Public Health Nutrition: 8(8), 1293–1299 DOI: 10.1079/PHN2005748

Sources of variation in nutrient intakes among men in Shanghai, China

Hui Cai[1], Gong Yang[1], Yong-Bing Xiang[2], James R Hebert[3], Da-Ke Liu[2], Wei Zheng[1] and Xiao-Ou Shu[1,*]

[1]Department of Medicine, Center for Health Services Research and Vanderbilt–Ingram Cancer Center, 6009 MCE, Vanderbilt University, 1215 21st Avenue, Nashville, TN 37232-8300, USA: [2]Department of Epidemiology, Shanghai Cancer Institute, Shanghai 200032, People's Republic of China: [3]Department of Epidemiology and Biostatistics, Arnold School of Public Health and South Carolina Cancer Center, University of South Carolina, Columbia, SC 29203, USA

Submitted 12 October 2004: Accepted 26 April 2005

Abstract

Background and objective: Random errors, from any source, will attenuate epidemiological risk estimates. Before we launched the Shanghai Men's Health Study (SMHS), a large population-based cohort study investigating the diet–cancer association among Chinese men, a dietary calibration study was conducted among 96 men aged 40–75 years (mean age 56.5 years), with biweekly 24-hour dietary recalls (24HDRs) implemented over a 1-year period. Data from this study were analysed to evaluate the nature and magnitude of variances for intake of 26 nutrients among SMHS participants, to compare variance ratios of 26 nutrients among Chinese men and women and individuals in other studies, and to estimate the number of 24HDRs required for future dietary calibration studies in similar populations.

Design: Ninety-six healthy, free-living men in Shanghai were administered biweekly 24HDR interviews 24 times over a 1-year period. To assess between-individual and within-individual contributions to variance, a mixed effects model was fitted and ratios of within-individual to between-individual ($\hat{\sigma}^2_w/\hat{\sigma}^2_b$) dietary intake variances were computed.

Setting: Shanghai, China.

Results: In agreement with reports from studies conducted in the USA and many other countries, we found that within-individual variances were usually larger than between-individual variances in dietary intake for all nutrients. The sum of all other variation (e.g. weekday and weekend, seasonal, interviewer) accounted for less than 5% of total variation. Ratios of within- to between-individual variances (for log-transformed data) ranged from 1.25 for carbohydrate intake to near 8 for δ-tocopherol intake.

Conclusions: The results of this study suggest that among middle-aged and elderly Chinese men in Shanghai, within- and between-individual variation account for more than 95% of the total variation for 26 nutrients. Further dietary validation studies in the same population could be adequately carried out with only 12 days of dietary recalls, if 100 participants were enrolled.

Keywords
Nutrients
24-Hour dietary recall
Component of variance
Within-individual variation
Between-individual variation
China

Increasing evidence has linked dietary intake with health outcomes, and particularly with chronic diseases[1,2]. However, obtaining an accurate estimate of long-term habitual food intake remains a major obstacle in diet and health research. Although diet records or 24-hour dietary recalls (24HDRs) obtained from free-living individuals provide the most accurate measurement of dietary intake on a particular day, their utilisation as a usual measurement of long-term dietary intake is tempered by the considerable day-to-day variation of each individual's food intake[3–6]. Therefore, repeated administration of the 24HDR is required to estimate usual dietary intake. Given the practical difficulties involved, the 24HDR is often used as a means to validate food-frequency questionnaires (FFQs), an instrument used to collect usual dietary patterns over a relatively long period. Two important issues of concern for this application are the number of days of 24HDR and the sample size required[7,8]. Dietary intake in free-living persons differs daily and seasonally in response to environmental, cultural and ecological factors.

*Corresponding author: Email xiao-ou.shu@vanderbilt.edu

The various sources of variation determine the times the 24HDR must be administered and the sample size required for a dietary validation study.

The vast majority of published studies focused on evaluating the within- and between-individual variation of dietary intake have been conducted in Western countries[9–15]. Only a few studies designed to evaluate sources of variance for 24HDRs have been conducted outside these countries[16]. In addition, most studies have estimated sources of variance based on only a few (two to 12) administrations of the 24HDR and only over relatively short time periods (less than 1 year)[17]. In many of those studies variance components have been estimated only for macronutrients. Furthermore, there are no published estimates of within- and between-individual variances in consumption of macronutrients and micronutrients among Chinese men.

The Shanghai Men's Health Study (SMHS), a large population-based cohort study of dietary and cancer risk among Chinese men, was launched in 2002. Before it began, we conducted a dietary calibration study among 96 male residents of Shanghai to estimate sources of variation in their dietary intake and to evaluate the validity and reliability of the FFQ we planned to use in the SMHS. In the calibration study, biweekly 24HDRs were implemented over a 1-year period. In the present paper we evaluate the major sources of dietary variation in this study population and calculate the ratios of within-individual to between-individual variance ($\hat{\sigma}^2_w/\hat{\sigma}^2_b$) for 26 nutrients. Variance ratios (VRs) among Chinese men and women and Chinese men and people in other countries are compared. The number of 24HDRs required for future dietary calibration studies in this study population is estimated and implications for other epidemiological studies are discussed.

Subjects and methods

Subjects and data collection

A dietary calibration study was conducted in 2001 involving 96 husbands of participants in the Shanghai Women's Health Study (SWHS). Study participants were contacted twice per month by nine interviewers during a 12-month period to provide their intake levels of foods over the past 24 h, which yielded a total of 24 days of 24HDR. The particular days that subjects were interviewed were chosen to ensure a balanced representation of weekdays and weekend days (16.1 weekdays and 7.6 weekend days, on average). All recalls were obtained by an unannounced in-person interview in the evening after dinner. Subjects were asked the name and the amount of foods they had consumed at each meal during the past 24 h[18]. Daily nutrient intakes used for analysis were then derived from the reported food intakes using a Chinese food composition table[19].

Statistical analysis

The major objective of this statistical analysis was to estimate the nature and magnitude of within- and between-individual variance of nutrient intakes derived from the 24HDRs over the 1-year assessment period. Sources of dietary variance that we examined included: (1) between-individual (i.e. variation from subject to subject); (2) season (i.e. variation of dietary intake across the four seasons); (3) type of day (i.e. weekday and weekend day); (4) sequence (i.e. order of the interview, 1st to 24th), (5) interviewer; and (6) within-individual (i.e. day-to-day variation unaccounted for by the other sources of variation mentioned above).

Descriptive analysis included statistical characteristics of 26 nutrients. Intake of 58% of the nutrients under study had skewness ≥ 3 or kurtosis ≥ 7, although intakes of most macronutrients were nearly normally distributed. Data for all of the 26 nutrients were log-transformed to achieve normality (see Table 2). The variances ratios (VRs) reported in this paper are based on both untransformed and natural log-transformed data.

The data were analysed using the following random effects model:

$$y_{ijklm} = \mu + subject_i + b_1x_1 + b_2x_2 + \cdots + \varepsilon_{ijklm}, \quad (1)$$

where y_{ijklm} is intake nutrient for the ith participant of the jth weekday or weekend day during the kth season at the lth sequence and visited by the mth interviewer; μ is mean of a nutrient intake; $subject_i$ is the random variable for variation among subjects; x_1, x_2,... represent the separate random effects of day, month, sequence and interviewer; and ε_{ijklm} is an error term, including the within-person variance. Estimates of within-individual variance ($\hat{\sigma}^2_w$) and between-individual variance ($\hat{\sigma}^2_b$) were calculated by setting mean squares (MS) equal to their expected values. Also, the residual approach of energy adjustment was used for calculating VRs. To do this, the dependent variable y_{ijklm} was replaced by the residual variable, which was derived from the regression of the specific nutrient value on total energy intake ($nutrient = a_0 + a_1 energy + \varepsilon$), which represents the difference in nutrient intake not attributed to differences in total energy intake.

Because three study participants had fewer than 24 days of recall, the analysis was based on an unbalanced model. Variances were estimated using the MIXED procedure in the Statistical Analysis System (SAS version 9.1, 2002–2003; SAS Institute, Cary, NC, USA). The ratios of within-individual to between-individual variance components were estimated by:

$$\mathrm{VR} = \frac{\hat{\sigma}^2_w}{\hat{\sigma}^2_b}. \quad (2)$$

Thus, for a given correlation coefficient for a person's unobserved usual intake with the average diet recalls (e.g. $\rho_0 = 0.7$) and a known VR for a nutrient, the required

https://doi.org/10.1079/PHN2005748 Published online by Cambridge University Press

repeat dietary recalls (k) for a dietary calibration study could be estimated by the following formula:

$$\rho_0 = \frac{1}{1 + (\mathrm{VR}/k)}. \quad (3)$$

Results

Nearly all study participants (98%) provided 24 days of 24HDRs. Three subjects had fewer than 24 24HDRs (one each had two, 22 and 23 days of 24HDRs). Thus, we used a total of 2279 dietary records for the current analysis.

The demographic characteristics of the study participants are shown in Table 1. The average age of study participants was 56.5 (standard deviation 10.1) years and 12.6% of subjects had completed college. Approximately 74% of subjects had an annual family income between 10 000 and 30 000 yuan (equivalent to $US 1205–3615 at the current exchange rate).

Table 2 presents a summary of statistics on nutrient intakes in the study population. Macronutrient intakes tended to have less variation (coefficient of variation (CV): 25.8% for energy to 64.1% for fat) than did consumption of vitamins (CV: 39.4% for thiamine to 313.9% for retinol) and minerals (CV: 30.3% for phosphorus to 98.6% for sodium). Retinol had the largest total variation (CV = 313.9%). All macronutrients were approximately normally distributed. Distributions of many of the micronutrients were badly skewed, kurtotic or both, especially those micronutrients with large CVs. The variance attributed to weekday and weekend day, seasonal, interviewer and sequential variance accounted for less than 5% of total variance (Table 3), indicating that these factors were not the main sources of observed variation in dietary intake in this study population. Ratios of within-person (residual) to between-individual (subject) variance were greater than 1. For the vast majority of micronutrients, the within- to between-individual variance ratios were above 2, with the highest ratio being noted for retinol (VR = 29.58). The ratios for minerals were between 1.69 (phosphorus) and 6.62 (copper). In general, VRs for the log-transformed data were similar to or smaller than those for the untransformed data with the exception of ascorbic acid, carotene, α-tocopherol and phosphorus. Changes of VRs between transformed and untransformed data were most evident for many vitamins and minerals, especially for those micronutrients whose distributions were very skewed or kurtotic or both. When we adjusted for energy intake using the residual method, nearly all nutrient VRs were increased (comparing Table 4 with Table 3), indicating that the adjustment tended to reduce between-person variability. For some of the nutrients, such as thiamine, iron, magnesium, manganese and zinc, the VRs increased up to 2 times or more, compared with those without energy intake adjustment. Adjustment for energy intake using the density method produced results similar to those derived using residuals (data not shown).

Table 1 Demographic characteristics of participants of the 24-hour dietary recall*

	Male	
	Mean	SD
Age (years)	56.5	10.1
Body mass index (kg m^{-2})	24.2	3.3
Height (cm)	168.9	5.6
Weight (kg)	69.2	10.6
	n	%
Education		
≥ College	12	13
High school	23	24
Middle school	40	42
Elementary/under	20	21
Annual income (yuan)†		
< 10 000	18	19
10 000– < 20 000	44	46
20 000– < 30 000	26	27
≥ 30 000	7	8

SD – standard deviation.
*Based on the 96 Shanghai Men's Health Study validation study participants.
†$US 1 ≈ 8.3 yuan.

Figure 1 illustrates the effects of the VR and the number of days of 24HDR on the estimation of the correlation between unobserved true intakes with the average of diet recalls. In general, with a fixed number of study participants, the smaller the VR and/or the more days of recalls, the higher the correlation. For example, with a VR of less than or equal to 5, 10–15 days of 24HDR would result in a correlation coefficient greater than 0.7, while 20 days of 24HDR would result in a correlation coefficient of 0.8. According to the VRs presented in Table 3, a validation study would require about 12 days of 24HDR for an adequate evaluation of the intake of most nutrients in this Chinese population. Similar analyses can be done to derive the sample size of the validation study if the correlation, VR and number of 24HDRs are provided. For example, a validation study would require a sample size of about 162 for validating the measurement of protein intake in the study population if the correlation were 0.95 and 10 replicates of 24HDR would be implemented[9,20].

Discussion

Measuring long-term or 'habitual' diet in free-living populations is an extremely challenging but necessary step in most epidemiological studies of diet and health. A well-designed FFQ may give a good approximation of long-term diet, although an absolute value of intake is hard to ascertain because an FFQ, with a focus on a hundred or fewer foods, cannot account for all relevant dietary exposures[16]. In addition, subjects have difficulty reporting dietary intake because food consumption tends to vary considerably from day to day[17]. Measurements based on instruments designed to focus on daily

https://doi.org/10.1079/PHN2005748 Published online by Cambridge University Press

Table 2 Descriptive data based on 24-hour diet recall interviews for the Shanghai Men's Health Study (SMHS)*

Nutrient	Mean	SD†	CV‡	Range	Skewness§	Kurtosis¶
Energy (kcal day^{-1})	1860	480.5	25.8	3910.2	0.5	1.1
Carbohydrate (g day^{-1})	297.3	81.0	27.2	593.6	0.2	0.3
Fat (g day^{-1})	40.6	26.0	64.1	222.8	1.6	4.4
Protein (g day^{-1})	76.6	25.6	33.5	218.7	1.1	2.9
Fibre (g day^{-1})	10.0	5.4	53.9	94.9	3.9	40.3
Thiamine (mg day^{-1})	1.0	0.4	39.4	3.7	1.1	2.4
Riboflavin (mg day^{-1})	0.9	0.5	52.7	5.2	2.7	12.3
Ascorbic acid (mg day^{-1})	68.8	47.9	69.6	389.7	1.5	3.9
Niacin (mg day^{-1})	16.1	6.9	43.3	81.9	2.2	9.8
Total vitamin A (μg day^{-1})	568.2	731.4	128.7	11 571.6	7.4	82.2
Retinol (μg day^{-1})	207.9	652.8	313.9	11 250.9	10.7	138.4
Carotene (μg day^{-1})	2272.0	2104.9	92.6	22 846.5	2.3	9.5
Total vitamin E (mg day^{-1})	14.7	10.2	69.1	107.9	2.2	8.3
α-Tocopherol (mg day^{-1})	5.4	3.6	67.8	39.0	2.3	9.3
β/γ-Tocopherol (mg day^{-1})	4.5	4.9	108.4	67.7	3.3	23.5
δ-Tocopherol (mg day^{-1})	3.6	4.3	120.3	36.1	2.7	9.8
Calcium (mg day^{-1})	493.8	295.9	59.9	2621.0	1.8	5.7
Copper (mg day^{-1})	2.4	1.8	73.5	18.3	5.8	41.4
Iron (mg day^{-1})	21.3	8.4	39.3	91.4	2.3	11.4
Potassium (mg day^{-1})	1750.0	639.3	36.5	5294.1	1.1	2.3
Magnesium (mg day^{-1})	297.7	98.3	33.0	801.0	1.2	2.8
Manganese (mg day^{-1})	6.3	2.0	32.1	23.2	1.6	7.6
Sodium (mg day^{-1})	932.1	918.9	98.6	11 589.8	2.9	15.4
Phosphorus (mg day^{-1})	1017.9	308.9	30.3	2415.0	0.8	1.7
Selenium (mg day^{-1})	51.5	30.3	58.8	374.9	2.3	10.9
Zinc (mg day^{-1})	11.8	3.8	32.1	39.8	1.3	3.9

* Results are based on the 96 SMHS validation study participants.
† SD is the sample standard deviation.
‡ This is the SD/mean times 100.
§ Skewness is the third moment about the mean, which expresses the symmetry of the distribution.
¶ Kurtosis is the fourth power of the deviation from mean, which describes the 'peakedness' of the distribution.
(A normal distribution is a smooth symmetric function with a value of zero for both skewness and kurtosis based the estimates obtained from SAS PROC UNIVARIATE).

consumption, such as the 24HDR, provide absolute values of intake but are extremely vulnerable to either within-individual sources of variation or between-individual sources of variation, unless an adequate number of replicate measurements and/or a large enough sample size is collected[9,11,14,20]. With a sufficient number of replicates the values obtained should have the lowest error of any assessment method[12]. While they are seldom used as the primary dietary exposure assessment in analytical epidemiology studies, short-term methods such as the 24HDR are used to assess fluctuations in dietary intake (i.e. to ascertain the magnitude of within-individual errors) and to provide comparative data for studies of the relative validity of some other method, such as the FFQ.

Information from a 24HDR can be applied to estimate the magnitude of within-individual error and its effect on the measurement of diet–disease associations. This technique requires at least two replicate measurements from a random sub-sample and may produce an estimate useful in determining the sample size and the optimum number of replicate measurements required to study a particular diet–disease relationship. Despite the potential utility of this information, very little work has been done on identifying contributors to total variability in dietary intake in human populations. This is the first such study conducted in Chinese men. Most North American studies have involved six[9,21] or seven[10] days of diet recalls or records. Given that the Chinese diet is still influenced by seasonal availability of certain foods, particularly vegetables, it was anticipated that more replicates might be needed to capture the resulting increase in variation. In our study, we administered 24 24HDRs over a 1-year period.

Our findings suggest, that among SMHS participants, the major sources of variation in dietary intake (>95%) could be ascribed to between- and within-individual variation. Taken together, other sources (day of the week, season of the year, etc.) contributed less than 5% to total variation. These results are similar to those observed in the SWHS[17] and in most other studies on the subject[9,12,15,16,22–24]. The Spearmen correlation coefficients between VRs of 26 nutrients of men in our study and that of women in the SWHS were 0.88 for untransformed data ($P < 0.0001$) and 0.93 for log-transformed data ($P < 0.0001$). The consistency of these results shows that profiles of intra- and inter-individual VRs between men and women in Shanghai, China were very similar. We found that very little variance can be ascribed to day of the week or season of the year. This indicates that shorter-term variations cannot be predicted by knowing the day of the week or the season during which diet is measured. As with our previous work

https://doi.org/10.1079/PHN2005748 Published online by Cambridge University Press

Table 3 Between- and within-individual variances (as a percentage of the total variance) and their ratios (σ_w^2/σ_b^2) for selected nutrients among participants in the Shanghai Men's Health Study

Nutrient	Day*	Season†	Interviewer‡	Sequence§	Subject¶	Residual‖	VR**	VR_log††
Energy (kcal day^{-1})	0.27	0.14	2.11	0	36.30	61.17	1.68	1.73
Carbohydrate (g day^{-1})	0.49	0.07	3.18	0.03	45.27	50.95	1.13	1.25
Fat (g day^{-1})	0	0.15	0.96	0.45	22.19	76.26	3.44	3.22
Protein (g day^{-1})	0	0.30	0.70	0.31	36.88	61.81	1.68	1.79
Fibre (g day^{-1})	0	0.43	0.16	1.20	16.72	81.49	4.87	2.99
Thiamine (mg day^{-1})	0.09	0.11	1.80	0.73	26.65	70.61	2.65	2.53
Riboflavin (mg day^{-1})	0.44	0.32	0	0.66	22.43	76.14	3.39	2.22
Ascorbic acid (mg day^{-1})	0	0	0	1.52	21.28	77.20	3.63	5.92
Niacin (mg day^{-1})	0	0.58	0.34	0.71	29.01	69.35	2.39	2.10
Total vitamin A (μg day^{-1})	0	0.30	0	1.63	4.75	93.32	19.64	5.92
Retinol (μg day^{-1})	0.01	0	0	0.39	3.26	96.35	29.59	5.41
Carotene (μg day^{-1})	0.01	1.34	0.76	2.13	14.90	80.85	5.43	6.89
Total vitamin E (mg day^{-1})	0	0.54	0	0	16.37	83.10	5.08	4.98
α-Tocopherol (mg day^{-1})	0	1.54	1.16	0.12	22.73	74.44	3.27	4.07
β/γ-Tocopherol (mg day^{-1})	0	0	0	0	11.86	88.14	7.43	6.62
δ-Tocopherol (mg day^{-1})	0	0.26	0	0	8.81	90.93	10.32	8.05
Calcium (mg day^{-1})	0	0.25	0	0.60	22.54	76.61	3.40	2.53
Copper (mg day^{-1})	0	1.03	1.06	0.10	12.83	84.98	6.62	3.56
Iron (mg day^{-1})	0	0.50	0	0.26	23.24	76.00	3.27	2.56
Potassium (mg day^{-1})	0	0.10	1.67	0.72	34.60	62.90	1.82	1.73
Magnesium (mg day^{-1})	0	0.45	0.67	0	30.75	68.12	2.22	2.13
Manganese (mg day^{-1})	0.35	0.03	0.44	0.16	28.10	70.92	2.52	2.12
Sodium (mg day^{-1})	0	0.79	0.58	0.3	17.55	80.79	4.60	3.44
Phosphorus (mg day^{-1})	0	0.55	0.54	0.36	36.63	61.92	1.69	1.81
Selenium (mg day^{-1})	0	0.63	0	0.73	23.95	74.69	3.12	2.71
Zinc (mg day^{-1})	0	0.71	0.38	0.28	33.09	65.55	1.98	1.88

* Percentage of variance attributable to the specific day of the week.
† Percentage of variance attributable to the specific season of the year.
‡ Percentage of variance attributable to the specific interviewer.
§ Percentage of variance attributable to the order of interview.
¶ Percentage of variance attributable to subjects (i.e. between-individual).
‖ Percentage of variance attributable to within-individual sources.
** Ratio of within-individual to between-individual variance (σ_w^2/σ_b^2).
†† Ratio of within-individual to between-individual variance (σ_w^2/σ_b^2), based on log-transformed data.

on the SWHS, sequence and interviewer had little effect, a finding also consistent with that observed in other studies[9,12,15,16,22–24].

The within- to between-person variability ratios were generally larger than 1, as reported in other studies[9,11,12,15,16,22–24]. For carbohydrate intake, the within-individual variance was approximately equal to the between-individual variance, a ratio similar to that observed in India and Japan[16,25], but lower, in general, than those observed in Western and Korean populations (Table 5). Beaton and co-workers[24] have suggested that within-person variation in nutrient intake is largely determined by the culture of a particular population. Apparently, Chinese and Japanese men have less day-to-day variation in carbohydrate intake and little day-to-day variance in protein and fat intake. For micronutrients, particularly vitamin A, retinol, vitamin E, δ-tocopherol, copper and sodium, the within-individual variation was much larger than between-individual variation. We found that the VRs tended to be higher with an adjustment for energy intake when compared with the unadjusted model for most nutrients in this study; this also is consistent with the results of many other studies[9]. This difference was due to the reduction in between-person variance after energy intake adjustment.

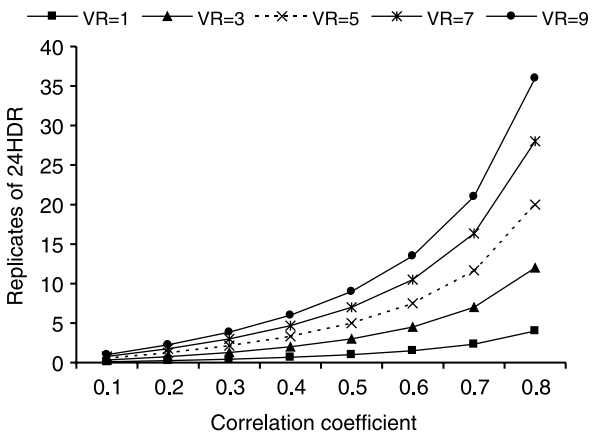

Fig. 1 Relationship between the number of replicates of a 24-hour dietary recall (24HDR) and correlation coefficient for different variance ratios (VR)

Based on these results, we estimate that a future dietary validation study enrolling 100 participants, in a similar population, would require approximately 10 days of dietary recalls for most micronutrients that have a VR smaller than or equal to 5. For the macronutrients, where the VR is ≈1.0, only a few days of 24HDR would be needed. This should guarantee that the correlation

https://doi.org/10.1079/PHN2005748 Published online by Cambridge University Press

Table 4 Between- and within-individual variances and their ratios ($\hat{\sigma}^2_w/\hat{\sigma}^2_b$) for selected energy-adjusted nutrient intakes among participants in the Shanghai Men's Health Study*

Nutrient	Day†	Season‡	Interviewer§	Sequence¶	Subject‖	Residual**	VR††	VR_log‡‡
Energy (kcal day^{-1})	0.16	0.08	0	0.56	40.8	58.40	1.43	1.53
Carbohydrate (g day^{-1})	0.10	0.14	1.17	0.55	30.58	67.46	2.21	2.58
Fat (g day^{-1})	0.01	0.12	0.39	0.52	32.82	66.13	2.01	2.48
Protein (g day^{-1})	0	0.36	0.55	1.69	10.89	86.51	7.94	4.77
Fibre (g day^{-1})	0	0.37	0.12	1.23	13.55	84.72	6.25	6.35
Thiamine (mg day^{-1})	0.21	0.27	0	0.54	17.53	81.46	4.65	3.10
Riboflavin (mg day^{-1})	0.01	0	0	1.50	18.51	79.98	4.32	7.34
Ascorbic acid (mg day^{-1})	0.06	0.33	0	0.82	19.61	79.18	4.04	4.23
Niacin (mg day^{-1})	0	0.28	0.12	1.61	4.38	93.61	21.39	6.75
Total vitamin A (μg day^{-1})	0	0	0	0.37	3.25	96.37	29.64	6.22
Retinol (μg day^{-1})	0.07	1.40	0.69	2.08	14.08	81.68	5.80	7.48
Carotene (μg day^{-1})	0	0.33	0	0	14.55	85.12	5.85	6.42
Total vitamin E (mg day^{-1})	0.02	1.29	0.90	0	20.03	77.77	3.88	5.37
α-Tocopherol (mg day^{-1})	0	0	1.25	0	11.75	87.00	7.40	6.90
β/γ-Tocopherol (mg day^{-1})	0	0.28	0	0.01	8.37	91.35	10.91	9.07
δ-Tocopherol (mg day^{-1})	0	0.19	0.21	0.62	19.58	79.39	4.05	2.96
Calcium (mg day^{-1})	0	0.82	0.52	0	10.61	88.05	8.30	7.62
Copper (mg day^{-1})	0.15	0.31	0	0.17	12.51	86.87	6.94	6.02
Iron (mg day^{-1})	0	0.63	1.11	1.11	27.09	70.06	2.59	2.45
Potassium (mg day^{-1})	0.04	1.49	0.31	0.36	17.41	80.40	4.62	4.96
Magnesium (mg day^{-1})	0.01	0	0.37	0.24	9.29	90.09	9.70	6.74
Manganese (mg day^{-1})	0	0.95	1.42	0.32	15.00	82.30	5.49	4.56
Sodium (mg day^{-1})	0	0.60	0	0.8	27.69	70.92	2.56	3.04
Phosphorus (mg day^{-1})	0	0.55	0	0.76	19.93	78.75	3.95	3.59
Selenium (mg day^{-1})	0.11	0.35	0	0.71	19.16	79.67	4.16	4.43
Zinc (mg day^{-1})	0.16	0.08	0	0.56	40.80	58.40	1.43	1.53

* All data presented are adjusted for total caloric (energy) intake using the residual method[6].
† Percentage of variance attributable to the specific day of the week.
‡ Percentage of variance attributable to the specific season of the year.
§ Percentage of variance attributable to the specific interviewer.
¶ Percentage of variance attributable to the order of interview.
‖ Percentage of variance attributable to subjects (i.e. between-individual).
** Percentage of variance attributable to within-individual sources.
†† Ratio of within-individual to between-individual variance ($\hat{\sigma}^2_w/\hat{\sigma}^2_b$).
‡‡ Ratio of within-individual to between-individual variance ($\hat{\sigma}^2_w/\hat{\sigma}^2_b$), based on log-transformed data.

Table 5 Comparison of variance ratios (VRs) of selected nutrients across selected studies*

Nutrient	Beaton *et al.*†		Hunt *et al.*†		Hartman *et al.*‡	Hebert *et al.*§		Ogawa *et al.*¶		Oh *et al.*‖		China**	
	M	F	M	F	M	M	F	M	F	M	F	M	F
Energy (kcal)	1.0	1.4	1.0	0.8	1.5	0.8	1.1	1.0	1.8	4.3	2.3	1.7	1.1
Carbohydrate (g)	1.7	1.4	2.0	1.2	1.1	0.8	0.9	0.8	1.5	5.4	3.3	1.1	1.0
Fat (g)	1.2	1.7	1.2	0.9	1.9	0.9	0.8	3.2	3.3	9.8	5.3	3.4	3.6
Protein (g)	1.4	1.4	1.2	1.3	2.2	n/a	n/a	1.8	2.5	4.5	1.9	1.7	1.6
Fibre (g)	n/a	n/a	n/a	n/a	1.1	2.3	2.8	n/a	n/a	n/a	n/a	4.9	4.3
Thiamine (mg)	2.5	3.8	n/a	n/a	2.9	1.2	1.5	4.3	4.2	7.7	2.9	2.6	2.4
Riboflavin (mg)	2.4	2.2	n/a	n/a	2.0	0.3	0.4	2.0	2.2	3.9	5.3	3.4	3.5
Ascorbic acid (mg day^{-1})	4.0	2.3	2.3	2.8	2.9	3.5	4.6	3.6	3.2	12.5	3.7	3.6	4.7
Niacin (mg)	n/a	n/a	n/a	n/a	2.8	n/a	n/a	3.5	4.3	5.6	2.9	2.4	2.0
Total vitamin A (μg day^{-1})	>100	47.6	1.6	2.5	4.6 (log)	n/a	n/a	n/a	n/a	2.3	5.9	19.6	12.8
Retinol (μg day^{-1})	n/a	n/a	n/a	n/a	n/a	n/a	n/a	52.9	n/a	n/a	n/a	29.6	22.4
Carotene (μg day^{-1})	n/a	n/a	n/a	n/a	n/a	n/a	n/a	3.4	3.1	n/a	n/a	5.4	7.9
Calcium (mg day^{-1})	2.6	2.3	1.1	1.7	1.5	1.2	1.5	1.8	2.1	10.7	4.9	3.4	4.2
Iron (mg day^{-1})	3.6	2.6	1.8	1.5	n/a	0.5	0.7	2.6	2.4	11.3	2.3	3.3	3.4
Potassium (mg day^{-1})	n/a	n/a	0.9	1.2	n/a	n/a	n/a	2.2	1.8	3.7	1.9	1.8	1.7
Sodium (mg day^{-1})	n/a	n/a	n/a	n/a	2.2	0.4	0.4	2.1	3.1	n/a	n/a	4.6	11.6
Phosphorus (mg day^{-1})	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.6	2.1	5.2	1.7	1.7	1.5
Zinc (mg day^{-1})	n/a	n/a	2.7	1.7	n/a	0.5	0.7	n/a	n/a	n/a	n/a	1.9	1.5

M – males; F – females; n/a – not available.
* The VRs are derived from untransformed data, with no energy adjustment data.
† Data come from reference 7, p. 41.
‡ Data come from reference 22.
§ Data come from reference 16.
¶ Data come from reference 25.
‖ Data come from reference 27.
** Data come from reference 17.

https://doi.org/10.1079/PHN2005748 Published online by Cambridge University Press

coefficients between usual daily dietary intake and estimated usual intake will be ≥0.7 or more[22,26]. If nutrients with a very large VR are the major exposure of interest (e.g. vitamin A, retinol, vitamin E, δ-tocopherol, copper and sodium), more replicates would be needed to derive a reliable and valid estimation of usual intake. Because the day-to-day and seasonal variations tended to be small, the timing of the survey may not be of major concern for this type of study.

In conclusion, the results in our study conformed to the results of similar studies conducted in other countries. The present investigation suggests that day-to-day fluctuation was the major source of variance in daily nutrient intake for this male population in Shanghai, China. Ten to fifteen days of 24HDR are needed if this methodology is to be used as the 'gold' standard for validating a dietary intake in a future study with 100 participants in the same population.

Acknowledgement

This study was supported by the National Institutes of Health, grants RO1 CA82729 and RO1 CA70867.

References

1 Shikany JM, White GL Jr. Dietary guidelines for chronic disease prevention. *Southern Medical Journal* 2000; **93**: 1138–51.
2 Willett WC. Diet and cancer: one view at the start of the millennium. *Cancer Epidemiology, Biomarkers & Prevention* 2001; **10**: 3–8.
3 Bingham SA, Gill C, Welch A, Day K, Cassidy A, Khaw KT, *et al*. Comparison of dietary assessment methods in nutritional epidemiology; weighed records v. 24 h recalls, food frequency questionnaires and estimated-diet records. *British Journal of Nutrition* 1994; **72**: 619–43.
4 Subar AF, Thompson FE, Kipnis V. Subar *et al*. respond to 'A further look at dietary questionnaire validation' and 'Another perspective on food frequency questionnaires'. *American Journal of Epidemiology* 2001; **154**: 1105–6.
5 Hebert JR, Miller DR. Methodologic considerations for investigating the diet–cancer link. *American Journal of Clinical Nutrition* 1988; **47**: 1068–77.
6 Hebert JR, Clemow L, Pbert L, Ockene IS, Ockene JK. Social desirability bias in dietary self-report may compromise the validity of dietary intake measures. *International Journal of Epidemiology* 1995; **24**: 389–98.
7 Willett W. *Nutritional Epidemiology*, 2nd ed. New York: Oxford University Press, 1998.
8 Stram DO, Hankin JH, Wilkens LR, Pike MC, Monroe KR, Park S, *et al*. Calibration of the dietary questionnaire for a multiethnic cohort in Hawaii and Los Angeles. *American Journal of Epidemiology* 2000; **151**: 358–70.
9 Beaton GH, Milner J, McGuire V, Feather TE, Little JA. Source of variance in 24-hour dietary recall data: implications for nutrition study design and interpretation. Carbohydrate sources, vitamins, and minerals. *American Journal of Clinical Nutrition* 1983; **37**: 986–95.
10 Hunt WC, Leonard AG, Garry PJ, Goodwin JS. Components of variance in dietary data for an elderly population. *Nutrition Research* 1983; **3**: 433–44.
11 Sempos CT, Johnson NE, Smith EL, Gilligan C. Effects of intraindividual and interindividual variation in repeated dietary records. *American Journal of Epidemiology* 1985; **121**: 120–30.
12 Hebert JR, Hurley TG, Chiraboga DE, Barone J. A comparison of selected nutrient intakes derived from three diet assessment methods used in a low-fat maintenance trial. *Public Health Nutrition* 1988; **1**: 207–14.
13 Ziegler RG, Wilcox HB 3rd, Mason TJ, Bill JS, Virgo PW. Seasonal variation in intake of carotenoids and vegetables and fruits among white men in New Jersey. *American Journal of Clinical Nutrition* 1987; **45**: 107–14.
14 Liu K. Consideration of and compensation of intra-individual variability in nutrient intakes. In: Kohlmeier L, Helsing E, eds. *Epidemiology, Nutrition and Health*. London/Niigate, Japan: Smith-Gordon/Nishimura, 1989.
15 Tarasuk V, Beaton GH. The nature and individuality of within-subject variation in energy intake. *American Journal of Clinical Nutrition* 1991; **54**: 464–70.
16 Hebert JR, Gupta PC, Mehta H, Ebbeling CB, Bhonsle RR, Varghese F. Sources of variability in dietary intake in two distinct regions of rural India: implications for nutrition study design and interpretation. *European Journal of Clinical Nutrition* 2000; **54**: 479–86.
17 Cai H, Shu XO, Hebert JR, Jin F, Yang G, Liu DK, *et al*. Variation in nutrient intakes among women in Shanghai, China. *European Journal of Clinical Nutrition* 2004; **58**: 1604–11.
18 Shu OX, Yang G, Jin F, Liu DK, Kushi L, Wen WQ, *et al*. Validity and reproducibility of the food frequency questionnaire used in the Shanghai Women's Health Study. *European Journal of Clinical Nutrition* 2004; **58**: 17–23.
19 Wang GY, Shen ZP, ed. *Chinese Food Composition Table*. Beijing: People's Health Publishing House, 1991.
20 Liu K, Stamler J, Dyer A, McKeever J, McKeever P. Statistical methods to assess and minimize the role of intra-individual variability in obscuring the relationship between dietary lipids and serum cholesterol. *Journal of Chronic Disease* 1978; **31**: 399–418.
21 McGee D, Rhoads G, Hankin J, Yano K, Tillotson J. Within-person variability of nutrient intake in a group of Hawaiian men of Japanese ancestry. *American Journal of Clinical Nutrition* 1982; **36**: 657–63.
22 Hartman AM, Brown CC, Palmgrem J, Pietinen P, Verkasalo M, Myer D, *et al*. Variability in nutrient and food intakes among older middle-aged men. *American Journal of Epidemiology* 1990; **132**: 999–1012.
23 Nelson M, Black AE, Morns JA, Cole TJ. Between- and within- subject variation in nutrient intake from infancy to old age: estimating the number of days required to rank dietary intakes with desired precision. *American Journal of Clinical Nutrition* 1989; **50**: 155–67.
24 Beaton GH, Milner J, Corey P, McGuire V, Cousins M, Stewart E, *et al*. Source of variance in 24-hour dietary recall data: implications for nutrition study design and interpretation. *American Journal of Clinical Nutrition* 1979; **32**: 2546–9.
25 Ogawa K, Tsubono Y, Nishino Y, Watanabe Y, Ohkubo T, Watanabe T, *et al*. Inter- and Intra-individual variation of food and nutrient consumption in a rural Japanese population. *European Journal of Clinical Nutrition* 1999; **52**: 781–5.
26 McAvay G, Rodin J. Interindividual and intraindividual variation in repeated measures of 24-hour dietary recall in the elderly. *Appetite* 1998; **11**: 97–110.
27 Oh SY, Hong MH. Within- and between-person variation of nutrient intakes of older people in Korea. *European Journal of Clinical Nutrition* 1999; **53**: 625–9.