Design and characterization of dietary assessment in the German National Cohort

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Abstract

Background/Objectives The aim of the study was to describe a novel dietary assessment strategy based on two instruments complemented by information from an external population applied to estimate usual food intake in the large-scale multi-center German National Cohort (GNC). As proof of concept, we applied the assessment strategy to data from a pretest study (2012–2013) to assess the feasibility of the novel assessment strategy.

Subjects/Methods First, the consumption probability for each individual was modeled using three 24 h food lists (24h-FLs) and frequencies from one food frequency questionnaire (FFQ). Second, daily consumed food amounts were estimated from the representative German National Nutrition Survey II (NVS II) taking the characteristics of the participants into account. Usual food intake was estimated using the product of consumption probability and amounts.

Results We estimated usual intake of 41 food groups in 318 men and 377 women. The participation proportion was 100, 84.4, and 68.5% for the first, second, and third 24h-FL, respectively. We observed no associations between the probability of participating and lifestyle factors. The estimated distributions of usual food intakes were plausible and total energy was estimated to be 2707 kcal/day for men and 2103 kcal/day for women. The estimated consumption frequencies did not differ substantially between men and women with only few exceptions. The differences in energy intake between men and women were mostly due to differences in estimated daily amounts.

Conclusions The combination of repeated 24h-FLs, a FFQ, and consumption-day amounts from a reference population represents a user-friendly dietary assessment approach having generated plausible, but not yet validated, food intake values in the pretest study.

Introduction

The desire to facilitate dietary measurements in large-scale epidemiologic studies is probably as old as the estimation of diet itself in such studies [1]. Dietary data from large-scale epidemiologic studies are used for investigations of the diet-disease relations that often form the basis for dietary recommendations. Thus, dietary assessment in such studies needs to provide estimates of an individual's usual food intake with a minimum burden to the participant and should also reflect the intake of the study population [2].

Evidence suggests that self-reported dietary assessment instruments have imperfect validity in estimating an individual's diet [3–5] and could therefore, generate underestimated and/or biased diet-disease relations [6–8]. Specifically, validation studies using recovery biomarkers indicate that self-reported intakes of macro- and micronutrients such as total energy, protein, potassium, and sodium are under-reported and misspecified [7, 9]. Bias appears to be less severe when intake estimates are derived from short-term dietary assessment instruments such as 24 h dietary recalls (24h-DRs) [4–7, 9–11]. Recent statistical

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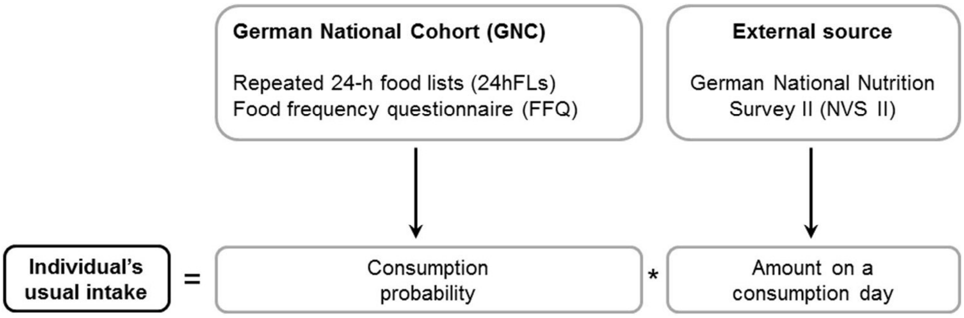

Fig. 1 Dietary assessment strategy of the novel blended approach applied in the German National Cohort (GNC)

developments suggest that the combination of short-term and long-term dietary assessment techniques—such as repeated 24h-DRs and food frequency questionnaires (FFQs)—yield less biased estimates of usual food intake than stand-alone instruments [12–16]. Hence, we combined the information from repeated applications of a recently developed short-term 24 h food list (24h-FL) [17] designed to represent a simplified web-based dietary questionnaire, one FFQ, and information from an external source as reference population to estimate usual food intake.

The aim of the current study was to present the methodological concept of usual food intake estimation based on the abovementioned combination of information and to apply this concept to food intake data collected in a pretest study for the large-scale multicenter German National Cohort (GNC) [18, 19].

Methods

Study population

The main phase of the GNC began in 2014 and it comprises a random sample of the general population drawn from population registries in 18 study centers [18, 19]. In accordance with the guidelines and recommendations of the German Society for Epidemiology to assure Good Epidemiologic Practice [20], pretest studies were conducted between 2011 and 2013 to select appropriate methods and instruments, to develop standard operating procedures, and to test the exposure assessment program according to its feasibility, acceptability, and expected duration.

The pretest study II consisted of a basic program that was mandatory for all study centers. It also included an optional dietary assessment module, which was performed by 16 of 18 study centers. The ethics committees of each local study centers approved the study protocol of the pretest study including the optional modules and written informed consent was obtained from all study participants [18].

In the pretest study II, participants were asked to complete three 24h-FLs on non-consecutive days over a period of 1.5 months after their visit to the study center, and one FFQ. Participants could complete the first 24h-FL at their visit to the study center and had to complete the FFQ within 2 weeks thereafter. Participants who were willing to fill in the questionnaires via the internet received an individual access code for a web-based internet-portal during the course of the study and were asked by e-mail to fill in the 24h-FL on a specific day. These days were selected at random by a computer program. Participants without internet access received the questionnaires as paper version, and completion of the 24h-FL on a specific day was organized via phone calls. Completed paper versions of the 24h-FLs were returned by mail with pre-paid envelopes.

Data collection took place from August 2012 to April 2013. Since the repeated dietary assessment would have exceeded the pretest study period, study centers terminated all reminder activities by the end of April 2013, even though not all participants had completed three 24h-FLs by that time. Of 1010 study participants who took part in the dietary assessment, 999 provided at least one completed 24h-FL or one FFQ. After exclusion of 2 participants with no 24h-FL, 301 participants with no FFQ, and 1 participant with missing anthropometric data, a data set including at least one 24h-FL and one FFQ was available for 695 study participants (318 men and 377 women), forming the basis for the present analysis.

Dietary assessment approach

Figure 1 shows the blended dietary assessment strategy in the GNC. Usual food intake is assessed by estimating two components, which are subsequently, multiplied. The first component consists of the estimated individual consumption probability from repeatedly filled in 24h-FL and one FFQ—estimated by a mixed effects logistic regression model in which the frequency information from the FFQ is used as covariate. The second component consists of the specific consumption-day amount provided from a reference population—estimated by a mixed effects linear regression model.

The idea of subdividing the assessment process into such components was outlined by Tooze et al. [16]. Further, the EPIC-Potsdam study showed that self-reported potion sizes from FFQ adds little information to the variance of food intake [21] implying that consumption frequencies has a stronger influence on the variation in food and nutrient intake between persons than portion sizes. Hence, the novel aspect of the current dietary assessment strategy is the probability component derived from the 24h-FL.

The individual food intake probability is multiplied by the person-specific daily consumption amount to obtain an estimated usual (habitual) intake value for each food item. The consumption-day amounts of food intake were derived from a reference population. For nutrient calculations, the food items were linked to the German Nutrient Database (Bundeslebensmittelschlüssel, BLS Version 3.02), the national food composition database.

Dietary assessment instruments

The 24h-FL was designed for simple and quick application with low burden for study participants and is available as a web application and a print version with the option of optical scanning. The 24h-FL generates binary information (consumption versus no consumption) for pre-specified foods consumed during the previous day. The feasibility of this food list was evaluated in GNC pretest study I (August 2011 to February 2012). In that study, the instrument was found to be acceptable to participants and appeared feasible for application in large multicenter cohort studies, with an average completion time of 8–10 min [17].

The 24h-FL was designed to explain at least 75% of variation in nutrient intake of each of the 27 selected nutrients and four major food groups (fruits, vegetables, meat and meat products, and milk and dairy products) based on 24h-DR data from the representative German National Nutrition Survey II (NVS II) [17, 22]. In the pretest study, two food items were identified as missing by study participants and were subsequently, added to the 24h-FL. After further discussion with leading nutritionists, 10 additional food items were incorporated in the 24h-FL. Thus, the final version of the 24h-FL comprises 258 food items.

In addition, an FFQ was developed as a web application and as a print version with the option of optical scanning. The FFQ is based on the German version of the multilingual European Food Propensity Questionnaire [13] and it was aligned with the food item list of the 24h-FL. The FFQ inquired about the intake frequencies of 133 foods and beverages during the previous 12 months. Portion sizes for food items are graphically displayed with pictograms [13]. The frequency scales have a closed-ended format of discrete categories that range from "never", "1 time per month" to "11 times per day or more frequent", depending on the food item. Food item frequencies from the FFQ were converted to mean frequencies per day; for example, 1 time/week was converted to one-seventh times per day.

The specific consumption-day amounts of food intake were derived from the representative NVS II. Amongst others, dietary intake in the NVS II was assessed from 2005 to 2007 by telephone interviews on two non-consecutive days using the 24h-DR method EPIC-Soft [22, 23] (renamed GloboDiet in 2014). Dietary data of 12,502 NVS II study participants aged 20–80 years were used. A list of concordance was established that link each food consumed at the NVS II with the list of food items of the 24h-FL.

Formation of food groups and nutrient/energy intake

In the pretest data set, the number of applied 24h-FLs and FFQs was low compared to the expected numbers, which will be provided within the GNC due to the lower number of participants. In the present data set, statistical modeling of individual usual food intakes on the single food item level was often not possible due to high proportion of nonconsumers in the 24h-FL. Thus, 39 food groups comprising food items with a similar composition or nutrient content (e.g., bread or milk and dairy products) were formed for the current analysis [24]. Two further food groups were also formed that reflected either vegetarian (e.g., vegetarian casserole) or non-vegetarian (e.g., lasagne) mixed dishes (for listing of food groups please see Tables 3 and 4). Information on single food item consumption provided by the 24h-FL was summarized by defining an occurrence variable for each food group with a value of 1, if at least one single 24h-FL food item was covered by the corresponding food group and a value of zero if the corresponding 24h-FL food item was not consumed on that day. FFQ information was also summed up into reported frequencies at the food group level using the same approach as was done with the data from the 24h-FL. Likewise, the daily consumption amounts were summarized taking the 24h-FL food item specific daily amounts, if eaten.

For each food item of the 24h-FL, nutrient values were also calculated, weighted by the amounts of the detailed corresponding food items eaten in the NVS II. The nutrient values for each food item of the 24h-FL were multiplied by the estimated usual food intakes of that food item, calculated for each individual. Energy intake (EI) was calculated for all food groups. Total individual EI was calculated by summing the EI of the food groups. An additional food group was also formed that comprised foods not covered by the 24h-FL but reported in NVS II. The energy amount of this food group was added to the total energy as a constant.

Missing data

The FFQs were considered complete if information was provided for at least 80% of core food items. Fats used for food preparation (e.g., butter and plant oils) or additives to hot beverages (e.g., cream, sugar, and sweeteners) were not considered as core food items. Missing data on the FFQ were found for only 44 food items, with a maximum of 12 missing values in one FFQ item. Most food items had only one missing value. To retain all observations in the analyses, missing values on the FFQ were single imputed by applying linear regression models to food item frequencies taking sex, age, body mass index (BMI), and study site into account.

When a participant was unable to report which kind of fat was typically used for food preparation, information on discretionary fats was single imputed by modeling individual consumption probabilities (pi) for all fats applying a mixed effects logistic regression, adjusted for sex, age, BMI, and study site. For each imputation, a random number u_j from a uniform distribution (0, 1) was drawn. If u_j was ≤pi we assumed that this fat item was consumed on the specific assessment day.

Statistical analysis

Descriptive statistics of the study population are shown as frequencies and proportions, or means with standard deviations (SD). Study participants completed up to three 24h-FLs. Hence, nine different reporting scenarios existed for each food group. Study participants with one 24h-FL could report 0 or 1 consumption days for each food group on the available 24h-FL. Study participants with two 24h-FLs could report 0, 1, or 2 consumption days for each food group on the two available 24h-FLs. Study participants with three 24h-FLs could report 0, 1, 2, or 3 consumption days for each food group on the three available 24h-FLs. For simplification, Table 3 summarizes these nine possible reporting patterns in the simplified categories of 0, 1, 2, or 3 times of reported food intake.

The mixed effects logistic regression model with random intercept was applied to estimate individual probabilities of food consumption and used the occurrence variable collected by 24h-FLs as outcome variable and the following regression variables: age, sex, BMI, habitual frequency of food intake taken from the FFQ, and study center. Age and BMI were coded as continuous variables, sex as binary variable, habitual frequency as ranked variable from 0 to several times a day, and study center as indicator variable. Individual consumption probability was calculated for all food groups including the different methods of preparation and fat content (e.g., raw vs. cooked). The mixed effects linear regression model with random intercept was applied to estimate individual daily amounts of food consumption and used the daily amounts collected in the NVS II as outcome variable and age, sex, and BMI as regression variables using the same coding as in the mixed effects logistic regression model [25]. In the food group "Miscellaneous", consumption-day amounts of negative values were estimated for nine participants. Those were replaced by half of the lowest standard consumption-day amount with positive value estimated in that food group.

Especially, BMI is used to estimate resting energy expenditure (REE). Correspondingly, we included BMI as predictor for EI. Furthermore, we found in a previous work that the intake of some food groups benefit of using BMI as predictor [25].

Usual food group intakes, total EI, and estimated energy expenditure distributions are shown as percentiles (5th–95th), means, and SDs. Usual food intake was not calculated for the food group "offal" since only 15 participants consumed foods of that particular group on a single consumption day.

Misreporting

EI was compared with estimated total energy expenditure (TEE). Estimated energy expenditure was calculated as the product of REE and physical activity level (PAL), which was assumed to be 1.6 for all study participants because information on individual PAL was unavailable for this study. The REE was estimated according the prediction equations given by Müller et al. [26] (Table 7) taking weight, age, sex, and BMI into account.

For classifying misreporters the Goldberg method [27] was adopted and the ratio (EI:TEE) of reported EI and estimated TEE and the corresponding SD was calculated. Study participants who fell below the cutoff of mean(EI:TEE) − 1.5 × SD were classified as under-reporters and those who fell above the cutoff of mean(EI:TEE) + 1.5 × SD as over-reporters. All others were classified as acceptable reporters. Mean bias (=(mean(EI) − mean(TEE))/mean(TEE)) was calculated. Spearman partial correlation φ between EI and TEE adjusted for age, BMI, and education was calculated.

All analyses were carried out using SAS, version 9.4, and SAS Enterprise Guide, version 6.1 (SAS Institute, Cary, NC).

Results

In phase II of the GNC pretest studies, the dietary assessment included 996 out of 1010 participants who completed at least one 24h-FL. Participants who did not additionally complete an FFQ also tended to not complete a second or third 24h-FL. Of subjects who did not complete an FFQ, only 15.3% completed a second 24h-FL and 6.0% completed a third 24h-FL. On the other hand, among participants who completed an FFQ, 84.6% completed a second

Table 1 Number of questionnaires and characteristics of participants with and without completed FFQ in phase II of the GNC pretest studies (2012–2013)

	With FFQ	No FFQ
Number of participants, *n*	695	301
Number of 24h-FL completed, *n* (%)	1760	365
Repeat 1	695 (100.0)	301 (100.0)
Repeat 2	589 (84.6)	46 (15.3)
Repeat 3	476 (68.5)	18 (6.0)
Women, *n* (%)	377 (54.2)	161 (53.5)
Age (years), mean (SD)	51.5 (11.8)	50.8 (12.4)
Body mass index (kg/m^2), mean (SD)	26.3 (4.6)	26.4 (4.3)
School level[a], *n* (%)		
Higher education entrance qualification	290 (47.7)	130 (44.2)
Secondary school qualification	310 (51.0)	160 (54.4)
None	8 (1.3)	4 (1.4)

A total of 1010 participants took part in the dietary assessment

FFQ food frequency questionnaire, *GNC* German National Cohort, *24h-FL* 24 h food list, *SD* standrad deviation

[a]Ninety-four values are missing

24h-FL and 68.6% completed a third 24h-FL. However, completion status of an FFQ did not vary according to sex, age, BMI, or school level (Table 1). In this context, we like to remind readers that a common and frequently practised system of reminding participants to fill in the questionnaires did not exist in the pretest study. The mean time period between completion of the first and second 24h-FL was 26.3 days (median = 21 days, P5 = 15 days, P95 = 56 days). A similar time span was noted between the second and third 24h-FL (mean = 25.8 days, median = 20.5 days, P5 = 15 days, P95 = 51 days). Because estimation of usual food intake in the current study was based on the combination of 24h-FL data and FFQ, all further analyses were restricted to the 695 (69.8%) study participants who completed at least one 24h-FL and one FFQ. The mean age of those participants was 52 years (minimum = 20 years and maximum = 71 years), 54.2% were female, and the mean BMI was 26.3 kg/m^2 (Table 1).

The study population of this pretest study well reflected educated adult population in Germany with respect to basic socioeconomic variables including BMI. Table 2 shows that participants with different numbers of repeated 24h-FLs did not differ substantially regarding sex, age, BMI, or school level.

Table 3 shows the observed frequencies of intake per food group for men and women. In the first four columns, the distribution of the number of days with consumption is shown as percentage across the number of repeated 24h-FL. There are substantial differences between food groups, ranging from foods with a high percentage of being eaten at all three 24h-FLs such as bread, and rarely eaten foods with a high percentage of zero consumption on all days such as offal. A further column shows the proportion of 24h-FL with consumption, taking all days into account. Among solid foods, the most frequently consumed food groups were bread, sugar and confectionary, processed meat, milk and dairy products, and fresh fruits, and among beverages, coffee and non-alcoholic beverages. Spirits were only rarely consumed. Overall, the observed proportions of consumption were similar in men and women, with some exceptions. The largest differences in the proportions between sexes were seen for processed meat (75.0% in men vs. 60.8% in women with 24h-FL of consumption), meat (35.9% in men vs. 26.0% in women), fruiting vegetables (42.8% in men vs. 51.8% in women), and beer (28.1% in men vs. 6.9% in women). We were further interested in whether our observed proportions of 24h-FL with consumption fit with proportions found in the NVS II. When comparing the proportions of 24h-FL with consumption in the current study with the proportions of the 24h-DR in the NVS II, the proportions in the current study appeared to be slightly higher than in the NVS II. Differences of >10% in absolute values were found for certain food groups, including eggs, vegetable fats, fresh fruits, milk and dairy products, nuts, other vegetables, and root vegetables.

The results of the modeling of the individual probabilities multiplied by the consumption-day amounts for each food group are shown in Table 4. Overall, the approach generated mean EIs that amounted to 2707 kcal/day in men and to 2103 kcal/day in women. It seems as the food intake of the study population was estimated well if compared to the estimated energy expenditure as a surrogate for energy needs.

The ratio of EI:TEE was 0.96 (95% confidence interval (CI): 0.95; 0.97), 0.95 (0.94; 0.97), and 0.96 (0,95; 0.98) for all, men, and women, respectively. The mean bias was −4.0% (−5.2; −2.8%), −4.6% (−6.1; −3.1%), and −3.5% (95% CI: −5.3; −1.8%) for all, men, and women, respectively. The Spearman partial correlation was 0.70 (95% CI: 0.66; 0.74), 0.05 (−0.06; 0.16), and 0.10 (0.001; 0.20) for all, men, and women, respectively.

The Goldberg limits to classify misreporters were (0.75, 1.15) for men and (0.70, 1.22) for women as shown in Fig. 2. 24 (7.6%) and 20 (6.3%) of men were classified as under-reporters and over-reporters, respectively. 21 (5.6%) and 16 (4.2%) of women were classified as under-reporters and over-reporters, respectively.

Mean daily usual intakes of beverages were higher in men than in women, including beer, wine, juice, and soft drinks. In contrast, the estimated consumption of tea and non-alcoholic drinks per day was higher for women than men. Usual intakes of coffee, spirits, and other alcoholic drinks did not substantially differ between sexes. Similar to

Table 2 Number of completed 24 h food lists of participants with completed FFQ ($n = 695$) in phase II of the GNC pretest studies (2012–2013)

	Number of completed 24h-FLs		
	1	2	3
N	106	113	476
Sex, *n* (%)			
Men	54 (50.9)	51 (45.1)	213 (44.7)
Women	52 (49.1)	62 (54.9)	263 (55.3)
Age (years), mean (SD)	50.2 (12.3)	49.5 (11.7)	52.3 (11.6)
Body mass index (kg/m^2), mean (SD)	25.9 (4.0)	26.7 (5.0)	26.2 (4.7)
School level[a], *n* (%)			
Higher education and university entrance qualification	51 (49.5)	54 (50.0)	185 (46.6)
Secondary school qualification	51 (49.5)	54 (50.0)	205 (51.6)
None of the two above	1 (1.0)	0 (0)	7 (1.8)

FFQ food frequency questionnaire, *GNC* German National Cohort, *24h-FL* 24 h food list, *SD* standrad deviation

[a]Eighty-seven values are missing

beverage consumption, usual intakes of solid food items were generally higher in men than women. The most profound differences were observed for bread, red meat, processed meat, milk and dairy products, non-vegetarian dishes, pasta and rice, potatoes, and soup. Furthermore, the estimated consumption of fats such as butter was higher for men than for women but it was equal for vegetable oils and other fats. Estimated consumption of cake and cookies and sugar and confectionary was slightly higher in men than women. On the other hand, women tended to consume slightly more fresh fruits, fruiting vegetables, root vegetables, and other fruits than men. Differences in estimated usual food intakes between men and women were mostly due to differences in estimated person-specific daily consumption amounts (Supplemental Table 1).

The percentiles show a wide range of usual individual intakes across food groups, suggesting that the method was able to differentiate between individuals regarding their intakes.

Discussion

This article describes the concept and statistical background of a blended assessment strategy to estimate usual food intake of individuals in population-based studies that had been piloted for large-scale application in the pretest study phase of the GNC. The results of the pilot study indicate that the estimated dietary intake reflects plausible food intake. Further, individual usual intakes across food groups showed wide variation, suggesting that the assessment strategy was able to differentiate between individuals regarding their food intakes. The novelty of the assessment strategy is based on the statistical approach of separating the probability of intake from daily consumption amounts. Since the participant had to provide easy to obtain information only for estimating the individual probability, participant burden was reduced compared to traditional methods aimed at similar precision in quantifying dietary data.

The blended dietary assessment strategy was motivated by the need for rapid completion time and low participant burden in the GNC and it built on the previous development of a 24h-FL dietary assessment instrument for assessing an individuals' consumption probability. The average time needed to complete the 24h-FL was 9 min, with high acceptability by participants [17]. Although the instrument is easy to complete, the participation proportion dropped with subsequent applications and it reached a participation proportion of 68.5% when the 24h-FL was applied a third time. This drop was also caused by the termination of all reminder activities before the end of the pilot study phase. Furthermore, around 30% of FFQs were not completed. The non-completion of the questionnaires could not be explained by socioeconomic variables. Recently, a reminder system was developed to maintain a high participation proportion for both instruments, the 24h-FLs and the FFQ.

Recent statistical developments suggest that the combination of short-term and long-term dietary assessment techniques to estimate usual food intake reduces biases compared to stand-alone instruments [12, 13, 15]. Thus, further thoughts are needed to define the minimum set of information needed to calculate usual intakes. Currently, we calculated intakes if one 24h-FL and one FFQ were available. The statistical procedure cannot deal with the situation, if only a FFQ is available since the information of the FFQ is considered covariate information. In addition, the FFQ information is not directly comparable with information from a 24h-FL and the use of only one FFQ would generate different types of information with different bias

Table 3 Observed relative consumption frequencies in phase II of the GNC pretest studies (2012–2013) and in NVS II (2005–2007)

	Men, $n = 318$						Women, $n = 377$					
	Percentage of 24h-FLs with consumption (%)[a]Number of 24h-FL = 1 (maximum percentage)				Total proportion of 24h-FL = 1	Total proportion of 24h-DR > 0	Percentage of 24h-FLs with consumption (%)[a]Number of 24h-FL = 1 (maximum percentage)				Total proportion of 24h-FL = 1	Total proportion of 24h-DR > 0
Food group	0(100)	1(100)	2(83)	3(67)	GNC	NVS II	0(100)	1(100)	2(86)	3(70)	GNC	NVS II
Bread	2.8	18.2	19.5	59.4	94.2	94.3	2.7	15.1	21.2	61.0	94.0	93.9
Butter	33.0	24.5	17.0	25.5	54.0	46.8	28.4	25.2	21.8	24.7	55.8	45.1
Cabbage	57.6	31.5	8.8	2.2	22.3	12.6	54.1	35.3	8.5	2.1	22.9	12.9
Cake and cookies	32.7	28.0	21.7	17.6	49.7	39.9	21.8	35.0	27.6	15.7	53.6	44.9
Cheese	19.5	28.9	23.6	28.0	64.0	56.1	17.8	26.5	29.2	26.5	64.3	59.0
Eggs	50.9	32.7	12.9	3.5	27.6	13.7	48.5	37.4	10.1	4.0	27.2	14.3
Other fats	90.3	9.8	0.0	0.0	3.9	1.1	91.3	7.4	1.1	0.3	4.0	0.9
Vegetable fats	16.4	33.3	30.2	20.1	61.6	28.5	18.3	30.8	27.3	23.6	61.0	27.8
Fish	62.0	28.6	7.2	2.2	19.9	15.3	64.5	25.2	9.3	1.1	18.3	14.4
Fresh fruits	16.7	25.8	21.4	36.2	71.0	50.6	10.3	22.0	26.5	41.1	77.6	64.9
Other fruits	83.7	11.3	3.5	1.6	9.2	6.8	72.2	17.0	7.2	3.7	16.6	9.1
Legumes	89.0	9.8	1.3	0.0	4.9	5.6	86.5	10.3	3.2	0.0	6.5	6.0
Margarine	60.1	13.2	12.9	13.8	32.2	38.7	64.5	14.1	9.0	12.5	27.2	36.6
Meat	37.4	39.9	18.2	4.4	35.9	33.9	51.2	33.7	12.7	2.4	26.0	27.8
Processed meat	10.1	29.6	23.3	37.1	75.0	74.3	19.1	30.0	27.1	23.9	60.8	58.5
Milk and dairy products	15.7	26.4	28.6	29.3	68.6	46.2	9.3	25.7	28.1	36.9	75.2	55.2
Miscellaneous	67.0	19.5	7.6	6.0	21.0	19.6	67.1	16.2	10.6	6.1	21.8	21.0
Non-vegetarian dishes	70.8	23.3	5.0	0.9	14.5	11.3	78.3	17.5	4.0	0.3	10.3	9.3
Vegetarian dishes	88.1	10.4	0.9	0.6	5.7	1.9	84.4	11.4	2.9	1.3	8.3	2.6
Nuts	55.0	24.2	13.8	6.9	29.1	7.0	41.9	31.8	13.5	12.7	38.0	7.6
Offal	98.7	1.3	0.0	0.0	0.5	0.6	97.1	2.9	0.0	0.0	1.1	0.7
Other cereals	62.0	25.8	9.4	2.8	21.3	16.3	54.1	28.7	10.1	7.2	27.5	17.5
Pasta and rice	42.1	34.9	19.2	3.8	33.9	29.1	40.6	35.0	17.5	6.9	35.5	30.3
Potatoes	29.9	39.0	21.7	9.4	44.3	42.3	35.5	36.1	20.2	8.2	39.5	39.6
Poultry	70.8	24.8	4.4	0.0	13.5	11.4	71.1	22.8	5.8	0.3	13.8	11.0
Sauces	43.4	31.8	20.4	4.4	34.3	36.2	34.5	42.2	18.3	5.0	36.7	37.3
Soup	66.0	26.7	6.3	0.9	16.9	15.7	63.4	29.4	6.4	0.8	17.4	15.6
Sugar and confectionary	13.5	23.3	20.1	43.1	77.1	69.0	8.0	24.9	26.3	40.9	78.1	72.3
Fruiting vegetables	33.7	36.8	18.6	11.0	42.8	34.3	26.5	30.0	27.9	15.7	51.8	42.2
Leafy vegetables	58.2	29.9	7.9	4.1	23.1	27.0	51.5	33.2	11.7	3.7	26.4	31.2
Other vegetables	24.5	34.6	27.0	13.8	52.1	28.6	20.4	32.1	29.7	17.8	56.6	30.2
Root vegetables	57.9	28.3	10.7	3.1	23.7	7.4	50.9	30.8	12.2	6.1	28.7	9.7
Beer	56.3	24.8	11.3	7.6	28.1	33.1	88.1	7.7	2.9	1.3	6.9	7.1
Coffee	11.6	18.6	19.8	50.0	83.3	78.3	8.8	15.7	20.4	55.2	86.8	81.3
Juice	46.2	24.5	16.4	12.9	38.4	36.5	51.2	27.1	11.7	10.1	31.5	40.2
Other non-alcoholic drinks	8.5	20.4	23.3	47.8	84.2	82.2	3.7	15.9	21.8	58.6	91.9	92.4

Table 3 (continued)

Food group	Men, $n = 318$						Women, $n = 377$					
	Percentage of 24h-FLs with consumption (%)[a]Number of 24h-FL = 1 (maximum percentage)				Total proportion of 24h-FL = 1	Total proportion of 24h-DR > 0	Percentage of 24h-FLs with consumption (%)[a]Number of 24h-FL = 1 (maximum percentage)				Total proportion of 24h-FL = 1	Total proportion of 24h-DR > 0
	0(100)	1(100)	2(83)	3(67)	GNC	NVS II	0(100)	1(100)	2(86)	3(70)	GNC	NVS II
Other alcoholic drinks	81.1	16.0	2.2	0.6	8.9	9.5	74.8	17.2	6.4	1.6	13.6	10.6
Soft drinks	54.4	27.0	10.1	8.5	29.1	22.5	54.4	27.3	12.7	5.6	27.2	13.6
Spirits	89.0	8.2	2.8	0.0	5.5	2.6	93.1	6.1	0.8	0.0	3.0	1.2
Tea	74.5	13.5	5.0	6.9	17.7	20.0	63.7	16.2	10.1	10.1	26.0	20.5
Wine	70.1	17.9	7.6	4.4	18.5	14.4	67.1	21.0	9.3	2.7	18.6	14.8

24h-FL 24 h food list, 24h-DR 24 h dietary recall, *GNC* German National Cohort, *NVS II* German National Nutrition Survey II

[a]The nine possible reporting patterns (see section Statistical analysis) are summarized in the simplified categories of 0, 1, 2, or 3 times of reported food group intake

within a study. Previous methodologic studies were able to show that FFQ information improves the estimation from 24 h information, resulting in greater precision of the estimated individuals' usual food intakes and of the parameter estimation in a diet-health outcome model compared to 24 h information only [12, 15]. FFQ information can also help distinguish between usual consumers, never consumers, irregular consumers, and ever consumers. The number of repetitions of the 24h-FL affects the precision of the estimate of the consumption probability of an individual but not the population mean.

One challenge of our approach is the need for an adequate reference population for estimating person-specific consumption-day amounts. The reference population can be derived from an external source or by conducting a substudy within the main study. In our study, information on person-specific consumption-day amounts was obtained from 24h-DRs of the NVS II, a representative nutrition survey for Germany [22]. The NVS II was conducted more than 10 years ago, but is the most comprehensive source of nutritional data for the entire Germany. A third German nutrition survey is currently being planned. These future data may be used to update the derived individual usual food intakes to more present food intake in Germany.

The use of an appropriate dietary assessment instrument as reference and as a guide for the development of study specific dietary assessment instruments generates dietary intake estimates in a study that are close to intake values of the source population. Less biased dietary data in terms of absolute estimates ease their use for recommendations and dietary guidelines.

An unbiased estimate of the variance of dietary intake in a study population is only attainable if both the individual probability of consumption and the individual day amounts are estimated. The latter requires an estimate of the daily consumption for each individual, which can be challenging and time consuming in view of the low proportion of the variance that a portion size contributes to the overall variance of food intake between subjects [21]. Thus, we chose a compromise in that expected values of daily amounts obtained by a statistical model were used instead of individual values. This decision also affected our ability to establish the exact distribution of the daily amounts between individuals and generated slightly lower variances due to the use of expected values instead of individual values. However, the loss of variance may have been minimal since we use a mixed linear model that considered covariates (sex, age, and BMI). In future studies, the intake distributions will be compared to those obtained in the NVS II and the loss of variance will be further investigated.

Furthermore, the exact reproduction of the distributions of intake values within the source population may also depend on whether the estimation of intake probability is based on a 24h-FL or a full 24h-DR. However, the observed differences between GNC and NVS II in frequencies of consumption might not originate solely from the type of assessment instrument (24h-FL was repeated up to three times, the NVS II are based on two 24h-DRs) but by differences in time trends of consumption, characteristics of the study population, and local dietary practices.

The novel dietary assessment strategy showed low mean bias but weak Spearman partial correlations for EI compared to TEE. The mean bias is lower than for example in the pooled results from five validation studies [7] where the mean relative bias was −13% for men and −18% for women. The smaller mean bias in our study could be based on the fact that in the current study higher consumption probabilities were estimated and thus the individuals' EI

Table 4 Distribution of estimated individual usual food intakes (g/day), total energy intakes (kcal), and total energy expenditure (kcal) in phase II of the GNC pretest studies (2012–2013)

Food group[a]	Men, $n = 318$					Women, $n = 377$				
	Mean	SD	P5	P50	P95	Mean	SD	P5	P50	P95
Bread	161	17	124	166	170	117	12	93	120	124
Butter	15	10	2	17	28	10	6	1	11	18
Cabbage	23	9	12	22	40	22	10	10	20	40
Cake and cookies	69	31	26	69	125	62	23	26	62	101
Cheese	28	9	11	30	40	25	8	10	26	35
Eggs	24	12	10	21	49	19	9	9	18	36
Other fats	0.5	0.5	0.0	0.3	1.5	0.4	0.4	0.0	0.3	1.1
Vegetable fats	7	2	4	8	10	8	2	4	8	11
Fish	25	16	9	21	60	19	11	7	15	42
Fresh fruits	205	74	57	232	288	221	65	81	248	286
Other fruits	11	21	1	4	56	19	27	1	7	91
Legumes	3	4	0	2	11	4	4	0	2	13
Margarine	8	10	0	1	26	4	5	0	1	15
Meat	58	19	30	54	92	28	12	14	25	50
Processed meat	79	20	40	83	105	39	15	15	41	62
Milk and dairy products	191	66	68	205	280	173	46	86	183	240
Miscellaneous	4	6	0	1	17	6	8	0	2	25
Non-vegetarian dishes	34	27	10	24	99	16	12	5	12	41
Vegetarian dishes	13	23	2	6	57	15	25	2	6	69
Nuts	12	10	3	8	35	13	9	3	10	31
Other cereals	13	13	3	7	43	13	11	2	8	39
Pasta and rice	59	27	23	57	109	50	23	19	46	91
Potatoes	74	26	39	71	121	56	21	27	54	93
Poultry	21	11	10	19	44	16	10	7	14	34
Sauces	20	7	9	19	34	19	7	9	18	32
Soup	67	37	29	57	136	58	29	27	52	110
Sugar and confectionary	53	16	20	57	74	49	13	21	51	66
Fruiting vegetables	50	23	19	46	90	57	21	24	59	89
Leafy vegetables	21	13	4	18	47	22	12	8	19	45
Other vegetables	38	13	13	38	57	39	12	18	40	57
Root vegetables	13	9	5	10	32	18	13	6	14	48
Beer	230	244	29	120	756	24	54	5	9	111
Coffee	558	185	70	637	676	528	147	101	584	615
Juice	204	156	36	154	492	140	125	29	96	387
Other non-alcoholic drinks	1069	276	363	1139	1385	1286	206	898	1315	1517
Other alcoholic drinks	30	43	6	14	108	32	39	7	15	113
Soft drinks	173	175	28	95	571	123	114	26	80	362
Spirits	3	7	0	1	11	1	2	0	1	3
Tea	106	182	2	17	590	147	196	7	31	586
Wine	57	75	10	21	269	42	52	7	19	176
Total energy intake	2707	322	2222	2696	3225	2103	247	1706	2092	2525
Total energy expenditure[b]	2856	249	2521	2814	3297	2210	241	1958	2183	2665

GNC German National Cohort, *SD* standard deviation

[a]Usual food intake was not calculated for the food group offal

[b]Total energy expenditure = REE × PAL; estimation of resting energy expenditure (REE) according to Müller et al. [26] and physical activity level (PAL) assumed to be equal to 1.6 for all study participants. Individual information about PAL was not available for our study

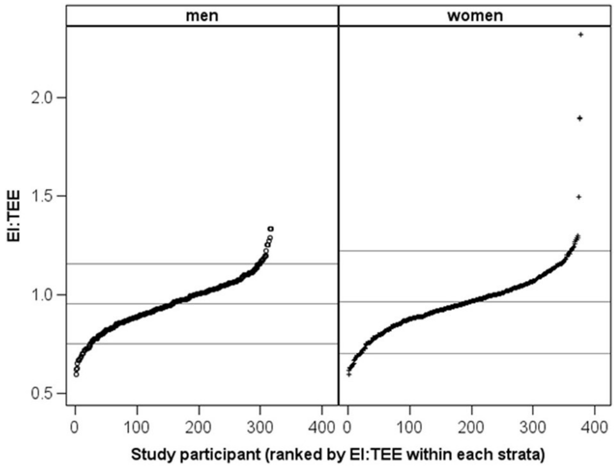

Fig. 2 Ratio of energy intake (EI) to total energy expenditure (TEE) by participants stratified by sex and ranked by ratio within each strata. Gray lines represent mean bias and Goldberg limits of mean ± 1.5 × standard deviation

was estimated to be higher. This could have led to lower mean bias compared to the five validation studies [7]. On the other hand, the Spearman partial correlations were smaller in comparison to five validation studies [7] where the correlation was 0.29 for men and 0.34 for women based on three 24h-DRs. This indicates that further evaluation of the proposed dietary assessment strategy is needed. But the low proportion of under- and over-reporter suggests that overall the estimated individuals' EIs are in the acceptable range and therefore, appears plausible.

Biomarker data were not available for the present study; hence, the predicted energy expenditure was used as a rough proxy to evaluate the relative validity in terms of plausibility. Further studies are required to evaluate the (relative) validity of the proposed dietary assessment strategy using biomarkers.

Even with a large sample size as being expected in the GNC, convergence problems in modeling-based probability calculations can occur. This could arise when the number of study participants reporting non-consumption is high on all 24h-FLs or the number of subjects with at least one consumption day is low. For example, in the current study, we observed that only 15 of 1760 24h-FLs included offal consumption. Thus, in the future even with the availability of the full GNC data we may only be able to calculate the individual probabilities for foods that are eaten frequently or regularly. Such foods usually, form the basis of the diet in a study population. Foods that are less regularly consumed will nevertheless provide valuable information on individual diet because they increase the variation between subjects but they may be less relevant for estimating overall consumption or overall nutrient intake in the population.

Conclusion

We presented a novel concept of dietary assessment in the GNC and showed that the application of repeated 24h-FLs, a FFQ, and data from a reference population represents a promising dietary assessment strategy in large-scale studies. However, there is a need for further investigation with regard to the (relative) validity of the usual intake estimates.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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