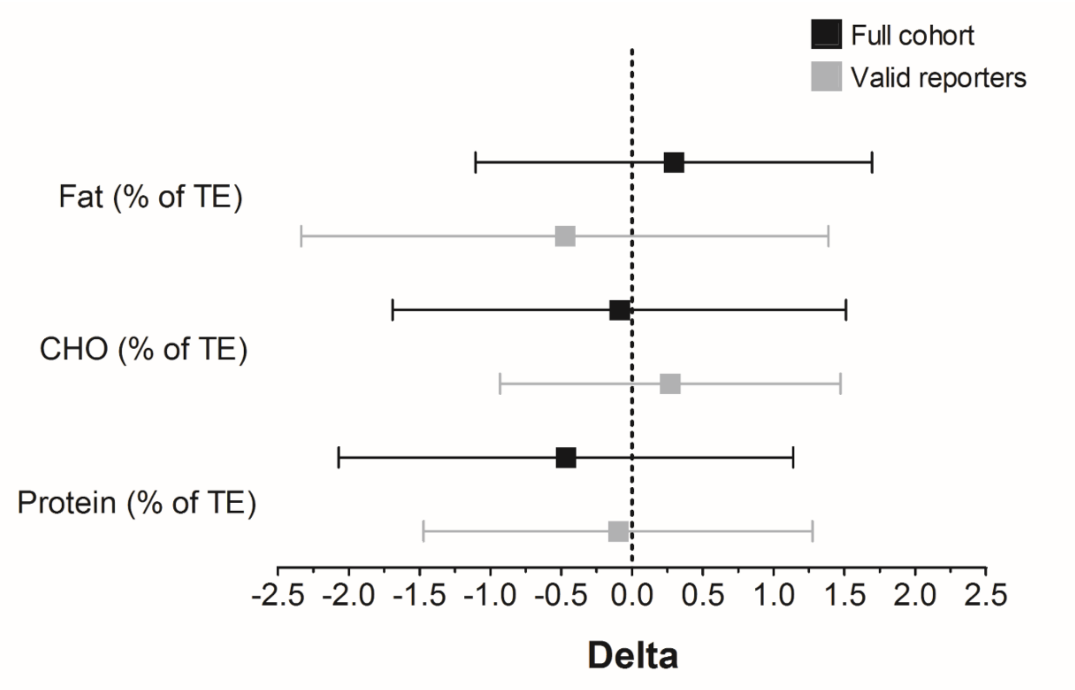
	n	Energy intake (kcal/day)		P[3]	SCC[4]	Quartiles %			
		Screening	Baseline			Exact classification[5]	Exact classification plus adjacent[6]	Misclassification[7]	Extreme misclassification[8]
Country[2]									
Greece	160	2376 ± 676	2056 ± 708	<0.001	0.54	44.4	81.3	13.1	5.6
Ireland	70	2625 ± 642	2546 ± 652	0.476	0.61	42.9	92.9	7.1	0
Netherlands	108	2556 ± 695	2393 ± 736	0.057	0.73	49.1	94.4	4.6	0.9
Poland	153	2411 ± 740	2201 ± 796	0.006	0.60	43.8	81.0	14.4	4.6
United Kingdom	49	2353 ± 584	2285 ± 584	0.528	0.70	42.9	87.8	12.2	0
Germany	27	2518 ± 562	2178 ± 530	0.015	0.59	42.9	85.7	7.1	7.1
FFQ completion period[9]									
Short	189	2342 ± 671	2233 ± 714	0.001	0.64	43.9	85.7	11.1	3.2
Medium	189	2468 ± 688	2207 ± 705	<0.001	0.66	45.0	87.3	9.5	3.2
Long	189	2465 ± 699	2296 ± 771	0.057	0.61	45.5	85.2	11.6	3.2
BMI category									
Underweight & normal	296	2331 ± 602	2164 ± 662	<0.001	0.68	42.2	85.8	11.5	2.7
Overweight	192	2528 ± 753	2259 ± 739	<0.001	0.60	45.3	87.5	9.4	3.1
Obese	79	2743 ± 794	2520 ± 878	0.065	0.50	53.2	83.5	11.4	5.1
Age group									
Under 45 years	359	2456 ± 690	2230 ± 718	<0.001	0.65	43.7	85.5	11.4	3.1
Over 45 years	208	2453 ± 679	2273 ± 752	0.007	0.62	46.6	87.0	9.6	3.4
Sex									
Male	233	2803 ± 696	2542 ± 817	<0.001	0.62	45.9	87.6	9.9	2.6
Female	334	2213 ± 563	2039 ± 581	<0.001	0.61	44.0	85.0	11.4	3.6

1, Values represent means ± SD or percentages. Mean difference between screening and baseline questionnaires was 2.7 ± 0.9 weeks. The expected value for a 4-category model is 25% exact agreement by chance.

2, Spain was excluded from the analysis due to a lack of participants (n=5) completing the two FFQs within the acceptable time frame (1 month).

3, Multiple linear regression tested for significant differences in energy intakes between screening and baseline FFQs (analyses were stratified by country, FFQ completion period, BMI category, age group and sex). Models were adjusted for country, time of FFQ completion, age and sex (except when used a stratifying variable).

4, Unadjusted Spearman correlation coefficients (rho) between screening and baseline FFQs. All results were significant to $P<0.001$.
5, Percentage of participants classified into the same quartile.
6, Percentage of participants classified into the same plus the adjacent quartile.
7, Percentage of participants classified two quartiles apart.
8, Percentage of participants classified three quartiles apart.
9, Short: 0-15.65 days; Medium: 15.66 – 22.63 days; Long: 22.64 – 31 days.



Supplemental Figure 1 Differences in percentage of energy from fat, carbohydrates and protein between administration of the Food4Me food frequency questionnaire at screening and baseline. Data represent delta in the total cohort (n=567) and in valid reporters (n=437). TE, Total energy; CHO, carbohydrate. Mean difference between screening and baseline questionnaires was 2.7 ± 0.9 weeks.