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Validity of a Dietary Questionnaire Assessed by Comparison With Multiple Weighed Dietary Records or 24-Hour Recalls

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The authors evaluated the validity of a 152-item semiquantitative food frequency questionnaire (SFFQ) by comparing it with two 7-day dietary records (7DDRs) or up to 4 automated self-administered 24-hour recalls (ASA24s) over a 1-year period in the women's Lifestyle Validation Study (2010–2012), conducted among subgroups of the Nurses' Health Studies. Intakes of energy and 44 nutrients were assessed using the 3 methods among 632 US women. Compared with the 7DDRs, SFFQ responses tended to underestimate sodium intake but overestimate intakes of energy, macronutrients, and several nutrients in fruits and vegetables, such as carotenoids. Spearman correlation coefficients between energy-adjusted intakes from 7DDRs and the SFFQ completed at the end of the data-collection period ranged from 0.36 for lauric acid to 0.77 for alcohol (mean $r = 0.53$). Correlations of the end-period SFFQ were weaker when ASA24s were used as the comparison method (mean $r = 0.43$). After adjustment for within-person variation in the comparison method, the correlations of the final SFFQ were similar with 7DDRs (mean $r = 0.63$) and ASA24s (mean $r = 0.62$). These data indicate that this SFFQ provided reasonably valid estimates for intakes of a wide variety of dietary variables and that use of multiple 24-hour recalls or 7DDRs as a comparison method provided similar conclusions if day-to-day variation was taken into account.

automated self-administered 24-hour recall; nutrient validation; reproducibility; semiquantitative food frequency questionnaire; 7-day dietary records

Abbreviations: ASA24, automated self-administered 24-hour recall; BMI, body mass index; ICC, intraclass correlation coefficients; NHS, Nurses' Health Study; NHS II, Nurses' Health Study II; 7DDR, 7-day dietary records; SFFQ, semiquantitative food frequency questionnaire; WebFFQ, web-based SFFQ.

In epidemiologic studies of dietary factors as determinants of diseases, food frequency questionnaires are commonly used to assess long-term or usual intake (1). Food frequency questionnaires are based on an individual's recall of usual intake over a specified time, and thus are subject to measurement error. Repeated dietary records or interviewer-aided 24-hour dietary recalls are commonly used to evaluate the validity of food frequency questionnaire. However, these methods are expensive to collect and process, and the results are unrepresentative of usual intake if only a few days are assessed (1).

Given the limitations of dietary assessment methods, much effort has been devoted to refining them and evaluating their ability to measure diet. The semiquantitative food frequency questionnaire (SFFQ) developed by our group has been a reasonably reproducible and valid measure of nutrient intakes among men and women in many populations (1–4). After modifications to incorporate changes in the food supply and eating patterns (e.g., new foods, foods with modified serving size and nutrient content), our current version of this SFFQ includes 152 food items. We have also developed and are using a web-based version of this questionnaire (WebFFQ) (5, 6). Due to changes in the food supply and increases in meals eaten away from home, and reflecting changes in the SFFQ since it was last evaluated in 1986 (1), we conducted a detailed validation study of both the paper and web versions of the current SFFQ.

The automated self-administered 24-hour recall (ASA24), developed by the National Cancer Institute (7), is self-administered over the internet at minimal cost. The ASA24 could serve as a lower-cost method to evaluate the validity of other dietary methods, but its performance as a comparison method has not been evaluated. Thus, the present study aimed to evaluate the reproducibility and validity of nutrient intakes measured by the paper and web SFFQs compared with both 7-day dietary records (7DDRs) and ASA24s among a subgroup of participants in the Nurses' Health Study (NHS) and Nurses' Health Study II (NHS II).

METHODS

Study population

The Lifestyle Validation Study is one of 3 studies comprising the Multi-Cohort Eating and Activity Study for Understanding Reporting Error (MEASURE), which was designed to investigate the measurement-error structure associated with self-reported dietary and physical activity assessments (8). The Lifestyle Validation Study was conducted within the NHS (9) and NHS-II (10, 11). The NHS began in 1976 when 121,701 female registered nurses, aged 30–55 years, in the United States were enrolled; the SFFQ was first administered to them in 1980. The NHS II cohort enrolled 116,671 US female nurses aged 24–44 years in 1989; the first SFFQ was administered to them in 1991. Participants in both cohorts completed mailed questionnaires on their medical history and lifestyle factors at enrollment, and they received follow-up questionnaires every 2 or 4 years to update their information on disease or potential risk factors. Diet has been assessed by SFFQ every 4 years. This study was approved by the human subjects committees of the Harvard T.H. Chan School of Public Health and Brigham and Women's Hospital.

In 2010, we randomly selected a subset of NHS and NHS II participants aged 45–80 years, from all geographical regions of the United States, who had completed the 2006/2007-cohort SFFQ, had previously provided blood samples, had access to broadband internet, and were not planning to make substantial changes in their diet or their physical activity. Women with history of coronary heart disease, stroke, cancer, or major neurological disease were excluded. The sample selection was stratified by age, and African-Americans were oversampled. A total of 5,509 women were invited to participate; 851 were eligible and consented to participate in the study, and due to budgetary constraints we enrolled 796 women. Participants received support from staff throughout the study via the internet, telephone, and mail, and they were offered $600 upon completion.

The study included anthropometric measurements, doubly-labeled water assessment of energy expenditure, fasting blood draws, dietary and physical activity questionnaires, saliva collections, activity monitor recordings, and multiple 24-hour and first morning urine collections. To represent the 1-year period typically used as the time frame for dietary questionnaires, we spread the dietary and biomarker measurements over a period of approximately 1 year and varied the order of measurements into 4 groups, randomly assigning participants to these groups (Figure 1). This analysis focused on the self-reported dietary measurements consisting of 2 paper SFFQs (a baseline SFFQ and a final SFFQ, at end of the participant's diet-data collection year), an online WebFFQ collected 2 weeks before or after completion of the second SFFQ, 4 ASA24s (1 per season), and 2 7DDRs approximately 6 months apart to capture seasonal variability. By design, the 7DDRs and ASA24s in the same phase were collected several weeks apart to avoid artificially high correlations (12). The paper SFFQ and 7DDR were mailed to and completed by the participants. The study was conducted during 2010–2012.

Among the 796 enrolled participants, 795 completed the baseline SFFQ, 774 completed at least one 7DDR, 692 completed at least one ASA24, 759 completed the final SFFQ, and 747 completed the WebFFQ. Of the 692 participants who completed ASA24s, 93 completed 1; 136 completed 2; 219 competed 3; and 244 completed 4. Lower completion rates for the ASA24 were likely related to difficulties with the online interface, which has been addressed in more recent versions. We excluded participants with SFFQ total daily energy intakes <600 kcal or >3,500 kcal or with more than 70 blank SFFQ items. Overall, 771 baseline SFFQs (97%), 742 final SFFQs (98%), and 721 WebFFQs (97%) were included. Our primary analysis included 632

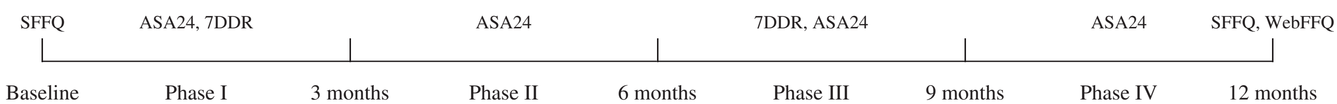

Figure 1. Timeline of the dietary assessment activity in the Lifestyle Validation Study, embedded in the Nurses' Health Study and Nurses' Health Study II, United States, 2010–2012. This figure shows the timeline for group 1 participants. Groups 2 and 4 were assigned similar data collection timeline as group 1, except groups 2 and 4 participants were asked to complete the 7-day dietary record (7DDR) in phases II and IV instead. Group 3 went through the same data collection timeline as group 1. Within the same phase, 7DDRs and automated self-administered 24-hour dietary recalls (ASA24s) were completed 2–5 weeks apart (to avoid artificially high correlations). For groups 1 and 3, the ASA24 was completed first, followed by the 7DDR in phase I, but this order was reversed in phase III. For groups 2 and 4, the 7DDR was completed first followed by the ASA24 in phase II, but this order was reversed in phase IV. Additionally, groups 1 and 3 completed the web-based version of the food frequency questionnaire (WebFFQ), which was enhanced by the use of branched questions, approximately 2 weeks before completion of the paper semi-quantitative food frequency questionnaire (SFFQ) (the final SFFQ, conducted at the end of the follow-up period), and groups 2 and 4 completed it approximately 2 weeks after completion of the final SFFQ. To minimize alteration in eating behavior, the participants were not told in advance the day that they would be asked to complete the ASA24; days were randomly selected and may or may not have included a weekend day.

participants with complete data for all 3 FFQs, and at least one 7DDR and one ASA24. At enrollment we collected information on year of birth, height, weight, ethnicity, and smoking status. Weight and height at enrollment were used to calculate body mass index (BMI, calculated as weight divided by the square of height (kg/m^2)), which was used to define subgroups according to BMI categories. Weight information was also collected every 3 months.

Semiquantitative food frequency questionnaire

The 152-food-item SFFQ is an expanded version of a previously validated questionnaire (1, 4, 13). Respondents were asked how often, on average, they consumed the specified amount of each type of food or beverage during the past year; 9 possible frequency categories ranged from never/almost never to ≥6 times per day. Open-ended questions were used for usual brand and type of margarine, cooking oil, cold breakfast cereal, and multivitamins. We also collected detailed information regarding the type of fat used at the table and in food preparation. Participants were also asked to report up to 3 foods consumed more than once per week that were not included in the SFFQ. Nutrient intakes were calculated from the questionnaire by multiplying a weight proportional to the intake frequency by the nutrient composition for the portion size specified for each food or vitamin supplement. Nutrients were then summed across all foods and supplements to obtain the total intake for each individual; we also calculated intakes not including supplements.

Over 200 nutrients and dietary constituents are derived from the SFFQ using an extensive food composition database (https://regepi.bwh.harvard.edu/health/nutrition/) based primarily on US Department of Agriculture publications supplemented by other published sources, personal communications from laboratories and manufacturers, and our own updated fatty-acid analyses of manufactured foods. The WebFFQ is similar to the paper version and used branched questions to collect details on items such as breakfast cereals and margarines.

Seven-day dietary record

The study's research dietitians developed the 7DDRs with detailed instructions and an instructional video provided on DVD. Each participant received a Primo Multifunction Kitchen Scale (Model P115NB; Escali Corporation, Burnsville, MN) and ruler (printed on the 7DDR booklet), the instructional DVD, and instructions (via telephone) explaining how to keep the 7DDRs. A computerized system was used to send reminders and encouragement emails to participants on days of diet recording. Participants measured and reported gram weights for foods before and after eating so actual intake could be computed, and they provided recipes of all home-prepared foods, including the number of servings in the recipe and the portions of the recipes that they consumed. Additionally, participants collected and returned labels of store-brand products. The Nutrition Coordinating Center at the University of Minnesota (14) used the Nutrition Data System for Research (NDSR 2011), primarily using US Department of Agriculture food composition sources, to analyze the 7DDRs (15, 16); over 150 nutrient and dietary constituents were derived.

Self-administered 24-hour dietary recall

Participants logged into the beta version of the ASA24 website to complete their 24-hour recalls (17). Participants were reminded on assigned days by our computerized system to complete their recalls. The US Department of Agriculture's Food and Nutrient Database for Dietary Studies (FNDDS 4.1) was used to derive 61 nutrients and dietary constituents (18). Because the beta version of ASA24 did not include supplement intake, we could use ASA24 nutrients only from food in our analyses.

Statistical analysis

The performance of the final SFFQ, which assessed intake over the same period as the 7DDR and ASA24 collection, was the primary focus of the current analyses. The validity of the baseline SFFQ, which referred to the year before collection of the 7DDRs and ASA24s, and of the WebFFQ was also evaluated. We analyzed intakes of total energy and the 44 common nutrients available from the 3 methods: the SFFQs, 7DDRs, and ASA24s. Because nutritional supplements contribute importantly to the intake of many micronutrients, we also evaluated the 22 nutrients including supplements available from both the SFFQs and 7DDRs. We additionally analyzed another 50 common nutrients (3 nutrients have with- and without-supplement values) in SFFQs and 7DDRs.

We first calculated mean values and standard deviations for absolute total daily nutrient intakes from the baseline and final SFFQs, WebFFQ, averaged 7DDRs (mean = 14 days), and averaged ASA24s (mean = 2.9 days). To assess the reproducibility of repeated SFFQ, 7DDR, and ASA24 assessments, rank intraclass correlation coefficients (ICCs) were calculated for each nutrient before and after adjustment for total energy intake. Energy-adjusted intakes are of greatest importance because individuals primarily alter their intakes of specific nutrients by changing the composition of their diet, keeping total energy constant (1, 19, 20). We used 2 energy-adjustment methods: the residual method (which uses the residuals from the regression of the nutrient intakes on total energy intake with a reference energy level of 1,800 kcal) and the energy density method (which divides the nutrient portion by total energy intake). Because most nutrient distributions were skewed toward higher values, we log-transformed all variables after setting zeros to a fixed nonzero value (0.0001 unit/day), and we then calculated residuals on the log scale. To reduce the influence of extreme nutrient intakes, analyses on correlations were based on the ranks of the log-transformed nutrient values and energy-adjusted nutrient values.

Because the primary issue in epidemiologic studies of nutrition is the ability of a method to rank subjects by intake of food or nutrients, we used rank correlation coefficients with intakes assessed by the comparison method to assess the validity of the SFFQ. In this analysis, the averaged 7DDR or ASA24 intakes were used as the comparison methods. We calculated Spearman correlation coefficients (r_s) and their 95% confidence intervals between nutrient intakes reported on each SFFQ and the corresponding intakes assessed by 7DDRs or ASA24s. Because random within-person variation in the 7DDRs or ASA24s attenuates these correlations, we deattenuated correlation coefficients to reduce the effect of random error in the comparison methods (21, 22), using a method to account for the variable number of repeats of the comparison method (22–25). Regression calibration coefficients for each nutrient, which can be used for the adjustment of the relative risk estimates (26), were derived from models predicting nutrient intakes based on 7DDRs or ASA24s, using intakes from each SFFQ.

Analyses were repeated in subgroups defined by age (45–60 years, 61–80 years) and BMI (<25, ≥25). We also performed similar analyses for the subgroup with a BMI of ≥30. We evaluated associations of the reporting error on the final SFFQ versus 7DDRs with age (continuous), BMI (continuous), white race, and smoking status. Bland-Altman plots were also created to evaluate reporting bias.

RESULTS

At baseline, participants had a mean age of 61 years and a mean BMI of 26.5; participants were predominately white (90%), and 2% were current smokers. The subgroups defined by age, BMI, and completion of 4 ASA24s had similar characteristics to the overall participants (Table 1). Women included in the primary analysis had similar characteristics (age, height, BMI, and smoking status) to women who agreed to participate, who were invited to participate, and who participated in the original NHS/NHS II cohorts (Web Table 1, available at http://aje.oxfordjournals.org/).

Table 1. Mean Values and Standard Deviations for Characteristics of the Participants in the Lifestyle Validation Study, United States, 2010–2012

Variable	Overall (*n* = 632)	Subgroup				
		Completed 4 ASA24s (*n* = 226)	Aged 45–60 Years (*n* = 309)	Aged 61–80 Years (*n* = 323)	BMI <25 (*n* = 298)	BMI ≥25 (*n* = 334)
Age, years	61 (10)	61 (9)	53 (5)	69 (5)	61 (10)	61 (9)
Height, m	1.64 (0.07)	1.64 (0.07)	1.66 (0.07)	1.63 (0.07)	1.65 (0.08)	1.63 (0.07)
Weight, kg	71.6 (15.5)	71.4 (15.7)	73.6 (17.2)	69.6 (13.3)	60.8 (6.7)	81.1 (14.7)
Weight change, kg[a]	−0.2 (2.7)	−0.1 (2.7)	−0.2 (2.9)	−0.2 (2.4)	−0.2 (1.8)	−0.2 (3.2)
BMI[b]	26.5 (5.4)	26.5 (5.4)	26.8 (6.0)	26.2 (4.8)	22.3 (1.8)	30.3 (4.8)
White[c]	90.4	90.7	86.1	94.4	94.0	87.1
Current smokers[c]	1.9	2.7	2.6	1.3	1.4	2.4
Total energy, kcal/day						
SFFQ (final)	1,857 (526)	1,814 (490)	1,864 (530)	1,852 (523)	1,846 (486)	1,868 (559)
7DDR[d]	1,741 (336)	1,738 (329)	1,788 (344)	1,695 (321)	1,714 (302)	1,765 (362)
ASA24[d]	1,821 (476)	1,801 (389)	1,846 (493)	1,797 (459)	1,792 (421)	1,846 (520)
Protein, % total energy						
SFFQ (final)	17.5 (3.0)	17.8 (2.9)	17.8 (3.1)	17.2 (2.8)	17.4 (2.8)	17.7 (3.1)
7DDR	16.9 (2.9)	16.9 (2.9)	16.8 (2.9)	16.9 (2.8)	16.8 (2.8)	16.9 (2.9)
ASA24	17.4 (3.8)	17.2 (3.4)	17.6 (3.9)	17.1 (3.8)	17.2 (3.5)	17.6 (4.1)
Total fat, % total energy						
SFFQ (final)	33.9 (6.1)	33.8 (6.1)	34.2 (5.8)	33.5 (6.3)	33.3 (6.3)	34.4 (5.9)
7DDR	34.4 (5.7)	34.2 (5.7)	35.0 (5.9)	33.9 (5.4)	33.9 (5.5)	35.0 (5.8)
ASA24	35.3 (7.0)	34.9 (5.9)	35.4 (6.4)	35.1 (7.5)	34.9 (7.0)	35.6 (7.0)
Carbohydrates, % total energy						
SFFQ (final)	47.3 (7.5)	47.1 (7.1)	46.9 (7.2)	47.6 (7.7)	47.8 (7.6)	46.8 (7.2)
7DDR	47.8 (7.6)	48.3 (7.5)	47.9 (7.5)	47.8 (7.7)	48.3 (7.6)	47.5 (7.6)
ASA24	45.5 (8.7)	46.2 (7.6)	45.6 (8.5)	45.4 (8.9)	45.7 (8.7)	45.3 (8.8)

Abbreviations: 7DDR, 7-day dietary record; ASA24, automated self-administered 24-hour dietary recall; BMI, body mass index; SFFQ, semi-quantitative food frequency questionnaire.

[a] Weight change was estimated over the 12 months of the study period.

[b] BMI was calculated as weight (kg)/height (m)^2.

[c] Values are presented as %.

[d] Values are for the averages of 2 weeks of dietary records for 7DDRs and up to 4 completed records for ASA24s.

Table 2. Mean Values and Standard Deviations for Absolute Daily Nutrient Intakes Estimated by Semiquantitative Food Frequency Questionnaire, 7-Day Dietary Record, and Averaged Automated Self-Administered 24-Hour Dietary Recall, Lifestyle Validation Study, United States, 2010–2012

Nutrient	Final SFFQ	Baseline SFFQ	WebFFQ	7DDR[a]	ASA24[a]
Total energy, kcal	1,857 (526)	1,931 (528)	1,770 (518)	1,741 (336)	1,821 (476)
Total fat, g	70 (25)	73 (26)	67 (24)	67 (19)	73 (27)
Saturated fat, g	22 (9)	23 (9)	21 (8)	22 (8)	25 (11)
Polyunsaturated fat, g	15 (6)	16 (6)	14 (6)	15 (5)	16 (7)
Monounsaturated fat, g	27 (11)	28 (11)	26 (11)	24 (7)	26 (11)
Arachadonic FA, g	0.18 (0.09)	0.19 (0.09)	0.18 (0.09)	0.11 (0.06)	0.13 (0.08)
Lauric FA, g	0.63 (0.59)	0.66 (0.61)	0.63 (0.59)	1.04 (0.89)	0.84 (0.89)
Linoleic FA, g	12.5 (5.1)	13.1 (5.5)	11.8 (5.4)	13.1 (4.3)	13.8 (6.2)
Linolenic FA, g	1.5 (0.9)	1.6 (1.0)	1.5 (1.1)	1.5 (0.7)	1.6 (1)
Omega-3 (DHA + EPA) FA, g	0.25 (0.22)	0.26 (0.23)	0.24 (0.21)	0.14 (0.15)	0.18 (0.31)
With supplements	0.47 (0.38)	0.49 (0.40)	0.47 (0.38)	0.32 (0.42)	
Oleic FA, g	25.0 (10.1)	26.0 (10.7)	24.1 (10.2)	22.8 (6.8)	24.5 (10.1)
Cholesterol, mg	238 (114)	241 (107)	229 (116)	233 (94)	269 (142)
Protein, g	81 (24)	84 (24)	77 (24)	73 (16)	77 (24)
Carbohydrate, g	219 (72)	229 (71)	208 (69)	208 (50)	205 (64)
Total sugar, g	100 (43)	103 (42)	94 (40)	92 (32)	97 (41)
Fiber, g	23.7 (8.6)	24.8 (8.6)	22.9 (8.5)	20.5 (6.5)	17.5 (7.0)
Alcohol, g	8.9 (12.5)	9.3 (12.4)	8.3 (11.1)	9.0 (12.0)	10.1 (15.5)
Retinol activity equivalents, μg	995 (406)	1,029 (431)	971 (411)	813 (388)	762 (482)
With supplements	1,805 (1,299)	1,879 (1,421)	1,830 (1,349)	1,477 (1,293)	
Alpha carotene, μg	852 (763)	919 (871)	850 (767)	609 (487)	495 (769)
Beta carotene, μg	5,974 (3,611)	6,153 (3,761)	5,882 (3,574)	3,979 (2,470)	3,335 (3,307)
With supplements	6,489 (4,046)	6,752 (4,316)	6,368 (3,972)	4,291 (2,818)	
Lutein-zeaxanthin, μg	3,794 (2,898)	3,749 (2,539)	3,725 (2,513)	2,237 (1,517)	2,589 (2,931)
Lycopene, μg	5,479 (3,970)	5,618 (4,454)	5,596 (4,585)	4,870 (3,543)	5,088 (5,402)
Beta cryptoxanthin, μg	111 (95)	120 (103)	107 (95)	154 (181)	99 (137)
Vitamin B1, mg	1.5 (0.5)	1.6 (0.5)	1.4 (0.4)	1.5 (0.4)	1.4 (0.5)
With supplements	8.6 (19.4)	8.8 (18.0)	7.9 (15.6)	11.0 (51.3)	
Vitamin B2, mg	2.2 (0.8)	2.3 (0.8)	2.1 (0.7)	2.0 (0.6)	2.2 (0.7)
With supplements	9.2 (17.3)	9.7 (17.6)	8.9 (15.9)	7.2 (18.0)	
Vitamin B3, mg	23.5 (7.1)	24.6 (7.5)	22.6 (7.2)	20.7 (5.5)	20.9 (6.9)
With supplements	49.3 (57.4)	53.7 (61.0)	47.1 (49.9)	54.4 (114)	
Vitamin B6, mg	2.2 (0.8)	2.3 (0.7)	2.1 (0.7)	1.8 (0.6)	1.9 (0.8)
With supplements	13.5 (28.3)	15.2 (32.2)	14.0 (29.6)	9.6 (26.8)	
Vitamin B12, mg	6.3 (2.8)	6.5 (2.7)	6.1 (2.6)	4.9 (2.7)	5.4 (4.7)
With supplements	55.2 (141.7)	61.0 (145.2)	51.2 (125.0)	73.1 (307.8)	
Natural folate, μg	319 (122)	331 (123)	310 (119)	232 (73)	233 (95)
Folic acid, μg	139 (115)	147 (109)	133 (92)	156 (99)	143 (111)
With supplements	424 (312)	442 (294)	412 (280)	438 (355)	
Dietary folate equivalents, μg	641 (263)	669 (241)	620 (218)	497 (182)	477 (212)
With supplements	1,126 (647)	1,170 (595)	1,095 (570)	1,062 (713)	
Vitamin C, mg	118 (60)	123 (61)	116 (62)	96 (51)	94 (67)
With supplements	311 (426)	325 (375)	319 (366)	311 (453)	
Vitamin D, mg	5.3 (3.1)	5.5 (3.1)	5.2 (3.0)	4.9 (2.7)	5.1 (3.9)
With supplements	20.4 (12.2)	21.5 (12.5)	23.6 (12.7)	31.5 (29.3)	

Table continues

Table 2. Continued

Nutrient	Final SFFQ	Baseline SFFQ	WebFFQ	7DDR[a]	ASA24[a]
Vitamin E, mg	9.9 (4.8)	10.3 (4.9)	9.5 (4.9)	9.2 (4.0)	8.2 (4.4)
With supplements	42.1 (71.7)	43.5 (67.5)	45.6 (83.8)	37.1 (54.0)	
Vitamin K, mg	195 (142)	191 (121)	190 (125)	129 (71)	156 (183)
With supplements	202 (143)	199 (122)	197 (126)	219 (1,806)	
Calcium, mg	909 (371)	954 (388)	880 (381)	843 (270)	959 (421)
With supplements	1,572 (638)	1,634 (641)	1,577 (648)	1,460 (799)	
Magnesium, mg	351 (106)	369 (112)	338 (106)	296 (77)	309 (103)
With supplements	425 (153)	446 (159)	414 (145)	380 (186)	
Iron, mg	14.1 (4.7)	14.7 (5.0)	13.4 (4.6)	13.7 (4.5)	13.8 (4.9)
With supplements	18.4 (10.1)	19.6 (10.6)	20 (10.7)	18.9 (12.3)	
Copper, mg	1.5 (0.5)	1.6 (0.5)	1.5 (0.5)	1.3 (0.5)	1.4 (0.8)
With supplements	2.5 (1.3)	2.6 (1.3)	2.5 (1.3)	2.1 (1.1)	
Zinc, mg	11.9 (3.7)	12.6 (3.9)	11.5 (3.7)	10.3 (3.2)	11.5 (4.6)
With supplements	21.7 (14.0)	22.5 (14.7)	22.4 (14.8)	19.9 (11.8)	
Phosphorus, mg	1,360 (414)	1,425 (422)	1,300 (415)	1,187 (274)	1,325 (409)
With supplements	1,391 (418)	1,458 (427)	1,339 (418)	1,209 (275)	
Choline, mg	343 (110)	353 (105)	330 (111)	295 (79)	313 (105)
With supplements	348 (115)	358 (107)	335 (113)	298 (85)	
Potassium, mg	3,251 (965)	3,389 (973)	3,143 (965)	2,632 (656)	2,801 (868)
With supplements	3,298 (976)	3,437 (987)	3,190 (972)	2,670 (665)	
Sodium, mg	2,061 (660)	2,152 (685)	1,947 (638)	2,647 (640)	3,087 (913)
Caffeine, mg	179 (139)	185 (136)	168 (129)	164 (112)	167 (134)

Abbreviations: 7DDR, 7-day dietary record; ASA24, automated self-administered 24-hour dietary recall; FA, fatty acid; DHA + EPA, eicosapentaenoic acid and docosahexaenoic acid; SFFQ, semiquantitative food frequency questionnaire; WebFFQ: web-based SFFQ.

[a] Participants completed an average of 14 days of 7DDR and an average of 2.9 days of ASA24.

The following results were based primarily on the intakes of total energy and 44 commonly investigated nutrients measured across SFFQ, 7DDR, and ASA24, as well as intakes of 22 nutrients for which supplements were measured in both the SFFQ and 7DDR. Additional results for specific fatty acids and other nutrients are shown in the web materials (Web Tables 2–4).

The distributions of absolute daily nutrient intakes are shown in Table 2. Most nutrients measured by the average of ASA24s and SFFQ had wider distributions compared with the average of the two 7DDRs. Average sodium intake assessed by the final SFFQ was lower than by 7DDR and ASA24. Intakes of energy, total protein, fat, and carbohydrate assessed by the final SFFQ were comparable to those assessed by ASA24s but were slightly higher than those assessed by 7DDRs. Intakes of supplements and of several nutrients contained in fruits and vegetables (such as carotenoids), were assessed as higher by the final SFFQ than by 7DDRs, which was largely due to extreme values in the final SFFQ for a few individuals.

We observed a high degree of reproducibility for nutrient intakes assessed by SFFQs spaced 1 year apart and by 7DDRs separated by 6 months (Table 3). ICCs for unadjusted intakes assessed by SFFQs ranged from 0.50 (iron with supplements) to 0.91 (alcohol). For unadjusted nutrients measured by two 7DDRs, ICCs ranged from 0.24 (lycopene) to 0.88 (caffeine). As expected, the reproducibility of the ASA24s over 1 year was much lower compared with the SFFQs and 7DDRs, with ICCs ranging from 0.10 (omega-3 (eicosapentaenoic acid and docosahexaenoic acid) fatty acids without supplements) to 0.62 (caffeine). The mean ICCs of the unadjusted nutrient intakes assessed by SFFQs, 7DDRs, and ASA24s were 0.68, 0.59, and 0.25, respectively (data not shown). The average reproducibility of nutrient intakes was slightly lower after adjustment for total energy intake for all dietary methods.

When using 7DDRs as the comparison method, the Spearman correlation coefficients between the unadjusted nutrient intakes from the final SFFQ, which assessed intake over the same period as the 7DDR collection, and intakes from the two 7DDRs ranged from 0.28 for total energy, polyunsaturated fat, and sodium to 0.86 for alcohol (Table 4). Results were similar when Pearson correlation coefficients were used (Web Table 5). The 2 energy-adjustment methods gave similar results, and energy adjustment increased the correlations between the final SFFQ and 7DDRs for most macronutrients but not all nutrients. For energy-adjusted intakes using the residual method, correlations ranged from 0.36 (lauric acid) to 0.77 (alcohol) (mean r = 0.53; mean

Table 3. Rank Intraclass Correlation Coefficients of Daily Nutrient Intake Assessed Using the Semiquantitative Food Frequency Questionnaire, 7-Day Dietary Record, and Automated Self-Administered 24-Hour Dietary Recall, Lifestyle Validation Study, United States, 2010–2012

Nutrient	SFFQ[a]			7DDR[a]			ASA24[a]		
	Unadjusted	Energy Density	Residual Method	Unadjusted	Energy Density	Residual Method	Unadjusted	Energy Density	Residual Method
Total energy, kcal	0.70			0.64			0.29		
Total fat, g	0.69	0.68	0.68	0.62	0.64	0.65	0.26	0.23	0.23
Saturated fat, g	0.71	0.69	0.69	0.65	0.65	0.65	0.28	0.26	0.25
Polyunsaturated fat, g	0.68	0.65	0.65	0.51	0.48	0.49	0.19	0.13	0.12
Monounsaturated fat, g	0.67	0.64	0.64	0.60	0.58	0.58	0.26	0.22	0.21
Arachadonic FA, g	0.66	0.63	0.62	0.55	0.51	0.51	0.17	0.16	0.16
Lauric FA, g	0.67	0.66	0.66	0.48	0.44	0.43	0.24	0.22	0.21
Linoleic FA, g	0.66	0.63	0.63	0.50	0.48	0.49	0.19	0.13	0.13
Linolenic FA, g	0.69	0.66	0.66	0.50	0.44	0.44	0.21	0.14	0.13
Omega-3 (DHA + EPA) FA, g	0.69	0.67	0.67	0.42	0.41	0.41	0.10	0.09	0.08
With supplements	0.77	0.74	0.73	0.63	0.61	0.63			
Oleic FA, g	0.66	0.64	0.65	0.60	0.58	0.58	0.25	0.21	0.20
Cholesterol, mg	0.69	0.62	0.62	0.61	0.58	0.58	0.20	0.16	0.16
Protein, g	0.66	0.63	0.62	0.65	0.60	0.61	0.25	0.22	0.21
Carbohydrate, g	0.72	0.73	0.73	0.69	0.74	0.74	0.36	0.34	0.34
Total sugar, g	0.73	0.78	0.78	0.73	0.75	0.75	0.37	0.37	0.37
Fiber, g	0.71	0.71	0.71	0.73	0.74	0.75	0.35	0.32	0.33
Alcohol, g	0.91	0.91	0.86	0.81	0.81	0.73	0.47	0.49	0.46
Retinol activity equivalents, μg	0.65	0.65	0.64	0.42	0.37	0.37	0.22	0.20	0.20
With supplements	0.68	0.69	0.68	0.65	0.64	0.65			
Alpha carotene, μg	0.69	0.65	0.65	0.37	0.37	0.37	0.15	0.14	0.14
Beta carotene, μg	0.70	0.66	0.67	0.45	0.43	0.44	0.22	0.20	0.20
With supplements	0.70	0.67	0.67	0.47	0.46	0.46			
Lutein-zeaxanthin, μg	0.71	0.69	0.69	0.51	0.49	0.50	0.23	0.21	0.21
Lycopene, μg	0.64	0.57	0.57	0.24	0.23	0.23	0.11	0.11	0.11
Beta cryptoxanthin, μg	0.74	0.72	0.72	0.31	0.31	0.31	0.19	0.17	0.15
Vitamin B1, mg	0.65	0.63	0.62	0.55	0.53	0.52	0.20	0.19	0.19
With supplements	0.68	0.68	0.67	0.72	0.71	0.71			
Vitamin B2, mg	0.67	0.71	0.70	0.70	0.67	0.69	0.31	0.31	0.31
With supplements	0.67	0.68	0.68	0.75	0.74	0.75			
Vitamin B3, mg	0.64	0.62	0.59	0.57	0.55	0.54	0.17	0.19	0.17
With supplements	0.69	0.71	0.70	0.72	0.71	0.72			
Vitamin B6, mg	0.63	0.62	0.60	0.59	0.57	0.58	0.22	0.20	0.19
With supplements	0.68	0.70	0.68	0.73	0.71	0.72			
Vitamin B12, mg	0.59	0.59	0.58	0.50	0.48	0.48	0.13	0.12	0.11
With supplements	0.67	0.65	0.65	0.72	0.72	0.72			
Natural folate, μg	0.71	0.67	0.67	0.67	0.63	0.65	0.34	0.31	0.33
Folic acid, μg	0.59	0.60	0.60	0.59	0.59	0.59	0.22	0.22	0.23
With supplements	0.64	0.65	0.64	0.72	0.71	0.72			
Dietary folate equivalents, μg	0.59	0.58	0.57	0.59	0.56	0.56	0.23	0.20	0.20
With supplements	0.65	0.65	0.64	0.74	0.71	0.73			
Vitamin C, mg	0.71	0.68	0.68	0.59	0.56	0.57	0.30	0.27	0.28
With supplements	0.72	0.71	0.71	0.73	0.73	0.73			

Table continues

Table 3. Continued

Nutrient	SFFQ[a]			7DDR[a]			ASA24[a]		
	Unadjusted	Energy Density	Residual Method	Unadjusted	Energy Density	Residual Method	Unadjusted	Energy Density	Residual Method
Vitamin D, mg	0.68	0.67	0.67	0.61	0.57	0.58	0.22	0.20	0.20
With supplements	0.56	0.56	0.54	0.72	0.72	0.72			
Vitamin E, mg	0.65	0.64	0.64	0.55	0.53	0.53	0.26	0.23	0.23
With supplements	0.71	0.73	0.72	0.78	0.77	0.77			
Vitamin K, mg	0.71	0.69	0.69	0.50	0.48	0.48	0.20	0.17	0.17
With supplements	0.71	0.68	0.68	0.54	0.53	0.53			
Calcium, mg	0.64	0.65	0.64	0.71	0.68	0.70	0.30	0.25	0.26
With supplements	0.69	0.72	0.71	0.72	0.72	0.73			
Magnesium, mg	0.68	0.68	0.67	0.72	0.72	0.73	0.37	0.35	0.37
With supplements	0.67	0.70	0.69	0.78	0.78	0.80			
Iron, mg	0.62	0.56	0.55	0.59	0.54	0.54	0.21	0.19	0.19
With supplements	0.50	0.48	0.46	0.51	0.50	0.50			
Copper, mg	0.65	0.69	0.67	0.62	0.60	0.60	0.28	0.25	0.25
With supplements	0.60	0.64	0.62	0.64	0.65	0.64			
Zinc, mg	0.60	0.60	0.56	0.58	0.48	0.49	0.15	0.12	0.11
With supplements	0.61	0.61	0.60	0.67	0.66	0.66			
Phosphorus, mg	0.67	0.68	0.67	0.71	0.65	0.68	0.29	0.24	0.24
With supplements	0.67	0.68	0.66	0.71	0.66	0.68			
Choline, mg	0.69	0.62	0.62	0.68	0.61	0.63	0.24	0.19	0.19
With supplements	0.69	0.63	0.63	0.67	0.60	0.62			
Potassium, mg	0.71	0.68	0.68	0.74	0.70	0.73	0.37	0.33	0.36
With supplements	0.72	0.69	0.69	0.75	0.70	0.73			
Sodium, mg	0.73	0.68	0.69	0.58	0.50	0.50	0.24	0.20	0.20
Caffeine, mg	0.78	0.78	0.78	0.88	0.87	0.86	0.62	0.57	0.50

Abbreviations: 7DDR, 7-day dietary record; ASA24, automated self-administered 24-hour dietary recall; FA, fatty acid; DHA + EPA, eicosapentaenoic acid and docosahexaenoic acid; SFFQ, semiquantitative food frequency questionnaire.

[a] Two SFFQs, approximately 1 year apart; two 7DDRs, approximately 6 months apart; 4 ASA24s, approximately every 3 months over 1 year.

r = 0.57 after additionally including nutrients from supplements). After correcting for random within-person error in the 7DDRs, the mean Spearman correlation coefficient increased to 0.63 (mean r = 0.66 after additionally including nutrients from supplements), ranging from 0.46 (lauric acid) to 0.84 (alcohol) (Tables 4 and 5). When comparing the 22 common nutrients with supplements, the correlations between the final SFFQ and 7DDR were generally higher after including supplements (deattenuated: mean r = 0.71 with supplements and mean r = 0.63 without supplements) (Table 5). Similar patterns for energy-adjusted, deattenuated correlations with 7DDR were observed for the WebFFQ (mean r = 0.61) and the baseline SFFQ (mean r = 0.60) (Web Tables 6 and 7).

When the ASA24s were used as the comparison method, the unadjusted Spearman correlation coefficients for nutrients assessed by the final SFFQ compared with 4 ASA24s were lowest for lycopene without supplements (r = 0.23) and highest for alcohol (r = 0.75). Energy adjustment increased the correlations for many nutrients. Correlation coefficients further increased substantially after deattenuation (mean r = 0.62 vs. mean r = 0.43). The confidence intervals of the correlations of the final SFFQ with ASA24 were somewhat wider compared with the correlations with 7DDR after deattenuation even though the study sample size was large. For example, the deattenuated Spearman correlations for cholesterol intake were 0.65 (95% confidence interval: 0.58, 0.71) with 7DDR and 0.68 (95% confidence interval: 0.55, 0.79) with ASA24. Because the degree of correction depends on the ratio of within-person to between-persons variation in the ASA24, the effect of deattenuation for nutrients with very high within-person variation (as reflected by a low ICC) was large, and the confidence intervals of the corrected correlation were also generally wide. For example, the reproducibility of polyunsaturated fat (ICC = 0.12) and omega-3 (eicosapentaenoic acid and docosahexaenoic acid) fatty acids without supplements (ICC = 0.08) assessed by ASA24 was relatively low; therefore, the deattenuated correlations increased greatly, and the corresponding confidence intervals were wide (Table 4). Slightly lower magnitudes of

Table 4. Spearman Correlation Coefficients for Comparison of the Second Semiquantitative Food Frequency Questionnaire With 7-Day Dietary Record and Automated Self-Administered 24-Hour Dietary Recall, Unadjusted and Energy-Adjusted According to Energy Density and Residual Methods, Lifestyle Validation Study, United States, 2010–2012

Nutrient	Final SFFQ vs. 7DDR						Final SFFQ vs. ASA24					
	Unadjusted	Energy-Adjusted					Unadjusted	Energy-Adjusted				
		Energy Density	Residual Method	Deattenuated	95% CI	ICC[a]		Energy Density	Residual Method	Deattenuated	95% CI	ICC[a]
Total energy, kcal	0.28			0.31	(0.23, 0.38)	0.64	0.30			0.40	(0.31, 0.49)	0.29
Total fat, g	0.36	0.59	0.59	0.67	(0.60, 0.71)	0.65	0.34	0.55	0.55	0.76	(0.64, 0.84)	0.23
Saturated fat, g	0.44	0.62	0.61	0.69	(0.62, 0.73)	0.65	0.44	0.57	0.54	0.71	(0.60, 0.80)	0.25
Polyunsaturated fat, g	0.28	0.45	0.47	0.57	(0.49, 0.64)	0.49	0.24	0.40	0.41	0.70	(0.52, 0.83)	0.12
Monounsaturated fat, g	0.37	0.48	0.48	0.56	(0.49, 0.63)	0.58	0.30	0.40	0.40	0.60	(0.48, 0.69)	0.21
Arachadonic FA, g	0.36	0.44	0.43	0.52	(0.44, 0.59)	0.51	0.25	0.33	0.32	0.52	(0.38, 0.63)	0.16
Lauric FA, g	0.35	0.37	0.36	0.46	(0.37, 0.54)	0.43	0.34	0.34	0.33	0.48	(0.37, 0.58)	0.21
Linoleic FA, g	0.29	0.44	0.45	0.55	(0.47, 0.62)	0.49	0.25	0.39	0.41	0.70	(0.52, 0.82)	0.13
Linolenic FA, g	0.35	0.44	0.45	0.57	(0.48, 0.65)	0.44	0.27	0.33	0.34	0.58	(0.42, 0.70)	0.13
Omega-3 (DHA + EPA) FA, g	0.53	0.53	0.52	0.67	(0.58, 0.74)	0.41	0.27	0.30	0.29	0.64	(0.40, 0.80)	0.08
With supplements	0.62	0.62	0.60	0.69	(0.62, 0.74)	0.63						
Oleic FA, g	0.37	0.48	0.48	0.56	(0.48, 0.62)	0.58	0.30	0.40	0.40	0.60	(0.48, 0.69)	0.20
Cholesterol, mg	0.50	0.56	0.56	0.65	(0.58, 0.71)	0.58	0.39	0.42	0.42	0.68	(0.55, 0.79)	0.16
Protein, g	0.33	0.48	0.48	0.54	(0.47, 0.60)	0.61	0.30	0.38	0.37	0.54	(0.42, 0.64)	0.21
Carbohydrate, g	0.41	0.66	0.65	0.69	(0.64, 0.73)	0.74	0.44	0.58	0.58	0.73	(0.65, 0.80)	0.34
Total sugar, g	0.53	0.68	0.68	0.74	(0.69, 0.79)	0.75	0.54	0.64	0.63	0.75	(0.67, 0.81)	0.37
Fiber, g	0.46	0.64	0.62	0.66	(0.60, 0.70)	0.75	0.41	0.52	0.51	0.65	(0.56, 0.72)	0.33
Alcohol, g	0.86	0.86	0.77	0.84	(0.80, 0.87)	0.73	0.75	0.75	0.65	0.74	(0.68, 0.80)	0.46
Retinol activity equivalents, μg	0.45	0.48	0.49	0.66	(0.56, 0.74)	0.37	0.39	0.40	0.42	0.60	(0.48, 0.70)	0.20
With supplements	0.64	0.65	0.66	0.74	(0.68, 0.79)	0.65						
Alpha carotene, μg	0.49	0.48	0.47	0.64	(0.54, 0.72)	0.37	0.39	0.37	0.37	0.65	(0.50, 0.75)	0.14
Beta carotene, μg	0.51	0.53	0.52	0.66	(0.58, 0.73)	0.44	0.44	0.44	0.44	0.67	(0.55, 0.75)	0.20
With supplements	0.50	0.50	0.50	0.63	(0.54, 0.69)	0.46						
Lutein-zeaxanthin, μg	0.54	0.56	0.55	0.68	(0.60, 0.74)	0.50	0.44	0.47	0.47	0.70	(0.58, 0.79)	0.21
Lycopene, μg	0.40	0.38	0.37	0.61	(0.46, 0.72)	0.23	0.23	0.20	0.15	0.29	(0.14, 0.43)	0.11
Beta cryptoxanthin, μg	0.36	0.38	0.38	0.54	(0.43, 0.64)	0.31	0.39	0.41	0.42	0.59	(0.44, 0.70)	0.15
Vitamin B1, mg	0.36	0.53	0.54	0.65	(0.57, 0.71)	0.52	0.32	0.42	0.42	0.65	(0.52, 0.74)	0.19
With supplements	0.70	0.71	0.71	0.78	(0.73, 0.82)	0.71						
Vitamin B2, mg	0.52	0.57	0.61	0.67	(0.62, 0.72)	0.69	0.46	0.50	0.53	0.69	(0.60, 0.77)	0.31
With supplements	0.71	0.71	0.73	0.79	(0.74, 0.83)	0.75						

Table continues

Table 4. Continued

Nutrient	Final SFFQ vs. 7DDR						Final SFFQ vs. ASA24					
	Unadjusted	Energy-Adjusted					Unadjusted	Energy-Adjusted				
		Energy Density	Residual Method	Deattenuated	95% CI	ICC[a]		Energy Density	Residual Method	Deattenuated	95% CI	ICC[a]
Vitamin B3, mg	0.36	0.46	0.46	0.55	(0.47, 0.61)	0.54	0.29	0.40	0.38	0.59	(0.45, 0.69)	0.17
With supplements	0.67	0.70	0.71	0.78	(0.73, 0.82)	0.72						
Vitamin B6, mg	0.38	0.48	0.48	0.56	(0.49, 0.63)	0.58	0.33	0.38	0.38	0.57	(0.44, 0.67)	0.19
With supplements	0.68	0.67	0.68	0.74	(0.69, 0.79)	0.72						
Vitamin B12, mg	0.43	0.44	0.45	0.56	(0.48, 0.63)	0.48	0.32	0.31	0.31	0.56	(0.39, 0.69)	0.11
With supplements	0.69	0.67	0.68	0.74	(0.69, 0.79)	0.72						
Natural folate, µg	0.48	0.59	0.59	0.67	(0.61, 0.72)	0.65	0.40	0.51	0.50	0.64	(0.55, 0.71)	0.33
Folic acid, µg	0.56	0.59	0.59	0.69	(0.62, 0.74)	0.59	0.45	0.46	0.44	0.57	(0.46, 0.67)	0.23
With supplements	0.68	0.69	0.69	0.76	(0.71, 0.80)	0.72						
Dietary folate equivalents, µg	0.45	0.54	0.55	0.64	(0.57, 0.70)	0.56	0.36	0.39	0.40	0.56	(0.44, 0.66)	0.20
With supplements	0.68	0.70	0.71	0.77	(0.72, 0.81)	0.73						
Vitamin C, mg	0.49	0.53	0.52	0.61	(0.54, 0.67)	0.57	0.47	0.46	0.46	0.62	(0.52, 0.70)	0.28
With supplements	0.70	0.71	0.71	0.77	(0.72, 0.82)	0.73						
Vitamin D, mg	0.60	0.58	0.59	0.69	(0.62, 0.74)	0.58	0.51	0.51	0.52	0.77	(0.64, 0.85)	0.20
With supplements	0.63	0.59	0.60	0.66	(0.60, 0.71)	0.72						
Vitamin E, mg	0.40	0.47	0.47	0.56	(0.48, 0.62)	0.53	0.29	0.36	0.35	0.51	(0.39, 0.60)	0.23
With supplements	0.72	0.72	0.72	0.78	(0.74, 0.82)	0.77						
Vitamin K, mg	0.53	0.58	0.57	0.71	(0.63, 0.78)	0.48	0.37	0.41	0.41	0.64	(0.51, 0.73)	0.17
With supplements	0.53	0.56	0.56	0.67	(0.59, 0.73)	0.53						
Calcium, mg	0.56	0.61	0.63	0.68	(0.62, 0.73)	0.70	0.48	0.54	0.55	0.68	(0.57, 0.77)	0.26
With supplements	0.66	0.64	0.68	0.74	(0.69, 0.79)	0.73						
Magnesium, mg	0.43	0.65	0.66	0.72	(0.67, 0.77)	0.73	0.37	0.59	0.58	0.73	(0.65, 0.79)	0.37
With supplements	0.58	0.72	0.73	0.75	(0.70, 0.80)	0.80						
Iron, mg	0.35	0.48	0.48	0.56	(0.49, 0.63)	0.54	0.30	0.39	0.37	0.55	(0.43, 0.65)	0.19
With supplements	0.40	0.50	0.48	0.58	(0.50, 0.65)	0.50						
Copper, mg	0.36	0.51	0.50	0.58	(0.50, 0.64)	0.60	0.29	0.40	0.38	0.52	(0.41, 0.61)	0.25
With supplements	0.51	0.57	0.56	0.63	(0.56, 0.68)	0.64						
Zinc, mg	0.36	0.41	0.42	0.52	(0.43, 0.59)	0.49	0.31	0.28	0.29	0.53	(0.36, 0.66)	0.11
With supplements	0.61	0.60	0.61	0.68	(0.62, 0.73)	0.66						
Phosphorus, mg	0.41	0.58	0.60	0.67	(0.61, 0.71)	0.68	0.36	0.51	0.51	0.68	(0.57, 0.77)	0.24
With supplements	0.41	0.59	0.60	0.67	(0.61, 0.72)	0.68						

Table continues

Table 4. Continued

Nutrient	Final SFFQ vs. 7DDR						Final SFFQ vs. ASA24					
	Unadjusted	Energy-Adjusted					Unadjusted	Energy-Adjusted				
		Energy Density	Residual Method	Deattenuated	95% CI	ICC[a]		Energy Density	Residual Method	Deattenuated	95% CI	ICC[a]
Choline, mg	0.44	0.53	0.55	0.62	(0.56, 0.68)	0.63	0.35	0.40	0.40	0.61	(0.49, 0.71)	0.19
With supplements	0.43	0.52	0.54	0.61	(0.54, 0.67)	0.62						
Potassium, mg	0.45	0.57	0.60	0.65	(0.60, 0.70)	0.73	0.41	0.52	0.53	0.64	(0.56, 0.71)	0.36
With supplements	0.45	0.56	0.60	0.65	(0.60, 0.70)	0.73						
Sodium, mg	0.28	0.46	0.44	0.53	(0.44, 0.60)	0.50	0.26	0.31	0.29	0.43	(0.31, 0.53)	0.20
Caffeine, mg	0.78	0.76	0.76	0.80	(0.77, 0.83)	0.86	0.72	0.72	0.70	0.77	(0.71, 0.82)	0.50

Abbreviations: 7DDR, 7-day dietary record; ASA24, automated self-administered 24-hour dietary recall; CI, confidence interval; FA, fatty acid; ICC, intraclass correlation coefficient; DHA + EPA, eicosapentaenoic acid and docosahexaenoic acid; SFFQ, semiquantitative food frequency questionnaire.

[a] ICC for the comparison method is presented for energy-adjusted intake using the residual method in the log scale.

correlations with ASA24 were observed with the baseline SFFQ (deattenuated: mean $r = 0.57$) and with the WebFFQ (deattenuated: mean $r = 0.60$) (Web Tables 6 and 7).

The Spearman correlation coefficients showed similar patterns for the subgroup of women who completed 4 ASA24s (Web Table 8) and among different age groups (Web Tables 9 and 10). For participants with a BMI <25, the mean adjusted and deattenuated correlation coefficients (mean $r = 0.65$ vs. 7DDR; mean $r = 0.62$ vs. ASA24) were only slightly higher than those of the subgroups with BMI ≥25 (mean $r = 0.61$ vs. 7DDR; mean $r = 0.61$ vs. ASA24) and with BMI ≥30 (mean $r = 0.59$ vs. 7DDR; mean $r = 0.57$ vs. ASA24), regardless of which comparison method was used (Web Tables 11–13). The Bland-Altman plots (Web Figure 1) did not suggest obvious systematic bias for several nutrients of major interest. In general, BMI, white race, and smoking status were not associated with the reporting error in the final SFFQ relative to 7DDRs. Greater reporting error in the final SFFQ was observed with increasing age for many nutrients (e.g., total fat), but this tended to disappear after adjustment of energy intake (data not shown).

Similar regression coefficients (deattenuation coefficients) were obtained when nutrient intakes assessed by SFFQ were used to predict intakes assessed by 7DDR or by ASA24 (Web Table 14). Web Table 15 provides correlation and regression coefficients for the large number of additional nutrients that were available for the 7DDR and SFFQ but not available for the ASA24.

DISCUSSION

We evaluated the performance of both paper and web versions of our SFFQ by comparing resulting nutrient intakes with those measured by two 7DDRs and up to 4 ASA24s kept over a 1-year period among women aged 45–80 years participating in prospective cohort studies. The correlations were generally stronger when nutrient intakes were adjusted for total energy intake and when supplements were included in nutrient values. As a comparison method, after adjustment for within-person variation, the ASA24s performed similarly to the 7DDRs. In subgroup analysis, the correlation coefficient for our SFFQ was found to be similar among different age groups and only slightly lower among obese women than among normal weight women. Similar patterns of correlations were observed when comparing the baseline SFFQ, final SFFQ, and WebFFQ with the 7DDRs or ASA24s, although, as expected, the correlations were slightly lower for the baseline SFFQ, because this was completed a year before the collection of the 7DDRs and ASA24s.

Many validation studies have been conducted within large cohorts, comparing intakes from the study's SFFQ with intakes from dietary records or 24-hour recalls (1, 3, 4, 12, 27–31). In general, correlations between nutrients calculated from SFFQs and from multiple food records or diet recalls ranged from 0.40 to 0.70 (1), which suggests considerable error but still sufficient information to detect important hypothesized associations with disease. Among those

Table 5. Summary of Spearman Correlation Coefficients for the Comparison of Nutrient Intake From Each Semiquantitative Food Frequency Questionnaire With 7-Day Dietary Records and Automated Self-Administered 24-Hour Dietary Recalls, Overall and in Subgroups of Participants, Lifestyle Validation Study, United States, 2010–2012

Group or Subgroup[a]	Unadjusted				Energy-Adjusted				Deattenuated				ICC[b]			
	Mean	Min	Median	Max	Mean	Min	Median	Max	Mean	Min	Median	Max	Mean	Min	Median	Max
Overall (*n* = 632)																
Final SFFQ vs. 7DDR	0.44	0.28	0.43	0.86	0.53	0.36	0.52	0.77	0.63	0.46	0.65	0.84	0.56	0.23	0.58	0.86
Final SFFQ vs. ASA24	0.38	0.23	0.36	0.75	0.43	0.15	0.42	0.70	0.62	0.29	0.64	0.77	0.22	0.08	0.20	0.50
Baseline SFFQ vs. 7DDR	0.44	0.31	0.43	0.84	0.51	0.37	0.49	0.77	0.60	0.48	0.59	0.84	0.56	0.23	0.58	0.86
Baseline SFFQ vs. ASA24	0.38	0.18	0.35	0.75	0.41	0.11	0.39	0.74	0.57	0.18	0.59	0.79	0.22	0.08	0.20	0.50
WebFFQ vs. 7DDR	0.42	0.27	0.39	0.85	0.52	0.36	0.50	0.76	0.61	0.46	0.61	0.82	0.56	0.23	0.58	0.86
WebFFQ vs. ASA24	0.37	0.20	0.34	0.75	0.42	0.14	0.40	0.71	0.60	0.26	0.60	0.78	0.22	0.08	0.20	0.50
22 nutrients without supplements																
Final SFFQ vs. 7DDR	0.45	0.35	0.45	0.60	0.54	0.42	0.53	0.66	0.63	0.52	0.65	0.72	0.57	0.37	0.57	0.73
Baseline SFFQ vs. 7DDR	0.44	0.34	0.44	0.57	0.50	0.41	0.49	0.61	0.59	0.51	0.59	0.67	0.57	0.37	0.57	0.73
WebFFQ vs. 7DDR	0.42	0.32	0.41	0.56	0.52	0.43	0.51	0.61	0.61	0.52	0.61	0.67	0.57	0.37	0.57	0.73
22 nutrients with supplements																
Final SFFQ vs. 7DDR	0.60	0.40	0.64	0.72	0.64	0.48	0.67	0.73	0.71	0.58	0.74	0.79	0.68	0.46	0.72	0.80
Baseline SFFQ vs. 7DDR	0.58	0.43	0.60	0.72	0.61	0.48	0.62	0.72	0.67	0.58	0.69	0.76	0.68	0.46	0.72	0.80
WebFFQ vs. 7DDR	0.57	0.38	0.62	0.70	0.61	0.47	0.65	0.71	0.68	0.57	0.71	0.77	0.68	0.46	0.72	0.80
Subgroup with 4 complete ASA24s (*n* = 226)																
Final SFFQ vs. 7DDR	0.44	0.23	0.44	0.85	0.54	0.32	0.55	0.77	0.64	0.46	0.64	0.83	0.57	0.28	0.55	0.88
Final SFFQ vs. ASA24	0.41	0.24	0.40	0.75	0.45	0.24	0.45	0.71	0.63	0.42	0.65	0.80	0.22	0.08	0.20	0.51
Aged 45–60 years old (*n* = 309)																
Final SFFQ vs. 7DDR	0.46	0.24	0.45	0.85	0.54	0.28	0.53	0.78	0.63	0.41	0.65	0.83	0.56	0.15	0.57	0.87
Final SFFQ vs. ASA24	0.39	0.20	0.37	0.75	0.43	0.19	0.41	0.75	0.59	0.31	0.61	0.80	0.22	0.08	0.20	0.49
Aged 61–80 years old (*n* = 323)																
Final SFFQ vs. 7DDR	0.42	0.27	0.39	0.86	0.53	0.34	0.51	0.77	0.62	0.43	0.61	0.83	0.57	0.30	0.56	0.85
Final SFFQ vs. ASA24	0.38	0.18	0.36	0.78	0.46	0.13	0.44	0.70	0.61	0.21	0.60	0.76	0.23	0.07	0.22	0.53
BMI <25 (*n* = 298)[c]																
Final SFFQ vs. 7DDR	0.45	0.23	0.43	0.85	0.56	0.35	0.56	0.77	0.65	0.44	0.64	0.84	0.59	0.20	0.61	0.86
Final SFFQ vs. ASA24	0.43	0.24	0.43	0.75	0.46	0.12	0.46	0.73	0.62	0.25	0.62	0.80	0.25	0.08	0.24	0.53
BMI ≥25 (*n* = 334)																
Final SFFQ vs. 7DDR	0.44	0.29	0.44	0.86	0.50	0.34	0.49	0.76	0.61	0.48	0.61	0.82	0.54	0.25	0.53	0.86
Final SFFQ vs. ASA24	0.35	0.15	0.34	0.74	0.42	0.19	0.40	0.71	0.61	0.40	0.62	0.76	0.20	0.04	0.18	0.48
BMI ≥30 (*n* = 127)																
Final SFFQ vs. 7DDR[d]	0.39	0.16	0.40	0.85	0.47	0.27	0.46	0.75	0.59	0.34	0.58	0.78	0.49	0.16	0.48	0.86
Final SFFQ vs. ASA24	0.37	0.09	0.35	0.75	0.42	0.17	0.41	0.72	0.57	0.34	0.57	0.84	0.18	0.04	0.17	0.40

Abbreviations: 7DDR, 7-day dietary record; ASA24, automated self-administered 24-hour dietary recall; BMI, body mass index; ICC, intraclass correlation coefficient; Max, maximum; Min, minimum; SFFQ, semiquantitative food frequency questionnaire; WebFFQ: web-based SFFQ.

[a] The table shows the summary statistics for 44 common nutrients without supplements among SFFQ, 7DDR, and ASA24 unless otherwise indicated.

[b] ICC for the comparison method is presented for energy-adjusted intake using the residual method in the log scale.

[c] BMI was calculated as weight (kg)/height (m)^2.

[d] The ICC for retinol activity equivalent in the 7DDR was −0.02 among the subgroup of participants with BMI ≥30, and thus the deattenuated Spearman correlation coefficient was not available.

studies, our team has conducted 2 validation studies among Boston-area women in the NHS—Willett et al. (3) in 1980 ($n = 173$) and Willett et al. (1) in 1986 ($n = 191$)—comparing SFFQ with multiple 7-day weighed dietary records. In the 1980 study, we evaluated the 61-item SFFQ among 225 women aged 34–59 years. Correlation coefficients between energy-adjusted intakes from the 4 one-week diet records and those from the second SFFQ ranged from 0.36 for vitamin A without supplements to 0.75 for vitamin C with supplements (mean $r = 0.55$). In the 1986 study, we evaluated an expanded version of the questionnaire with 116 items. After deattenuation for week-to-week variation in diet records, the correlations between diet records and SFFQ reflecting the diet-record year ranged from 0.48 for polyunsaturated fat to 0.79 for total vitamin A without supplements (mean $r = 0.54$; mean $r = 0.64$ after deattenuation). In the current study, we evaluated many additional nutrients and enrolled many more participants. The deattenuated correlation coefficients between the energy-adjusted intakes assessed by the final SFFQ and two 7DDRs ranged from 0.46 for lauric acid to 0.84 for alcohol (mean $r = 0.63$; mean r = 0.66 after additionally including nutrients from supplements). Overall, these findings indicate that over 30 years, our SFFQ performed consistently well when compared with multiple diet records and that modifications to the questionnaire over time have adequately taken into account the many changes in the food supply and eating patterns that have occurred since 1980.

In addition, our study also suggested that after adjustment for within-person variation, the ASA24 used in our study performed similarly to the 7DDR as a comparison method when using deattenuated correlation coefficients and regression coefficients to assess validity. Because day-to-day variability in the intake of many nutrients is large, 4 ASA24s—spaced approximately every 3 months over a year—to estimate the true long-term intake may still be insufficient to accurately measure the intake of some nutrients, especially if used to assess validity on an individual basis (32). The ASA24 is designed to address the limitations of traditional 24-hour dietary recalls, which have limited utility in large studies because they rely on trained interviewers and are costly to administer. In a feeding study in which investigators unobtrusively assessed measured known intakes for 3 meals for 1 day, ASA24 assessment agreed well with a measure of true intakes in terms of portion size, food group intake, energy intake, and nutrient intakes, although the accuracy was slightly less compared with an interviewer-administered 24-hour recall (33). Thus, the ASA24 has the potential to be used as a comparison method in future validation studies if adjustment is made for day-to-day variation. Its potential as a dietary assessment method for large population studies needs further evaluation, especially for some nutrients that are contained in a relatively small number of seasonal foods, which would likely not be captured as well in a few 24-hour recalls compared with a FFQ that assesses "habitual" diet (34).

To our knowledge, this is the largest validation study on dietary assessment methods among women, but it has limitations. Study participants were female registered nurses from the NHS and NHS II cohorts. Our results, including the regression calibration equations, may not be generalizable to other populations, such as populations with large proportions of racial/ethnic minorities, subjects with diagnosed chronic diseases, or men. Errors in dietary assessments with the SFFQ, diet records, and 24-hour dietary recalls may be correlated; if so, the validity of SFFQ could be overestimated. However, many sources of error in dietary assessment by diet records and 24-hour recalls are likely to be uncorrelated, because they depend very differently on memory and assessment of serving sizes. Thus, the similar findings using both standards suggests that the results are likely to be reasonably valid. Also, recalls and diet records both have their own sources of error, and this could lead to underestimation of validity for the SFFQ. Further, differences in food composition tables used for the various dietary assessment methods might also contribute to differences between the 3 methods. (This difference was minimized in our study because the nutrient databases used to analyze the 3 different dietary methods were based on the US Department of Agriculture data in the same year.) Additional evaluation using nutritional biomarkers as standards can provide more information on the validity of different self-reported methods.

In conclusion, our data indicate that the 152-item SFFQ is reasonably valid and consistent for measuring nutrient intakes compared with multiple dietary records or 24-hour dietary recalls among women. If within-person variation is taken into account, the ASA24 and 7DDR provided comparable information when serving as the comparison method for assessing validity of the SFFQ, which has important implications for the design of future validation studies, because the cost of ASA24 administration is minor compared with that of 7DDR. Further studies could use web-based 24-hour recalls to validate change in diet as measured by food frequency questionnaires and to determine optimal dietary measurement methods that potentially combine both SFFQ and 24-hour recall approaches.

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