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Article

A National Dietary Assessment Reference Database (NDARD) for the Dutch population: rationale behind the design

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Abstract: The development of reliable Food Frequency Questionnaires (FFQs) requires detailed information about the level and variation of dietary food intake of the target population. However, these data are often limited. To facilitate the development of new high quality FFQs and validation of existing FFQs, we developed a comprehensive National Dietary Assessment Reference Database (NDARD) detailing information about the level and variation in dietary food intake of people 20-70 years old in the general Dutch population. This paper describes the methods and characteristics of the population included in the NDARD database. 1063 men and 985 women agreed to participate in this research. Dietary intake data were collected using different FFQs, web-based and telephone-based 24-hour recalls, as well as blood and urine-based biomarkers. The baseline FFQ was completed by 1647 participants whose mean BMI was 26±4 kg/m2; 1117 participants completed telephone-based recalls and 1781 participants completed web-based recalls. According to the baseline FFQ, the mean energy intake was 2051±605 kcal/day. The percentage of total energy intake from protein was 15±2 En%, from carbohydrates was 43±6 En%, and from fat was 36±5 En%. This database will enable researchers to validate existing FFQs and to develop new high quality dietary assessment methods.

Keywords: Dietary assessment; FFQ; recall; nutritional biomarker; validation

1. Introduction

In order to study the impact of diet on disease risk in observational studies, it is crucial to obtain valid information about the habitual dietary food intake of the population under study. Since food frequency questionnaires (FFQs) are relatively easy and inexpensive to process [1], large-scale epidemiological studies generally use FFQs to rank participants according to their nutrient or food intake [1]. However, it is challenging to develop a valid and reliable FFQ.

The first challenge in developing an FFQ is to accurately identify food items that contain the nutrients which are to be studied in the target population. In the Netherlands, we currently use the results of the Dutch National Food Consumption Survey (DNFCS), compiled from a representative sample of the Dutch population [2], to identify relevant food items [3]. One of the drawbacks of using the DNFCS data is that the data are collected by means of duplicate 24-hour recalls [2] and thus provide limited information on the day-to-day variation in dietary food intake. Therefore, the DNFCS data are considered to be insufficient since it does not represent the actual large within-person day-to-day variation of nutrients such as vitamin A, vitamin C, and cholesterol [1].

A second challenge arises when assessing the validity and reproducibility of the FFQ. FFQs are often validated by using other dietary assessment methods, such as 24-hour recalls, as the reference method. One major drawback of this approach is that the results of the validation study may be biased by correlated errors such as memory, use of the same food composition tables, and/or use of standard portion sizes [4]. A biomarker of food intake is considered to be a more independent reference method for the validation of an FFQ since this method has fewer correlated errors. Unfortunately, food biomarkers are only available for a limited number of nutrients/foods. Urinary nitrogen, potassium, sodium, and doubly labelled water are examples of validated recovery markers that are used to estimate absolute intakes [5]. Validated concentration markers, which are markers that are used to rank people according to their intake, include carotenoids and n-3 fatty acids [6,7].

Ideally, FFQs should be validated for each nutrient under investigation. However, since validation studies are cumbersome, costly, and inefficient, many of the nutrients studied in the FFQs used in biomedical research are not validated. In the absence of a validation study, the misclassification of the dietary intake of nutrients may remain unnoticed and result in flawed conclusions with respect to potential diet-disease relationships. Thus, it is clear that the validation of an FFQ is very important and that the simplification of the validation process would greatly benefit studies investigating the effect of diet on disease risk.

We believe that a database that includes data from multiple 24-hour recalls as well as biomarkers would save costs and time when creating new FFQs and examining the validity of newly developed FFQs. In addition, a national dietary reference database would provide the possibility to assess the validity and reproducibility of FFQs largely retrospectively. Therefore, we initiated the National Dietary Assessment Reference Database (NDARD) project in order to develop a national dietary assessment reference database that would provide data on nutrient levels and variations in habitual dietary food intake as assessed by multiple 24-hour recalls and biomarkers. As such, this database can 1) serve as the foundation for the development of new dietary assessment methods, and 2) facilitate the validation of existing and newly developed FFQs. With this manuscript we aim to describe the methods used to collect the NDARD-data and its population characteristics.

2. Materials and Methods

2.1. Design

The NDARD database contains data from 2048 men and women aged 20 to 70 years collected between May 2011 and February 2013, living in and around the city of Wageningen in the Netherlands. Municipality registries from Ede, Wageningen, Renkum, and Arnhem were used to select eligible participants. In addition, all of the households in the city of Veenendaal received an invitation to participate as well. To be eligible, participants had to be able to speak and write Dutch. Those who were interested were asked to register online. Once registered, eligible participants were invited to the study center and randomly assigned to either the 'FFQ-group' (n=959) or the '24-hour recall group' (n=1089). All participants - i.e. participants in the 'FFQ-group' *and* participants in the '24-hour recall group'- completed a general 183-item FFQ. Thereafter, data collection in the 'FFQ-group' focused on the validation of an unconventional FFQ: the Flower FFQ. In the '24-hour recall group', dietary data collection focused primarily on the collection of repeated telephone-based and web-based 24-hour recalls. Along with the assessment of dietary food intake, participants underwent anthropometric measurements and a venipuncture, collected 24-hour urine samples and completed questionnaires related to their health and lifestyle. Measurements were taken again after 12 and 24 months (**Table 1**). All of the participants gave written informed consent before commencing the study. The study was approved by the ethical committee of Wageningen University and conducted according to the declaration of Helsinki.

2.2. Dietary intake assessment

2.2.1. General FFQ

All participants completed a 183-item semi quantitative general FFQ. This FFQ was designed to cover ≥96% of the absolute level of food intake and ≥95% of the between-person variability of each nutrient studied as assessed in the DNFCS from 1998 [8]. Intake levels for energy, macronutrients, dietary fiber, and selected vitamins were validated [9-11]. Participants answered questions pertaining to frequency by selecting answers ranging from 'never' to '6-7 days per week'. Portion sizes were estimated using natural portions and commonly used household measures. Average daily nutrient intakes were calculated by multiplying the consumption frequency by the portion size and nutrient content in grams as indicated in the Dutch food composition table from 2011 [12]. The FFQ was self-administered and completed online (open-source survey tool Limesurvey™, LimeSurvey Project Team / Carsten Schmitz, Hamburg, Germany).

Table 1. Overview of measurements in the NDARD-project.

	Months						
Measurement	**0**	**6**	**12**	**18**	**24**	**30**	**36**
All subjects (n=2048)							
Anthropometric measurements	x		x		x		
Venipuncture	x		x		x		
24-hour urine collection	x		x		x		
Health questionnaires	x		x		x		
Lifestyle questionnaires	x		x		x		
FFQ group (n=959)							
General FFQ	x						
Flower basic FFQ	x	x	x				
Flower special FFQ 1			x	x	x		
Flower special FFQ 2					x	x	x
Flower special FFQ 3					x	x	x
24-hour recall (web based)	x	x	x	x	x	x	
Recall group (n=1089)							
General FFQ	x		x		x		
24-hour phone based recall	x	x	x		x		x
24-hour web based recall	X	x	x		x		x

FFQ: food frequency questionnaire

2.2.2. Flower FFQ

Participants assigned to the FFQ-group also completed a new type of FFQ, the Flower FFQ. The Flower FFQ was developed for the LifeLines cohort study [13] as an alternative to the regular FFQ, which is often a long and time-consuming questionnaire. The name Flower FFQ has been derived from its design. The questionnaire consists of one basic questionnaire about energy and macronutrient intake (the heart of the flower) and three complementary food questionnaires concerning specific (micro)nutrients (comprising the flower petals). The main FFQ contains 110 food items which are used to estimate the intakes of energy, fat, carbohydrates, protein, and alcohol. The first complementary FFQ (Flower special FFQ1) contains 59 food items and is used to estimate the intake levels of different types of fatty acids as well as caffeine. The Flower special FFQ2 consists of 61 food items and is used to estimate the intake levels of vitamin B_2, B_6, B_{11}, B_{12}, calcium, and soy. Lastly, the Flower special FFQ 3 consists of 64 food items and is used to estimate the intake levels of vitamin A, C, E, and dietary fiber. Combined, the four FFQs cover ≥96% of the absolute level of nutrient intake and ≥93% of the between-person variability of each nutrient as assessed in the DNFCS from 1998. Participants answered questions pertaining to frequency by selecting answers

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ranging from 'never' to '6-7 days per week'. Portion sizes were estimated using natural portions and commonly used household measures. Average daily nutrient intakes were calculated by multiplying consumption frequency by portion size and nutrient content per gram as indicated in the Dutch food composition table from 2006 [14]. The Flower FFQ was administered online via the open-source survey tool Limesurvey™.

2.2.3. Telephone-based and web-based 24-hour recalls

Participants in the 'recall-group' were invited to complete nine 24-hour recalls during a one-year period, where the minimum period between the completion of two recalls was at least two weeks. Three of nine 24-hour recalls were telephone-based and six recalls were web-based. The dates for either telephone-based or web-based 24-hour recalls were randomly selected, scheduled regularly throughout the year, and evenly distributed over week and weekend days. The mode of administration, via the telephone or the internet, was also randomly selected. When recall attempts or electronic invitations were denied, the recall was randomly rescheduled within the following 3 to 10 days. Telephone-based 24-hour recalls were performed by dieticians with interviewing skills using a standardized protocol. Recalls were conducted using the five-step multiple pass method, which is a validated technique that increases the accuracy of recalls [15-18]. Portion sizes were assessed using commonly used household measures, weight/volume, and standard portions. The recalls were transcribed into the food codes found in the 2011 Dutch food composition table [12]. Regular meetings were held with all of the dieticians and quality checks ensured the quality of phone-based recalls and data encoding. Web-based recalls were self-administered using the software program Compl-eat (www.compleat.nl). Invitations for the program were sent unannounced via e-mail and were valid for 24 hours. Compl-eat guided participants were asked to accurately report all of the foods and drinks that they consumed the previous day. Compl-eat was developed based on the five-step multiple pass method [15-18]. The program enabled participants to select standard foods and recipes that are commonly used in the Netherlands. If necessary, participants were able to adapt or describe personal recipes or make notes for clarification. Portion sizes were reported in commonly used household measures, standard portions, and weight in grams or volume in liters. Nutrient and energy intakes were again calculated by multiplying intakes by nutrient composition using the Dutch food composition database from 2011 [12]. Furthermore, the intake of dietary supplements or the need to follow a particular diet, prescribed or otherwise, were registered. Location and companionship of principal meals were also recorded. Additional information such as the need to follow a particular diet or the occurrence of special occasions such as birthdays or holidays were taken into consideration while checking the recalls. Adjustments were made using standard portion sizes and recipes following a protocol.

2.3. Anthropometric measurements

Anthropometric examinations were conducted by well-trained staff according to a standardized protocol at one of the three study centers. Height was measured, without shoes, with a stadiometer (SECA, Germany) to the nearest 0.1 cm. Weight was measured, without shoes or sweaters and with empty pockets, on a digital scale (SECA, Germany) to the nearest 0.1 kg. Waist and hip circumferences were measured twice to the nearest 0.5 cm using a measuring tape (SECA 201, Germany) and subsequently averaged. During the anthropometric examination session, information about medication and nutritional supplement use was collected. The type of medication was classified according to the Anatomical Therapeutic Chemical classification system.

2.4. Blood collection

After a 10-h overnight fast participants underwent a venipuncture at the Gelderse Vallei hospital in Ede or at the Rijnstate hospital in Velp. Biochemical analyses were performed in the hospital laboratories using either a Dimension Vista 1500 automated analyzer (Siemens, Erlangen, Germany) or a Roche Modular P800 chemistry analyzer (Indianapolis, USA). Both laboratories have joined the external quality control program in the Netherlands (SKML) and used the same methodology and standardized protocols for risk factor assessments. Blood samples were used to determine carotenoid and n-3 fatty acid concentrations which can be used as a reference for ranking based on fruit and vegetable intake [6] and fish intake [7]. The remaining plasma and serum samples have been stored at -80°C until further analysis is needed.

2.5. Urine collection

The participants were asked to collect urine during one 24-hour period each year. Prior to the day of the planned 24-hour urine collection, participants received verbal and written instructions, three 80 mg para-aminobenzoic acid (PABA) tablets (PABAcheck, Elsie Widdowson Laboratory, Cambridge, UK), and two three-liter containers containing the preservative lithium dihydrogenphosphate (25 g). Urine collection started following the first voiding after waking up and finished after the first voiding after waking up 24-hours later. The participants were instructed to record the beginning and the end times of the urine collection, the time at which the PABA tablets were ingested, their medication and nutritional supplement use, and any possible deviations from the protocol (e.g. missing urine). Urine containers were delivered to the Gelderse Vallei hospital in Ede or the Rijnstate hospital in Velp and were stored at 4°C for a maximum of three days until they could be transported to the study center. At the study center, the urine collections were mixed, weighted, aliquoted, and stored at -20°C until further analyses. PABA was used to check the completeness of the urinary collections and was measured using the HPLC method [19]. PABA is assumed to be excreted almost quantitatively within 24-hours. Therefore, a recovery of at least 78% (189.6 mg) of the ingested PABA was considered to be a complete urine collection. The total coefficient of variation (CV) for the PABA analysis was 9%. The within-run CV for PABA was 1.9% and the between-run CV for PABA was 1.3%. Urinary sodium and potassium concentrations were measured with an ion-selective electrode on a Roche 917 analyzer (Indianapolis, USA). Urinary creatinine concentrations were measured at 520 nm on the Synchron LX20 by the modified Jaffé procedure using a commercial kit. Total 24-hour sodium and potassium excretions were calculated by multiplying the total weight of the collected urine by the sodium or potassium concentration. Additionally, this was divided by 0.86 for sodium [20] and by 0.81 for potassium [21], assuming that this percentage of intake is excreted in the urine. The total 24-hour nitrogen excretion was determined by the Foss KjeltecTM 2300 analyzer [22] and the urinary nitrogen level was subsequently calculated by using the following formula: 6.25 * (urinary nitrogen / 0.81) [23] which takes into account nitrogen loss via feces and skin (approximately 19%). Three 24-hour 4.5 mL urine samples have been stored at -20°C in the NDARD biobank for future analyses.

2.6. Health and lifestyle questionnaires

The participants completed the health and lifestyle questionnaires online using Limesurvey™. The questionnaires included questions about demographics (e.g. birth country, marital status, household composition, and education), work history and current work situation, health and history of diseases, and current and previous smoking habits (e.g. amount smoked, age at the beginning and the end of smoking periods and the type of tobacco smoked as well as passive smoking). These general questions were predominantly derived from questionnaires from the LifeLines study [13]. Information about the participants' usual physical activity over the previous four weeks was assessed using the Short QUestionnaire to ASsess Health-enhancing physical activity (SQUASH) and the Activity Questionnaire for Adults and Adolescents (AQuAA). The SQUASH contains separate questions about commuting activities, leisure time activities, household activities, and activities at work and school covering three main queries: days per week, average time per day, and intensity. The total minutes of activity were calculated for each question by multiplying frequency by duration. The activity scores for separate questions were calculated by multiplying total minutes of activity by the intensity score. The total activity score was calculated by taking the sum of the activity scores for separate questions [24]. The AQuAA is based on the SQUASH questionnaire with the following adaptations: questions on light, moderate, and vigorous intensity activities as well as sedentary behaviors; questions about age-specific examples of activities; questions relating to activities performed in the previous seven days instead of an average week. The main outcomes are total physical activity score and the time spent on sedentary, light, moderate and vigorous intensity activities in minutes per week [25]. All questionnaires were repeated after 12 and 24 months.

3. Results

In **Table 2,** several selected general characteristics of the NDARD population are shown. Men and women were fairly equally represented, 52% vs. 48%. On average, participants were 51±12 years of age, 63% were classified as having a high educational level and 9% claimed to be current smokers. The mean BMI was 26±4 kg/m^2, where the BMI for men was slightly higher than that for women. General FFQ data were available from 1647 participants. In the FFQ group, 64 participants completed telephone based 24-hour recalls (1-2 recalls) and 832 participants completed web-based 24-hour recalls (anywhere from 1-15 recalls). In the recall group, 1053 participants completed telephone based 24-hour recalls (1-9 recalls) and 949 participants completed web-based 24-hour recalls (1-10 recalls). **Table 3** displays the habitual dietary intake of the NDARD-population. The average food energy intake can be broken down into total protein intake 15±2 %, total carbohydrate intake 43±6 %, total fat intake was 36±5 %, and total dietary fiber intake 24±7 grams per day. There were no large differences observed with regards to macronutrient intakes between men and women. However, we did observe that men consumed more alcohol, 15±15 grams, than women, 7±9 grams. Nine percent of the participants claimed that they followed a special diet (7% of the men and 12% of the women), and 41% reported nutritional supplement use (34% men, 49% women).

Table 2. Participant characteristics of the NDARD-project.

	n	All		Men		Women		FFQ-group		Recall-group	
		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Men, %	2048	52		100		0		50		53	
Age, years	2045	51	12	54	12	49	13	51	13	52	12
Education level, %	2038										
Low		7		9		6		7		7	
Intermediate		30		28		32		31		30	
High		63		63		62		62		63	
Area, %	2048										
Ede/Wageningen/Renkum		45		32		60		52		40	
Arnhem		11		7		15		11		11	
Veenendaal		44		61		25		37		49	
Smoking status, %	1541										
Current		9		10		8		9		10	
Former		40		45		34		40		39	
Never		51		45		58		51		51	
BMI, kg/m^2	2047	26	4	27	4	26	5	26	4	26	4
Waist circumference, cm	2044	92	13	97	11	86	12	92	13	92	13

Disease history, %						
Myocardial infarction	1945	2	3	1	2	2
Stroke	1946	1	1	1	1	1
Diabetes mellitus	1955	4	5	2	4	4
Cancer	1949	5	5	6	5	5

Table 3. Dietary food intake of the NDARD-participants as assessed with a general FFQ.

Dietary factor	All		Men		Women		FFQ-group		Recall-group	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
n	1647		857		790		666		981	
Total energy, kcal	2051	605	2244	631	1842	499	2033	623	2064	593
Total protein, energy%	15	2	15	2	15	2	15	2	15	2
Total carbohydrates, energy%	43	6	43	6	43	6	43	6	43	6
Mono- and disaccharides, energy%	19	5	18	5	20	5	19	5	19	5
Polysaccharides,% of energy	24	5	25	4	24	5	24	5	24	5
Total fat, energy%	36	5	36	5	36	6	36	5	36	6
Saturated fatty acids, energy%	12	3	12	3	12	3	12	3	12	3
Monounsaturated fatty acids, energy%	13	2	13	2	13	3	13	2	13	2
Polyunsaturated fatty acids, energy%	8	2	8	2	8	2	8	2	8	2
Trans fatty acids, energy%	0.6	0.2	0.6	0.2	0.5	0.2	0.5	0.2	0.6	0.2
Alcohol, gram	11	13	15	15	7	9	12	14	11	12
Dietary fiber, gram	24	7	25	8	23	7	24	8	24	7
Following diet regimen during the past month, %	9		7		12		10		9	
Nutritional supplement use, %	41		34		49		38		43	

4. Discussion

The NDARD project is a 4-year longitudinal study that has collected an extensive body of data on habitual dietary intake among 2048 Dutch adults living in and around the city of Wageningen in the Netherlands. These data are meant to serve as the basis for the development of a gold-standard national dietary reference database that can be used for the development of novel FFQs and the validation of existing and newly developed FFQs.

A major asset of the NDARD-database is that it contains data obtained by FFQs, multiple 24-hour recalls, and biochemical markers, all covering a similar time window. This allows validation of the FFQs against multiple recalls, recovery markers, and concentration markers [26]. The first validation studies using the NDARD-database have been published [27-29] and ongoing work addresses the validation of the Flower FFQ. In addition, a national FFQ for the Netherlands, the FFQ-NL1.0, has been validated in a subsample of 450 participants examining multiple 24-hour recalls, urinary nitrogen and potassium, and plasma concentrations of fatty acids and carotenoids [30]. These examples illustrate that the NDARD is already a well-functioning reference database to conduct validation studies. Apart from concurrent validation, we can use NDARD for 'backward' validation of existing FFQs and 'forward' validation of FFQ-like instruments that are under construction for (sets of) prioritized nutrients and/or food habits. Dutch FFQs are generally developed from 24-hr recalls with food codes detailed to the level of the Dutch food composition table (NEVO-table). To arrive at FFQ-items, these food codes are grouped together and their nutrient composition is obtained as a weighted average of the intake of the underlying items based on 24-hour recalls [31] available from, e.g. national food consumption surveys [2]. Subsequently, the nutrient intake according to the FFQ is simulated based on various options for grouping into FFQ-items and compared to the original 24hR intake (for foods) and biomarker data (for nutrients) in the NDARD. Thus, depending on their objectives, FFQs differ in their grouping of food codes into FFQ-items; lumping together highly different composed foods into FFQ-items will increase the systematic and random between-person errors in estimated nutrient intake, known to be relatively large in FFQs. As errors in memory and response may also be related to lumping foods together into items, such simulations could help to identify which potential FFQs would not perform well due to unfavorably composed items. If this approach appears rather robust, unnecessary costs due to data collection, biochemical analyses, and reference methods (24-hour recalls, dairies) can be avoided or reduced in future studies.

In this paper, we focus on the methods of the 'basic' sample of the NDARD project that comprises data collected from 2048 Dutch adults, aged 20-70 years, living in the central part of the Netherlands. The nutritional data described in the results section of this paper includes data that were collected using a general FFQ and completed by both the recall-group as well as the FFQ-group. When compared to the dietary data collected in the DNFCS from 2007-2010 [2], the dietary food intake in the NDARD population closely resembled the dietary food intake reported in earlier studies. For instance, according to FFQ data, the breakdown of the total energy intake for women in the NDARD population was 15±2 % of energy from protein, 43±6% of energy from carbohydrates, and 36±6 % of energy from fat. Correspondingly, in the DNFCS study from 2007-2010, the food intakes of these macronutrients for women aged 19-69 years were around 16 % from protein, 45 % from carbohydrates, and 34 % from fat. The data on alcohol intake was similar when comparing the data collected in the NDARD database as compared to the DNFCS database. Fiber intake was somewhat higher in the NDARD population (24 gram) than in the DNFCS (20 gram). As in the NDARD population, no major differences were observed in macronutrient intake between men and women in the DNFCS. Alcohol intake seemed to be only exception to this. Since the DNFCS aims to recruit a study population that is representative of the Dutch population, the similarities between data from the NDARD database and DNFCS database proves that we were able to recruit a representative sample of the Dutch population. We have found that the participants in the NDARD project are relatively high educated. Nevertheless, in order to generate an even more comprehensive database we plan on including partner studies.

In conclusion, in the absence of a gold standard reference database, the evaluation and validation of FFQs is currently very time-consuming and expensive. Therefore, the development of the NDARD database is considered to be a great benefit to current and future FFQs making their validation more accurate and cost and time effective. To the best of our knowledge, the NDARD database is the first of its kind.

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