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ABBREVIATIONS

AMPM	Automated Multiple-Pass Method
BIC	Bayesian Information Criterion
BMI	Body Mass Index
EPIC	European Prospective Investigation into Cancer and Nutrition
FFQ	Food Frequency Questionnaire
GNC	German National Cohort
IQR	Interquartile Range
MSM	Multiple Source Method
NCI	National Cancer Institute
NVS II	National Nutrition Survey II
O	Objective
SD	Standard Deviation
SE	Standard Error
SPADE	Statistical Program to Assess Dietary Exposure
24-h DR	24-hour Dietary Recall
24-h FL	24-hour Food List

I Introduction

In recent years, numerous large-scale cohort studies have been initiated in Europe aiming to investigate the causes of major chronic diseases such as cardiovascular diseases, cancer, diabetes, and neurodegenerative diseases [1-3].

It has been hypothesized that diet plays an important role in the development of these major chronic diseases. So far, nutritional epidemiological studies have not generated consistent information regarding the role of dietary factors in disease etiology [4]. Thus, the relationship between dietary factors and disease occurrence remains unclear to some extent.

One possible explanation for the inconsistency in previous studies is the methodological challenge regarding the valid estimation of long-term dietary intake. Due to cost and logistic advantages, food frequency questionnaires (FFQs) have long been the instrument of choice because many prospective studies require thousands of study participants. However, FFQs measure dietary intake with both systematic and random error [5], which may affect estimates of diet-disease associations [6-8]. Thus, improvements in assessment techniques are urgently needed [4, 9]. In this context, both new methodologies and new technologies are being considered to improve the assessment of usual dietary intake in large-scale epidemiological studies [10].

Recent methodological developments originate from research on measuring food and nutrient intakes in surveys [11-15]. These methods presume that the usual food intake of a subject equals the probability of a food consumed on a given day times the average amount of intake of that food on a typical consumption day. The detailed 24-hour dietary recall (24-h DR), when applied at least twice to the same individual, provides information on both the probability of consumption and the amount consumed [11, 16, 17] and thus, exemplifies the application of that assumption. An FFQ can add information about the frequency of dietary intake and also on never consumed foods, the so-called true non-consumption. The latter one is measured with error when only a limited number of 24-h DRs are applied. It has been suggested that an approach of combining instruments may provide high quality dietary information, especially for the assessment of foods that are not consumed every day [16, 18-20]. Although multiple administrations of detailed 24-h DRs in combination with an FFQ would be optimal, this is impracticable in large-scale cohort studies due to high costs and time expenditure associated with repeated applications of interviewer-administered 24-h DRs [4].

Detailed web-based 24-h DRs developed for self-administered use in cohort studies [21, 22] are likely to be more cost-effective with respect to administration [10], but might still be time-consuming for the study participant and are furthermore only limitedly available thus far. Interestingly, to further reduce demands on time, the development of FFQ-like, web-based, self-administered instruments has been initiated which recall the diet of the preceding 24-hour period [23, 24]. The available examples are typically closed-ended (i.e., participants choose foods from a finite list of items) and the tools are intended for stand-alone application only.

Taking into account these considerations, given the knowledge that the frequency of consumption contributes more to inter-individual variation in food and nutrient intake than inter-individual variation in portion sizes [25, 26], and statistical methods to estimate usual intake distributions are available [17], a 24-h food list (24-h FL) for repeated application should be developed for the current project. This 24-h FL assesses the probability of consumption, does not inquire about portion size and is intended to be used in a combined approach with an FFQ for the estimation of usual dietary intake in large-scale epidemiological studies in Germany. The overall objective of this investigation was to develop and evaluate a 24-h FL as an innovative approach for dietary assessment.

1 Dietary assessment in large-scale epidemiological studies

Dietary assessment in large-scale epidemiological studies aims to describe the intakes of a population using individual measures of food intake [27]. The common purpose of dietary assessment is to evaluate the dietary intake of a population in relation to some standard, for instance later incidence of disease or dietary requirements [12]. Relative ranking of food and nutrient intakes is sufficient for most research questions. Some study purposes, however, require quantitative estimates of intake [28].

1.1 The concept of usual dietary intake

1.1.1 General considerations

An individual's usual dietary intake is defined as the long-term average daily intake of a food or nutrient for a large number of days [29]. The concept of usual intake is important because diet-health hypotheses are based on dietary intakes over the long term [27]. Thus, the individual usual intake is the conceptually relevant exposure for large-scale epidemiological studies [30]. Ideally, a subject's usual food intake would be assessed by collecting information on food intake on each day of the period under study or at least on a large number of days [14]. In reality, this is rarely achievable [31]. As a compromise, information on food intake is assessed partially and subsequently extrapolated or modelled to estimate an individual's usual food intake [14].

In principle, there are two different ways to assess individual usual food intake: (1) to apply dietary assessment methods such as an FFQ that are designed to assess the long-term average intake directly by the study participant; or (2) to apply repeated short-term measurements such as a 24-h DR and to extrapolate this information to usual food intake [29]. Both approaches have their strengths and limitations with respect to the estimation of usual dietary intake. One potential source of error introduced by an FFQ is the cognitive challenge to recall dietary intake over a long period of time. Second, the finite list of food items and few selections for portion sizes can lead to reporting errors. On the other hand, an advantage of the FFQ is the relatively high reproducibility, so that repeated applications are not necessary [12, 14, 27]. 24-h DR are less cognitively challenging because study participants are asked to recall their food and beverage consumption from the previous day. The open-ended format of a 24-h DR avoids the finite food list problem [12, 27]. However, the variance of reported intake is inflated by day-to-day variation of individual food intake [29, 31]. This intra-individual variance may be regarded as random fluctuation above and below a subject's usual long-term average intake [31]. For the estimation of usual food intake, the intra-individual variance of data has to be eliminated by an appropriate statistical procedure [12, 29].

1.1.2 Trends over time of dietary assessment in large-scale epidemiological studies

The selection of the appropriate dietary assessment method for the estimation of usual food intake in large-scale epidemiological studies depends on the research question. For most epidemiological studies relating dietary intake to disease risk, relative ranking of food and nutrient intakes is adequate for determination of correlations or relative risks [28]. However, to evaluate the dietary intake of a population in relation to specific dietary recommendations, which is, for instance, relevant in cross-sectional nutrition surveys, estimates of the absolute energy and macronutrient intakes may be required [27].

For a long time, cost and logistic issues led to favor FFQs for large-scale prospective cohort studies, whereas 24-h DRs were mainly used in surveys [12, 27]. It had long been acknowledged that both systematic and random measurement errors were a problem when FFQs were used alone [5]. For random but not for systematic error, the average value of many repeated measures approaches the true value. Both error types can occur within a person and between persons [32]. The reason for still supporting the use of an FFQ in large-scale epidemiological studies was the reasonable ranking of study participants with respect to dietary intake [4]. Calibration studies have been implemented aiming to correct the risk estimate for measurement error caused by the FFQ [9, 14]. For instance, the 'European Prospective Investigation into Cancer and Nutrition' (EPIC), a large European multi-center study, collected 24-h DRs in a subgroup of the study sample in order to calibrate dietary intake data [33]. However, results from the 'Observing Protein and Energy Nutrition' (OPEN) study, using recovery biomarkers such as doubly labeled water and urinary nitrogen, suggested that the impact of FFQ measurement error on total energy and protein intakes was severe [8, 34]. This large measurement error may have led to considerable misclassification of study participants regarding their dietary intake and thus may have affected estimates of diet-disease associations. Hence, the utility of the FFQ has been questioned and the need for improved dietary assessment techniques has emerged [6, 7, 9, 35].

In this context, the use of new methodologies as well as new technologies has been considered for improvement of usual food intake assessment in large-scale epidemiological studies [10]. New methodologies relate to methodological principles of collecting dietary intake data, such as combining different assessment instruments [20], while new technologies refer to the collection procedure, such as the use of mobile phones [36] or web-based applications [21, 22].

One methodological approach that is considered as being suitable to improve dietary assessment originates from research on measurement of food and nutrient intakes in surveys [11-15]. According to these studies, data from a single 24-h DR can be used to estimate the mean usual dietary intake in a population. For estimates of the intake distribution, which are crucial for evaluating dietary adequacy in relation to recommended standards, multiple days of 24-h DRs are needed [27]. Simple averages over a small number of days do not adequately represent individual usual food intakes because of the day-to-day variability of a person's diet [12]. Thus, more sophisticated methods based on statistical modeling have been developed. These methods presume that the usual food intake of a subject equals the probability of a food consumed on a given day times the average amount of intake of that food on a typical consumption day. The 24-h DR, when administered at least twice for every individual, provides information on both the probability of consumption and the amount consumed [11, 16, 17] and thus, exemplifies the application of that assumption. However, the 24-h DR suffers from difficulties in adequately measuring the usual intake of foods that are not consumed nearly every day, also called episodically consumed foods [18]. Even with two administrations of 24-h DRs, the probability of consumption for most foods is poorly captured at the individual level. This has led to the extension of statistical procedures by implementing a combined use of both repeated 24-h DRs and an FFQ [11, 16, 18]. The FFQ assesses the probability of consumption, queried as frequency of usual intake over a specified period of time, and thus, levels out the weakness of the 24-h DR method. Thus, an FFQ can add information about the frequency of food intake. The reported frequencies are used as covariates in the model to enhance the estimation of usual intakes from 24-h DR data. Indeed, it has been suggested that an approach of combining instruments may provide high quality dietary information, especially for the assessment of foods that are not consumed every day [16, 18-20].

However, the application of multiple administrations of detailed 24-h DRs in combination with FFQs is impracticable in cohort studies due to the associated high costs and time expenditure of data collection [4, 10]. Technological progress and a significant increase in Internet usage in the past years has led to the development of detailed web-based 24-h DRs for self-administered use in cohort studies that might overcome some of the feasibility and financial issues (see 1.2.3) [21, 22]. To further reduce demands of time, the development of abbreviated, web-based, self-administered questionnaires has been initiated which recall the diet of the previous 24 hours [23, 24]. These instruments are typically closed-ended, i.e., participants choose foods from a finite list of items, and are intended for stand-alone application only.

This new methodological approach of combining dietary information from different assessment instruments by statistical modeling is promising in improving the accuracy of the estimates of an individual's usual dietary intake. The replacement of conventional 24-h DRs with innovative technologies still needs to be evaluated. Furthermore, scientific knowledge on the feasibility and performance of these new technologies in large-scale epidemiological studies is required [10].

1.2 Dietary assessment methods

In general, methods to collect dietary intake data can be divided into prospective and retrospective assessment instruments [27, 28, 30, 37]. Retrospective methods ask the study participant to report about past diet, either in an interview or questionnaire. The time period varies from the previous 24 hours to several weeks, months or years. The major strength of retrospective dietary assessment methods compared with prospective instruments is that they are less likely to alter eating behavior, since the information is collected after food intake. Typical retrospective instruments are the 24-h DR, the FFQ, and the diet history. In contrast, prospective methods record the study participant's actual diet at the time the foods are eaten. Thereby, reliance on memory is minimized. Typical prospective instruments are the diet record and the duplicate portion technique.

Furthermore, dietary assessment methods can be classified as short-term and long-term instruments [28, 30, 38]. Short-term dietary assessment methods are based on actual dietary intake on one or more days. They vary from recalling the intake from the previous 24-hour period (24-h DR) to keeping a record of the intake over one or more days (diet record). Long-term dietary assessment methods collect information on the average long-term diet, for example, food intake over the previous weeks, months or years (FFQ or dietary history). Comparing both approaches, the short-term methods allow greater specificity for describing foods and food preparation methods [28]. Overall, FFQs and 24-h DRs are two of the major dietary data collection instruments used in large-scale epidemiological studies [12].

1.2.1 The 24-hour dietary recall method

The 24-h DR is open-ended and collects detailed information about everything the study participant ate and drank from midnight to midnight over the past 24-hour period [28]. 24-h DRs provide accurate data of single days in terms of dietary quantification [14]. Due to a considerable day-to-day variation measured intake on a single day is a poor estimator of long-term intake [12, 38].

The state-of-the-art methods for 24-h DRs are based on a structured interview [27]. The study participant is requested to provide information on portion sizes, food preparation methods, recipe ingredients, brand names of commercial products and use of dietary supplements [14]. The conventional 24-h DR is conducted in person or by telephone using a computer-assisted interview [39, 40]. Recently, also self-administered computer- and web-based 24-h DRs have become available (see 1.2.3) [21, 22, 41]. The current state-of-the-art 24-h DR applied in US surveys is the US Department of Agriculture's Automated Multiple-Pass Method (AMPM) [40]. Food intake is recalled using a multiple-pass approach in an effort to retrieve forgotten eating occasions and foods. Within Europe, the multi-language program EPIC-SOFT is most commonly used [39]. EPIC-SOFT has been developed for the use in the EPIC study.

The validity of both conventional interview-based and self-administered 24-h DRs has been studied by comparing the reports of intake with biological markers such as doubly labeled water and urinary nitrogen [34, 42-44]. These studies have found underreporting for both energy and protein. For energy, underreporting was in the range of 3 to 34%, and for protein in the range of 11 to 28% [27].

The 24-h DR method has some strengths and limitations [27, 28]. For interviewer-administered recalls, literacy of the respondent is not required. However, when a 24-h DR is self-administered, literacy can be a constraint. Because food intake is recalled immediately the next day, study participants are generally able to recall most of the foods. Furthermore, as the method is open-ended, any food named by the study participants can be captured. The main limitation of the 24-h DR method is that study participants may not report their food consumption accurately for various reasons related to knowledge, memory, social desirability, and the interview situation.

1.2.2 The food frequency method

In contrast to 24-h DRs, nearly all FFQs are designed to be self-administered. Respondents are requested to report their usual frequency of consumption of a finite list of food items for a specified period of time in the recent past (mostly last month(s) or year). Finally, to estimate daily food and beverage intakes, the consumption frequency of a food is multiplied by its specified or standard serving size [27]. Many FFQs include portion size questions or specify portion sizes as part of each question. Of note, although the amounts consumed by study participants are considered important for the estimation of food intake, it is controversial as to whether or not portion size questions should be included in FFQs [27]. It has been shown that the frequency of consumption is a greater contributor than portion size to the variance in intake of most foods and nutrients [25, 26]. In contrast, other studies found small improvements in the performance of FFQs that ask about portion size [45, 46]. If portion size questions are omitted, a standard portion size can either be assigned identical for all study participants or specifically stratified for subgroups of the study population such as men and women [25, 47, 48] or estimated by using appropriate statistical models [11, 16, 49].

An FFQ must be connected to a nutrient database to allow estimation of nutrient intakes for a specified or standard portion size of a food item. Several approaches exist for the development of such a database. The most common approach is to use quantitative dietary intake information from the target population such as 24-h DR data and to therewith define the typical nutrient density of a particular food item. Hence, the mean or median nutrient composition of a food item can be estimated based on all reports of individual foods reported in the 24-h DRs belonging to that food item on the FFQ [27, 30].

The appropriateness of the food list is the crucial factor in the development of an FFQ. Obviously, a finite list of food items cannot capture a study subject's diet in all details [27, 38]. It is important to select the most informative items for the food list carefully. Brief FFQs have been developed to focus on the intake of specific nutrients whereas others allow a more comprehensive assessment of dietary intake [30]. The latter include generally between 50 and 150 food items [38]. For a food item to be informative it has to be consumed reasonably often by an appreciable number of individuals, it has to have a substantial content of the target nutrients, and the consumption of the food has to vary between individuals [30]. To develop an FFQ food item list, two main concepts of data-based approaches have been established: (1) identification of food items that discriminate the most between study participants, with stepwise linear regression and Max_r being the relevant statistical selection methods; and (2) identification of food items that are the most important contributors to the total absolute intake of a nutrient examining the pooled information only [30]. Open-ended methods such as 24-h DR data could be used as source data for approaches (1) and (2) [48, 50] or an existing FFQ could be modified using approach (1) [48, 51]. If food item selection is based on 24-h DR data many decisions must be made with regard to the combination of variables [30]. Open-ended methods are coded in much finer detail than being appropriate for food items on a questionnaire. For instance, several subtypes for the food items are available such as ‘margarine, not specified’, ‘margarine, olive oil’, ‘margarine, with yoghurt’, ‘mix of butter and margarine’, ‘margarine, vegetable fat’, and ‘margarine, based on sunflower seeds’ for margarine. For a food item on an FFQ, the question about margarine in general would be sufficient. In addition, 24-h DR methods often include recipes coded into ingredients that would also not be included on a questionnaire, even though the final dish would be listed.

The validity of FFQs has been studied using biomarkers such as doubly labeled water and urinary nitrogen representing usual intake without bias. These studies have found large discrepancies compared to self-reported absolute energy intake and protein intake, mostly pointing towards underreporting [34, 42].

The food frequency method also has some strengths and limitations [27]. Strengths of the FFQ approach include its low administration and processing costs. Moreover, the FFQ inquires about the study participant`s long-term food intake. FFQs are used to rank individuals according to their usual consumption of nutrients or foods rather than for estimation of absolute intake. The major limitation of the FFQ is that it results in a substantial amount of measurement error. Many details of dietary intake are not measured, and the quantification, if measured, is not as accurate as with 24-h DRs.

1.2.3 Innovative technologies for dietary assessment

Technological progress and a significant increase in Internet usage in the past years has resulted in the development of a number of innovative technologies for dietary assessment, especially for diet records, 24-h DRs and FFQs. A recent review classified available tools into mobile phone-based technologies, interactive computer-based technologies, web-based technologies, and personal digital assistant-technologies [10]. Mobile phone-based and personal digital assistant-technologies are suitable for electronic short-term dietary assessment. Typically, the dietary intake is recorded in real-time at the eating event. In contrast, interactive computer-based and web-based technologies ask study participants to report food consumption for a specified period of time in the past. These instruments are self-administered and allow for either short- or long-term dietary assessment. They involve a lot of programming and are characterized by various software components [4, 10, 52].

With respect to large-scale epidemiological studies, web-based instruments are of particular relevance as their application offers several potential advantages. First, time for data coding can be reduced as data are immediately stored. Moreover, most tools have the capacity to directly compute nutrient and food group intakes. Second, web-based 24-h DR offer the possibility to be applied in large-scale settings, which is currently not feasible with conventional 24-h DRs due to the high processing costs and the need for a large number of trained interviewers. New technologies allow self-administered application, which is promising in terms of cost reduction. Third, because of less respondent burden, compliance may increase and multiple applications may be more feasible compared to conventional instruments. Data can be collected at a time and location that is convenient for the study participant [4, 10, 52].

Up to now, two different self-administered and web-based 24-h DRs have become available in the US [21, 22], and further tools are under development, for instance in the UK (Cade and Wark, personal communication) and Germany (Nöthlings, personal communication). The instruments differ with respect to the number of foods available in the database and the way of collecting information on portion size. The ASA24, developed by the National Cancer Institute (NCI), represents a detailed automated self-administered 24-h DR for use in adults. It collects and codes dietary intake data and includes detailed questions about portion sizes and food preparation methods based on the five steps of the AMPM. The database includes approximately 8,000 foods. The ASA24 is available in English and Spanish [4, 22, 53]. A recent study assessed the validity of the ASA24 through a feeding study. Its performance was evaluated relative to a measure of true intakes from three known meals and to an interviewer-administered 24-h DR. It was shown that both the ASA24 and the conventional 24-h DR captured about 80% of the foods and drinks actually consumed and based on these findings, the authors concluded a good performance [54]. The web-based 24-h DR DietDay contains 9,349 foods, assesses information on portion sizes and preparation methods, and was designed for repeated administrations. The DietDay also applies multiple steps similar to the AMPM approach [21]. The validity of six administrations of the DietDay was tested using the doubly labeled water method. Underreporting for energy was found to be in the range of 30%, which is comparable to conventional 24-h DRs. Moreover, multiple administrations of the DietDay performed better in terms of underreporting than an FFQ [44].

To further reduce demands on time for dietary assessment, the development of abbreviated, web-based, self-administered instruments has been initiated that recall the diet of the preceding 24 hours, but with a finite list of food items [23, 24]. The Oxford WebQ, for instance, has been especially designed for the use in several large-scale prospective studies in the UK [24]. The instrument is close-ended like an FFQ, but is intended to be administered at multiple time points in a study like a 24-h DR [27]. It obtains information on consumption amounts of 21 food groups, and the median time for self-completion is 12.5 minutes. The nutrient intakes are calculated automatically and stored in a secure database. Compared to an interviewer-administered 24-h DR, the Oxford WebQ provided similar mean estimates of energy and nutrient intakes and study participants were reasonable well ranked [24].

Available innovative technologies of conventional instruments are promising to enhance dietary assessment through lower costs and more efficient data collection. However, scientific knowledge on the feasibility and performance of these technologies is currently still limited, particularly with regard to their application in larger populations. In addition, the accuracy of fully automated 24-h DR needs further evaluation [10].

1.2.4 Combined approaches for the estimation of usual dietary intake

Besides those innovative technological approaches, new methodological concepts, which combine dietary information from different assessment instruments by statistical modeling, have been proposed for an improved usual intake measurement (see 1.1.2) [11, 13, 16, 18]. These approaches result from the better understanding of strengths and weaknesses of each of the instruments. Today, several statistical procedures for estimating the usual intake distribution from repeated 24-h DRs are available. The majority of these methods can be applied only to foods that are consumed daily [13, 55]. However, a number of foods are expected to be consumed episodically or rarely. As these foods are not consumed every day, short-term measurements may contain many zero intakes of these foods [19].

To overcome this problem, two methods have been developed that are also able to estimate the usual intake distribution for episodically consumed foods if at least two repeated measurements of a 24-h DR for some study participants are provided: the *NCI Method* [13], and the *Multiple Source Method* (MSM) [16]. Both methods follow a two-step approach. The first part includes an estimation of the probability of consumption (i.e., positive intake reported on the 24-h DR) and the second part entails an estimation of the amount consumed. The final usual intake distribution is obtained by combining the estimated probability of consumption and the usual amount of food intake on consumption days. For daily consumed foods, only the second part of the model is of relevance whereas for episodically consumed foods, the probability of consumption has to be estimated in addition. In both methods, the probability of consuming a food is estimated using a logistic regression model. Covariates such as age, sex, or body mass index can be included in the model to represent the effect of personal characteristics. For the estimation of the amount consumed, a transformation step is first used to obtain symmetrically distributed data. Next, the mean usual intake and the intra- and inter-individual variance on the transformed scale are estimated. The last step eliminates the intra-individual variance and the results are back-transformed to the original scale. The second part of the model is restricted to observed positive intakes on the 24-h DR. As before, covariates can be included in the model to represent the effect of personal characteristics on the consumption-day amount (i.e., total daily intake of a food or food group). Moreover, frequency information from an FFQ can be used for the estimation of the probability of consumption (see 1.1.2), but can also contribute to estimating the amount consumed. For MSM, the FFQ can further be used to identify true consumers among those considered non-consumers according to the 24-h DR. Study participants who report non-consumption of a food item or food group on the FFQ are defined as true non-consumers, if they additionally do not report consumption of the particular food group in the 24-h DRs. Here, the probability of consumption as well as the consumption-day amount is set to zero. For study participants who are not defined as true non-consumers, but do not report consumption on the 24-h DRs, the probability of consumption is estimated following the first part of the model. The consumption-day amount is estimated through simulation based on covariate information.

2 Objectives

The combined use of different instruments to provide information on the probability of consumption, the consumption-day amount and true non-consumption is to-date the most promising approach to dietary assessment in large-scale epidemiological studies. However, the applicability of repeated 24-h DRs in large-scale epidemiological studies has been questioned.

Building on the current knowledge of the estimation of usual food intake using statistical procedures and backed by the insight that the frequency of food intake represents a larger contribution to inter-individual variation in food and nutrient intake than inter-individual variation in portion sizes, the overall objective of this investigation was to develop and to evaluate an innovative approach for dietary assessment in large-scale epidemiological studies for Germany.

The specific objectives (O) of this thesis were as follows:

O1: To develop a simply structured 24-h FL with a rapid completion time to collect information on the probability of consumption.

O2: To identify determinants of food and beverage intakes on consumption days in order to derive standard consumption-day amounts.

O3: To test the feasibility of the 24-h FL in a large-scale setting and to evaluate the tool.

O4: To conduct an application example for the estimation of usual dietary intake.

II SUBJECTS AND METHODS

1 Study design

1.1 German National Nutrition Survey II

The German National Nutrition Survey II (NVS II) is a nationwide food consumption survey which was carried out from November 2005 to January 2007 in a representative sample of the German-speaking population [56]. Study participants were selected by local register offices in about 500 randomly chosen municipalities across Germany. To offset possible socio-demographic distortions among study participants in comparison to the German population, a weighting factor according to sex, age, geographic region, educational level, employment and size of household was generated [57]. The weighting factor was based on the Microcensus 2006, which provides representative statistics of the population in Germany [58].

In the NVS II, a variety of dietary assessment methods was applied [59]. Amongst others, participants completed two non-consecutive applications of a computerized and well-established 24-h DR interview program (EPIC-SOFT) [39]. Therefore, the program was adapted to German habits [59]. The interview was conducted by telephone and time intervals between EPIC-SOFT administrations ranged from one to six weeks. The two 24-h DRs were randomly sampled and approximately equally distributed over weekdays and weekends (75% and 25%, respectively) [56]. Energy and nutrient intakes were calculated based on the German Nutrient Database (BLS 3.02) [60]. To develop the 24-h FL (O1) and to identify determinants of food and beverages intakes on consumption days (O2), data from 12,502 NVS II study participants aged 20 to 80 years were used (Figure II-1).

1.2 Pilot study *Diet* of the German National Cohort

The study aim of the German National Cohort (GNC), a joint interdisciplinary endeavor of scientists from the Helmholtz and the Leibniz Association, universities and other German research institutes, is to investigate the development of major chronic diseases, the subclinical stages and functional changes [1, 61, 62].

The pilot study *Diet* for the GNC took place from August 2011 to February 2012 in Germany. Participating study centers were located in Augsburg, Berlin-North, Berlin-South, Freiburg, Kiel, and Regensburg. GNC pilot study participants were recruited based on address lists obtained from municipal population registries and comprised a sample of men and women aged 20 to 70 years. Augsburg and Regensburg included samples with larger proportions of individuals in older age groups, whereas the other centers used simple random samples. The pilot study *Diet* was conducted to test the feasibility of the 24-h FL in a large-scale setting and to evaluate the tool (O3). Moreover, data of GNC pilot study participants were used to provide an application example for the estimation of usual dietary intake (O4) (Figure II-1).

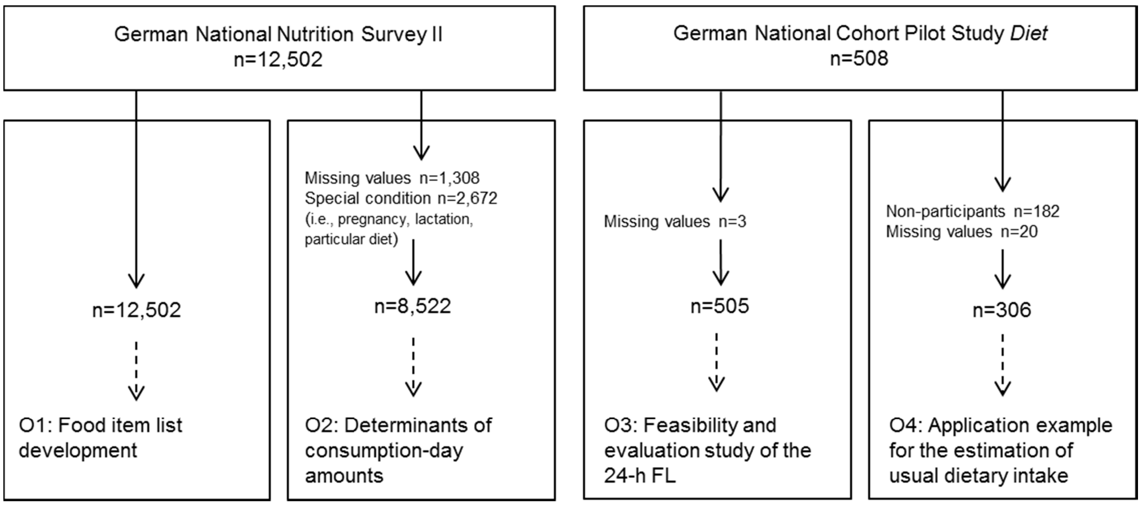


Figure II-1. Overview of source data for the development and evaluation of an innovative approach for dietary assessment in large-scale epidemiological studies

2 Analytical approaches

2.1 Development of the 24-hour food list (Objective 1)

2.1.1 Study population

Data from 12,502 NVS II participants aged 20 to 80 years were analyzed to identify food items characteristic of the German diet and to therewith compose an item list for the 24-h FL. NVS II participants completed an EPIC-SOFT interview on two non-consecutive days and reported a total of 1,882 individual food items and recipes.

2.1.2 Statistical analysis

Within EPIC-SOFT, food items were either reported as single items (e.g. apple) or as recipe ingredients within complete recipes (e.g. pizza). In addition, information about fat added during cooking of food was assessed separately for single items. For analysis, single items, single items summed up with cooking fat information, and complete recipes were used as far as those were suitable for implementation in the 24-h FL. Prior to analysis, EPIC-SOFT food items similar in composition or usage, such as green and red peppers or different types of margarines, were combined to include 1,301 food items for item selection. Since NVS II participants reported food consumption on two separate days, the mean values of food and nutrient intakes from those two days were used.

The food item list was composed using a hierarchy of statistical methods (Table II-1). First, stepwise linear regression analysis was employed to identify food items that most discriminated between individuals [30]. Total nutrient intake from foods was defined as the dependent variable and nutrient intakes from individual food items were defined as the independent variables. The stepwise regression method combines elements of both forward selection and backward elimination. The initial model contains only a constant term. Variables are then successively considered for inclusion depending on their contribution to explanation of variance of the dependent variable. In each step, variables included previously are also considered for possible elimination if they no longer make any contribution to prediction of the dependent variable [63]. Food items were chosen that reflected at least 75% of variation in nutrient intake for each of 27 nutrients (energy, protein, carbohydrate, fat, saturated fatty acids, monounsaturated fatty acids, polyunsaturated fatty acids, cholesterol, omega-3 and omega-6 fatty acids, fibre, alcohol, vitamins A, C, B6, B12, E, D, K, thiamine, riboflavin, ß-carotene, folate, sodium, calcium, magnesium, and iron) [30, 51]. Calculations were performed for all NVS II participants and NVS II participants stratified by sex and age (20 to 24, 25 to 34, 35 to 50, 51 to 64 and 65 to 80 years of age). In addition, all calculations were performed with and without inclusion of a weighting factor in the respective analysis. Second, to ensure that important food items had not been missed, items reflecting at least 60% of variation in intakes of four major food groups (fruits, vegetables, meat and meat products, and milk and dairy products) were identified also using stepwise linear regression analysis. Again, this analysis was performed for all NVS II participants and NVS II participants stratified by sex and age, but for the weighted EPIC-SOFT interviews only. Third, contribution analysis according to Block [48, 50] was applied for all NVS II participants and NVS II participants stratified by sex and age. That analysis identified food items that contributed at least 50% to the absolute intake of the 27 nutrients. After informative food items were selected, they were combined to create suitable items for the final list of items used in the 24-h FL. All statistical analyses were conducted using SAS (version 9.3, 2008, SAS Institute Inc., Cary, NC, USA). The regression models were run using the SAS procedure PROC REG with the model option SELECTION = STEPWISE.

Table II-1. Development of the 24-h food list – statistical strategies to select informative food items

Statistical methods	*Target information*	*Study participants (n=12,502)*	*Variables used*	*Criterion statistic[1]*
Stepwise linear regression	Nutrients	a) NVS II participants (weighted[2] and unweighted 24-h DRs)	Food items and recipes derived by EPIC-SOFT[3]	$R^2 \geq 0.75$
		b) NVS II participants stratified by sex (weighted[2] and unweighted 24-h DRs)		
		c) NVS II participants stratified by age[4] (weighted[2] and unweighted 24-h DRs)		
	Food groups	a) NVS II participants (weighted 24-h DRs [2])	Food items and recipes derived by EPIC-SOFT[3]	$R^2 \geq 0.60$
		b) NVS II participants stratified by sex (weighted 24-h DRs [2])		
		c) NVS II participants stratified by age[4] (weighted 24-h DRs [2])		
Contribution analysis	Nutrients	a) NVS II participants	Food items and recipes derived by EPIC-SOFT[3]	50%
		b) NVS II participants stratified by sex		
		c) NVS II participants stratified by age[4]		

Abbreviations: NVS II, National Nutrition Survey II; 24-h DR, 24-hour dietary recall

[1]R^2 coefficient of determination; percentages of total intake; [2]Weighted by sex, age, geographic region, and other socioeconomic factors according to the Microcensus 2006 [58]; [3]n=1,301 items; [4]20-24, 25-34, 35-50, 51-64 and 65-80 years of age

2.2 Determinants of consumption-day amounts (Objective 2)

2.2.1 Study population

A total of 12,502 NVS II participants completed two EPIC-SOFT 24-h DRs. Figure II-2 shows the exclusion criteria of the analytical study population for the present study. NVS II subjects were excluded if they were lactating or pregnant women, or if they had a particular diet such as a slimming diet or a diet related to health conditions (n=2,672) because it was assumed that those study participants did not consume typical amounts of foods and beverages. In addition, NVS II subjects with missing values on socio-demographic factors and smoking were excluded (n=1,308). This resulted in a study population of 8,522 participants for analysis.

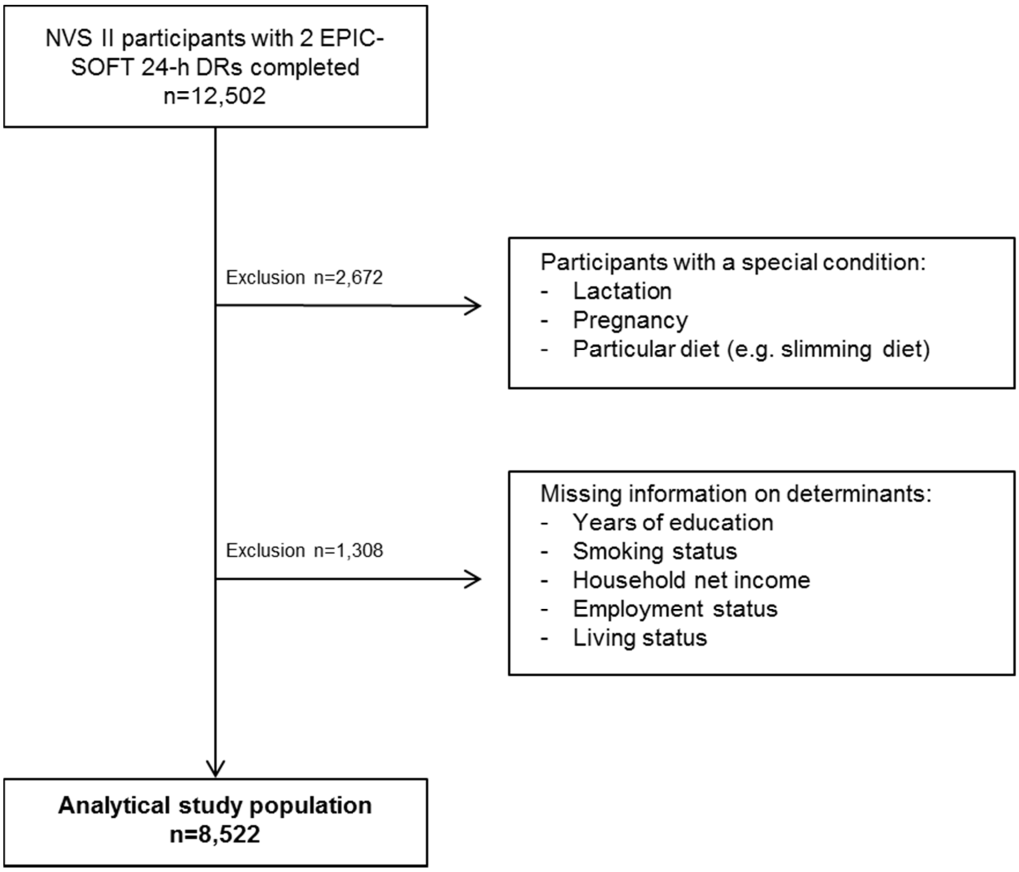


Figure II-2. Exclusion criteria for the analytical study population within the study population of the National Nutrition Survey II

2.2.2 Variable assessment for use in analysis

Demographic, socioeconomic and lifestyle variables were assessed in a computer-assisted personal interview at on-site study centers [56, 64]. Additionally, anthropometric measurements were conducted. The body mass index (BMI) was computed based on anthropometric measures that were assessed in three different ways: (1) measures of body weight and height following a standardized protocol [65] (n=5809); (2) self-reported weight and height (n=2694); and (3) for participants with missing information on weight and height, the BMI was calculated based on sex and age specific mean values for BMI from NVS II participants with information on measured or self-reported weight and height (n=19). Years of education were determined according to the International Standard Classification of Education 1997 [66].

Food intake according to 24-h DR data was categorized into 15 food groups: bread and buns, breakfast cereals, pasta, rice, potatoes, milk and dairy products (incl. curd cheese), cheese, fresh fruits, vegetables, processed meat, meat, fish and shellfish, soup and stew, cake and cookies, sweets and salty snacks; and 7 beverage groups: water, soft drinks, fruit and vegetable juice, coffee, tea, wine, beer. Food grouping according to the 24-h FL was used. Therefore, all reports of individual foods reported in the 24-h DRs belonging to the respective food group on the 24-h FL were combined for analysis. The food and beverage groups and the general food items within each group are listed in Table IX-1 (Appendix).

2.2.3 Statistical analysis

Descriptive statistics of the study population for sex, age, BMI, smoking status (current, former, never), years of education (≤10, 12 to 13, 14 to 16, 17 to 18 years), living status (together with a partner yes, no), household net income (<1,500, 1500 to <3,000, ≥3,000 €), and employment status (yes, no) were computed as percentages for categorical variables and as mean and standard deviation (SD) for continuous variables.

To account for repeated measurements of dietary intake on the same study participant, mutually adjusted linear mixed-effects models with subject-specific random effects were fit to identify determinants associated with amounts consumed for each food or beverage group separately. The consumption-day amount, which was defined as the total intake (in grams) of food and beverage groups per day, was treated as dependent variable. Sex, age, BMI, smoking status, years of education, living together with a partner, household net income, and employment status were investigated as determinants. To check for multicollinearity, the variance inflation factor was calculated. The phi coefficient was determined to measure the association between determinants. All statistical analyses were conducted using SAS (version 9.4, 2008, SAS Institute Inc., Cary, NC, USA).

To determine the most relevant predictors of consumption-day amounts, the LASSO as a popular shrinkage and variable selection method for linear (mixed effects) models was used. First, the dependent variable was Box-Cox transformed to obtain normally distributed residuals. Further statistical analysis was conducted using the package lmmlasso in R (version 3.1.1). To pick the most suitable LASSO model, the Bayesian information criterion (BIC) was chosen for the selection of the regularization parameter [67].

2.3 Feasibility and evaluation study of the 24-hour food list (Objective 3)

The feasibility and evaluation study of the web-based 24 h FL was embedded in the pilot study *Diet* for the GNC and covered a period of three to six months, depending on the organizational flow within study centers.

2.3.1 Study population

In total, 508 GNC pilot study participants (Augsburg n=76, Berlin-North n=27, Berlin-South n=45, Freiburg n=157, Kiel n=102 and Regensburg n=101) were invited to complete the online 24-h FL and to evaluate the questionnaire. In Berlin-North, only individuals with Internet access were asked to participate, whereas the other study centers invited all GNC pilot study subjects to participate. Participants with missing values on baseline characteristics were excluded from the analysis (n=3).

2.3.2 Variable assessment for use in analysis

Demographic, socioeconomic and lifestyle variables were assessed in a computer-assisted face-to-face interview in the respective study center. Participants were randomly prompted to complete the online 24-h FL three times. Time intervals between administrations ranged from 10 days to four weeks due to the different workflows in the study centers. In Augsburg, participants were asked to complete the first 24-h FL during their visit at the study center. In Berlin-North, Berlin-South, Freiburg, and Kiel, participants were asked to complete the 24-h FL online at home when prompted on an unannounced day after their visit to the study center. In Regensburg, participants were asked to complete the first 24-h FL online at home any time after their visit to the study center. Repetitions of 24-h FL were prompted via e-mail or phone calls on unannounced days. Furthermore, participants were requested to complete an FFQ for the assessment of true non-consumption that has been developed to capture dietary habits within the last year in the German population [48]. The FFQ was available as web-based version or paper version in some centers.

To evaluate the 24-h FL, participants were asked to fill in an online evaluation form directly after they had completed the first 24-h FL. They were requested to rate the understandability of the 24-h FL (introduction section, questions, food groups), the perceived completeness of the list of food items, the usability of the questionnaire, and the effectiveness of the visual presentation. Participants were queried about whether the 24-h FL represented their diet over the past 24 hours, whether they experienced difficulties in locating foods or matching them to the item list, whether the number of legends was sufficient, and whether they would consider repeating the online 24-h FL. To assess whether all relevant food items had been included, participants were asked to declare missing items.

2.3.3 Statistical analysis

Descriptive statistics of the GNC pilot study population, including sex (men vs. women), age (20-49 years vs. 50-70 years), BMI (<25 kg/m^2 vs. ≥25 kg/m^2), education (secondary school vs. high school), smoking status (ever vs. never), and marital status (married vs. single or divorced) were computed as absolute numbers and percentages according to study center. Response proportions were calculated taking into account the reasons for non-participation except for Berlin-North because at that study center, participant recruitment was restricted to individuals with Internet access and the reasons for non-participation were not inquired about. In the current project, a positive response was defined as completion of at least one 24-h FL. In addition, response proportions were calculated for study centers that used comparable recruitment approaches (i.e., Berlin-South, Freiburg, Kiel, and Regensburg) to account for differences in recruitment and prompting procedures across study centers.

The median time needed to complete each 24-h FL was recorded by an online study management system (https://sms.dife.de/tools/current/de). To evaluate the extent to which participants were prone to reactivity, agreement was assessed between the day on which a 24-h FL was prompted and the day on which it was completed. Evaluation forms corresponding to the first 24-h FL completed were analyzed by calculating the percentages of each possible response option. Moreover, to evaluate the appropriateness of the item list, each food item was checked as to whether or not it was chosen by at least one study participant. To further evaluate the performance of the 24-h FL, classification of consumers vs. non-consumers was compared across the 24-h FL and the FFQ. Therefore, the analysis was restricted to foods collapsed to food groups queried about in both the 24-h FL and the FFQ. Information on food group intake (yes vs. no) of GNC pilot study participants with one, two, or three 24-h FLs completed was compared to the results of the FFQ. Although multiple applications are recommended, participants with only one completed 24-h FL were analyzed in order to obtain information on feasibility and need for repetitions of the close-ended 24-h FL. Participants were categorized as consistently classified across instruments, if they were consumers according to at least one 24-h FL and the FFQ, or if they were non-consumers according to all 24-h FLs completed and the FFQ. If the comparison of the instruments showed disagreement, i.e., foods not chosen in a 24-h FL were generally consumed according to the FFQ, or foods reportedly consumed in a 24-h FL but were not consumed according to FFQ, then participants were categorized as inconsistently classified. Three scenarios were analyzed: (a) three 24-h FLs were completed; (b) two 24-h FLs were completed; and (c) only one 24-h FL was completed. To maintain sample size, for scenarios (b) and (c) one or two 24-h FLs were randomly chosen for those participants with two or three 24-h FLs completed, respectively. All statistical analyses were performed using Statistical Analysis Software (version 9.3, 2008, SAS Institute Inc., Cary, NC, USA).

2.4 An application example for the estimation of usual dietary intake (Objective 4)

2.4.1 Study population

The present analysis was based on 306 eligible GNC pilot study participants, after exclusion of non-participants in the pilot study (n=182) and participants with missing information on relevant baseline characteristics and incomplete recording of the 24-h FL due to technical problems (n=20).

2.4.2 Variable assessment for use in analysis

Demographic, socioeconomic and lifestyle variables were assessed in a computer-assisted face-to-face interview in the respective study center. Years of education were determined according to the International Standard Classification of Education 1997 [66]. Anthropometric measurements including body weight and height were performed following a standardized protocol. Participants were randomly prompted to complete the online 24-h FL three times (see O3).

2.4.3 Statistical analysis

Descriptive statistics of the GNC pilot study population, including sex, age, BMI, smoking status (current, former, never), years of education (≤10, 12 to 13, 14 to 16, 17 to 18 years), and household net income (<1500, 1500 to <3000, ≥3000 €) were computed as percentages for categorical variables and as mean and SD for continuous variables.

For each lead item on the 24-h FL (i.e., cooking fats, salad dressing oils and additions for coffee and tea were excluded n=233), the probability of consumption p_i was calculated based on the number of 24-h FLs completed ranging from $p_i = 0$ if an item was consumed in none of the 24-h FLs completed to $p_i = 1$ if an item was consumed in all of the 24-h FLs completed. The consumption-day amount Y_i was defined as the total amount in grams of a food item consumed on a consumption-day (g/day). To predict the consumption-day amount Y_i, a regression equation was determined for each lead item on the 24-h FL using linear mixed-effects models based on NVS II 24-h DR data. To compare the relevance of different determinants for the estimation of usual dietary intake, two prediction models were generated: (1) a parsimonious model including sex, age and BMI as independent variables (model A); and (2) a comprehensive model with additional inclusion of smoking status, years of education, and household net income (model B). Living and employment status have not been assessed in the pilot study of the GNC. Therefore, these variables could not be evaluated. The consumption-day amount Y_i for each GNC pilot study participant was subsequently predicted depending on model A and model B, respectively. Finally, the usual dietary intake for each food item and study participant was estimated by multiplication of the probability of consumption and the standard amount consumed:

$$\text{Intake}_i = p_i * Y_i$$

To describe the usual intake distribution for both models, percentiles (25th, 50th, and 75th), mean, SD, minimum, and maximum values were reported for each food item. Differences between model A and model B were tested using the Wilcoxon signed rank sum test. A p value of <0.05 was considered as statistically significant. To evaluate the effect of the application of either model A (parsimonious) or model B (comprehensive) on the ranking of study participants, tertiles of usual dietary intake for each food item were compared across models. For this purpose, the study population was restricted to observed positive intakes for each food item on the 24-h FL, respectively. The unweighted Cohen's kappa coefficient was calculated to evaluate the agreement of ranking between the two models. The strength of agreement was interpreted according to the proposed guidelines by Landis and coworkers [68]. All statistical analyses were performed using Statistical Analysis Software (version 9.4, 2008, SAS Institute Inc., Cary, NC, USA).

III RESULTS

1 The item list and design of the 24-hour food list (Objective 1)

Exemplarily, Table III-1 and Table III-2 show informative food items for the nutrient omega-3 fatty acids that were selected by stepwise regression and contribution analysis using the NVS II 24-h DR data. The presented results are based on the unstratified NVS II study population. In total, eight food items were selected by stepwise regression together explaining 76% of variance in omega-3 fatty acid intake (Table III-1). These food items accounted for about 20% of absolute omega-3 FA fatty acid intake only. The food item 'herring' that explained most of the variance in intake (17%) contributed to 2% of absolute intake only whereas the food item 'margarine' that contributed most to absolute intake (10%) was selected only as 5th item in the stepwise regression analysis. Based on the contribution analysis, 22 informative food items were selected that contributed about 50% to total omega-3 fatty acid intake (Table III-2).

Table III-1. Food items selected by stepwise regression for the nutrient omega-3 fatty acids based on 24-h dietary recall data of the National Nutrition Survey II, n=12,502[1]

Food item	*Partial R^2*	*Model R^2*	*% total omega-3 FA intake*	*Cumulative % total omega-3 FA intake*
1. Herring	0.17	0.17	2.08	2.08
2. Chips, crisps	0.14	0.31	1.99	4.07
3. Nuts	0.12	0.43	2.03	6.10
4. Salmon	0.10	0.53	2.49	8.59
5. Margarine	0.08	0.61	10.31	18.90
6. Flax seed oil	0.06	0.67	0.18	19.08
7. Fried herring	0.05	0.72	0.25	19.33
8. Flax seed	0.04	0.76	0.36	19.69

Abbreviations: FA, fatty acids; 24-h DR, 24-hour dietary recall

[1]All NVS II participants, weighted 24-h DRs

Table III-2. Food items selected by contribution analysis for the nutrient omega-3 fatty acids based on 24-h dietary recall data of the National Nutrition Survey II, n=12,502[1]

Food item	*% total omega-3 FA intake*	*Cumulative % total omega-3 FA intake*
1. Margarine	10.31	10.31
2. Apple	3.71	14.02
3. Butter	3.67	17.69
4. Pork	3.13	20.82
5. Salmon	2.49	23.31
6. Tart, pie	2.13	25.44
7. Herring	2.08	27.52
8. Nuts	2.03	29.55
9. Chips, crisps	1.99	31.54
10. Salami	1.97	33.51
11. Wheat bread and buns, baguette	1.97	35.48
12. Bratwurst	1.85	37.33
13. Semi-hard cheese	1.75	39.08
14. Saithe, pollock	1.66	40.74
15. Egg	1.54	42.28
16. Frankfurter, wiener, hot dog	1.51	43.79
17. Whole grain bread and buns	1.41	45.20
18. Milk	1.37	46.57
19. Brown (rye wheat) bread and buns	1.21	47.78
20. Multigrain bread and buns	1.06	48.84
21. Lettuce	0.89	49.73
22. Chicken	0.89	50.62

Abbreviation: FA, fatty acids

[1]All NVS II participants

Table III-3 gives a summary about the total number of food items that were selected by the different statistical and stratification approaches for the 27 different nutrients and four food groups. The number of food items selected by stepwise regression analysis for individual nutrients ranged from three food items explaining 75% of the variation in vitamin A intake to 97 food items explaining 75% of the variation in iron intake. After summing the selected food items, derived for the different stratification and weighting approaches, a total of 305 food items were selected by the stepwise regression approach. On top of this, five items were selected to explain the variation in intakes of four major food groups and another four items were selected based on their contribution to the absolute intake of the 27 nutrients. In the end, the selected food items were combined to food items suitable for an item list. The initial 24-h FL consisted of a total of 246 food items which are listed in Table III-4.

The 24-h FL was designed to assess information on the consumption (yes vs. no) of selected food items during the previous 24 hours according to food groups. Specifically, participants were asked whether a particular food group had been consumed. If the answer was yes, a drop-down menu appeared which contained a list of individual food items related to that particular food group (see Figure III-1 for an exemplary screenshot). From that list, the participant could then indicate the specific food consumed. In addition to questions on 23 main food groups, the 24-h FL inquired about five additional topics, i.e., spread, fat content of milk, dairy products, cheese, meat and processed meat, salad dressing oils, cooking fat, and additions for coffee and tea. The additional questions only popped up if the participants reported consumption of the related food items. To overcome the problem of unanswered questions, participants were not able to proceed to the next page until they had answered the question. The entire questionnaire can be viewed at https://sms.dife.de/tool/sv24/de.

The 24-h FL was implemented as a web-based questionnaire hosted by an online platform for questionnaires and study management (https://sms.dife.de/tools/current/de), developed and maintained by the Department of Epidemiology of the German Institute of Human Nutrition Potsdam-Rehbruecke (DIfE).

Table III-3. Number of food items selected as informative for intake of 27 nutrients and four food groups by two different statistical strategies based on 24-h dietary recall data of the National Nutrition Survey II, n=12,502

Nutrient / Food group	*Stepwise regression (1)*	*Contribution analysis (2)*	(1) *and (2)*[1]
Energy	96	39	39
Protein	84	36	33
Fat	64	36	33
Saturated FA	39	27	25
Monounsaturated FA	72	37	34
Polyunsaturated FA	53	33	22
Omega-3 FA	11	29	7
Omega-6 FA	47	37	22
Cholesterol	34	27	18
Carbohydrate	45	24	20
Dietary fiber	48	18	15
Alcohol	7	13	6
Vitamin A	3	18	1
ß-carotene	24	18	9
Thiamine	26	29	14
Riboflavin	23	30	16
Vitamin B_6	36	32	22
Vitamin B_{12}	16	24	9
Vitamin C	15	16	9
Vitamin D	15	17	5
Vitamin E	61	37	26
Folate	50	22	19
Vitamin K	10	21	4
Sodium	55	20	19
Magnesium	74	22	21
Calcium	19	14	9
Iron	97	39	32
Fruits	6	-	-
Meat and meat products	10	-	-
Milk and dairy products	1	-	-
Vegetables	21	-	-

Abbreviation: FA, fatty acids

[1]Number of food items selected by both stepwise regression and contribution analysis approach

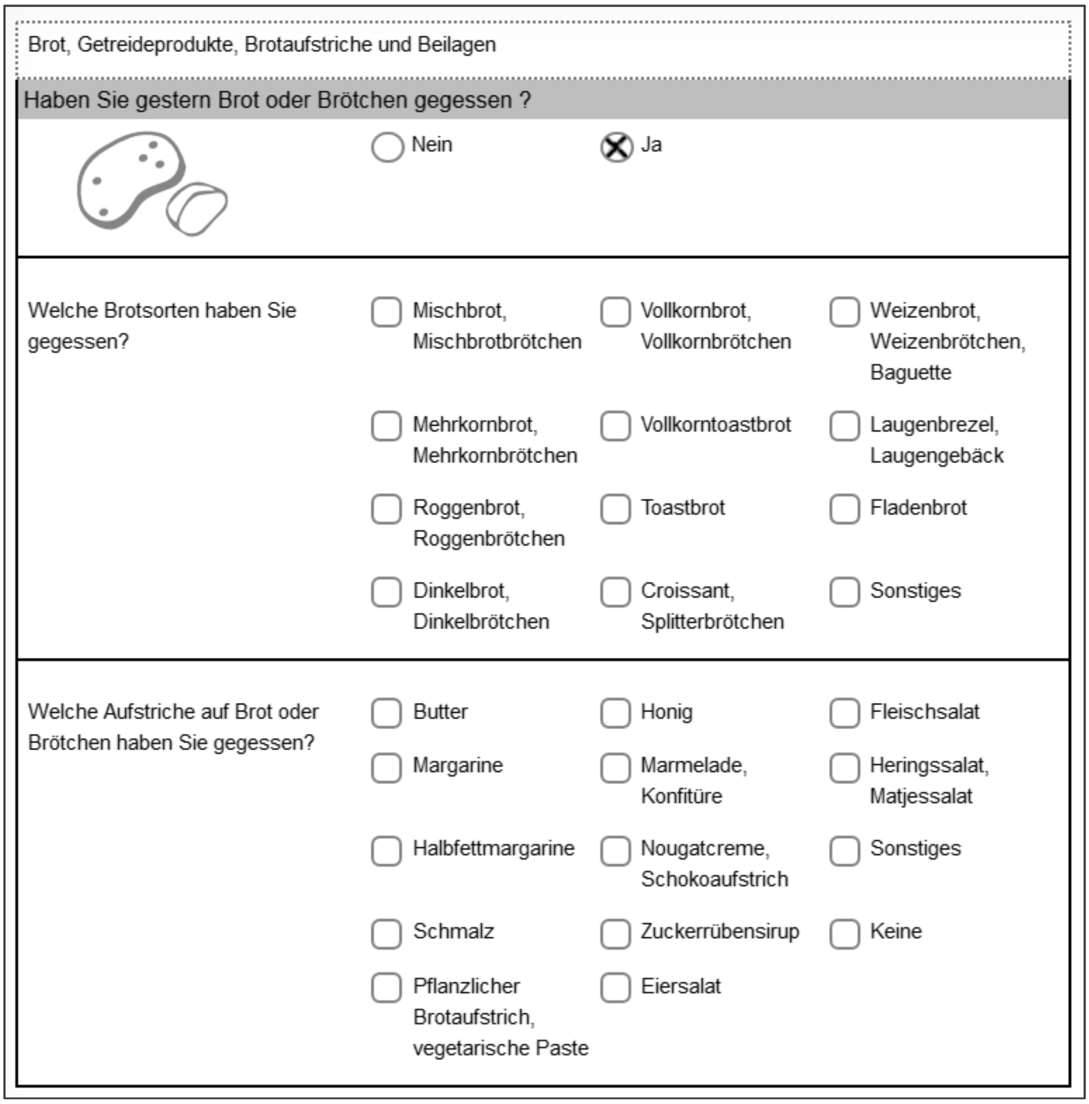
Table III-4. Overview of the initial 246 food items on the 24-h food list

Food or beverage group	*Included food items*
Bread and buns	Brown (rye wheat) bread and buns, multigrain bread and buns, rye bread and buns, dinkel wheat bread and buns, whole grain bread and buns, whole grain toast, toast, croissant, wheat bread and buns/baguette, lye pretzel/breads, flatbread
Spread	Butter, margarine, half-fat margarine, schmaltz, vegetarian bread spread, honey, marmalade/jam, hazelnut spread, sugar beet molasses, egg salad, meat salad, herring salad
Breakfast cereals	Muesli, corn flakes, wholemeal/rolled cereals/oat flakes, puffed rice
Pasta, rice and other grain products	Pasta/noodles, whole grain pasta, rice, groats, vegetable/cereal patty
Potatoes	Potatoes, pan-fried potatoes, mashed potatoes, potato dumplings, potato salad, filled potatoes, potato pancake, chips/French fries
Milk and dairy products	Milk, soured milk, buttermilk, soy milk, hot/cold cocoa, flavored milk (drinks), cream, kefir, plain yoghurt, flavored yoghurt, crème fraiche
Curd and cheese	Plain curd (quark), curd with herbs, cream cheese, soft cheese, mozzarella, feta, semi-hard and hard cheese, sour milk cheese
Fruits	Apple, pear, orange, tangerine, kiwi, cherries, plum, mirabelle plum, peach, apricot, nectarine, pomegranate, grapes, melon, banana, strawberries, blueberries, raspberries, gooseberries, fresh fig, cape gooseberry/physalis, fruit salad, stewed fruit, dried fruits
Nuts and seeds	Nuts, flax seeds, other seeds, trail mix
Vegetables	Lettuce, cucumber, tomatoes, capsicum/pepper, pickled cucumber/gherkin, carrots, turnip cabbage (kohlrabi), olives, avocado, broccoli, spinach, zucchini/courgette, aubergine/eggplant, cauliflower, white cabbage, kale/borecole, Brussels sprouts, red cabbage, sauerkraut, mushrooms, asparagus, legumes, mixed vegetables
Garlic and onion	Garlic, onion
Sausages and ham	Liver sausage, salami, mettwurst, cabanossi, bologna/polony, ham sausage, cooked ham, raw ham, poultry sausage, aspic, collared pork, blood sausage
Meat and meat products	Beef, poultry, veal, pork, lamb, venison, mixed ground meat, German beef roulade, beef goulash, chicken/turkey ragout, roast pork, pork goulash, gyros, shashlik/meat skewer, liver, other offal, bolognese sauce, frankfurter/wiener/hot dog, bratwurst, Bavarian veal sausage, Bavarian meat loaf, hamburger/meatball

Continued on the following page

Table III-4. Overview of the initial 246 food items on the 24-h food list *(continued)*

Food or beverage group	*Included food items*
Fish and seafood	Salmon, mackerel, herring, salted herring (matjes), fried herring, rolled pickled herring (rollmops), hot smoked herring (buckling), sprat, eel, redfish, trout, tuna, saithe/pollock, codfish, fish sticks, fish bake, calamari, craps/shellfish
Salad dressing oils, cooking fat	Butter, margarine, lard, bacon, olive oil, sunflower oil, flax seed oil, grape seed oil, safflower oil, wheat germ oil, vegetable oil, vinegar, vinegar and oil dressing, vinegar and oil dressing with herbs, French dressing, Cocktail dressing
Eggs	Boiled egg, fried egg/omelet
Soup and stew	Vegetable stew, stew with meat, clear soup, crème of vegetable soup
Gravy	Tomato sauce, (curry) ketchup, mayonnaise/remoulade, soy sauce, mustard
Mixed dishes and tofu	Pizza/baguette, Döner Kebab, lasagna, filled puff pastry, tofu, vegetable pie
Dessert	Ice cream, tiramisu, chocolate mousse, pudding, cold sweet soup with fruits, waffles, pancakes
Cake	Yeast cake and pastry, tart/pie, cream pie/cake with butter crème or custard filling, cheesecake, pound cake/muffins
Cookies and sweets	Cookies or biscuits with chocolate icing, cookies or biscuits without chocolate icing, filled chocolates, chocolate bar, other chocolate or sweets with chocolate, other sweets without chocolate
Salty snacks	Crisps and crackers
Non-alcoholic beverages	Mineral water/drinking water, lemonade, diet lemonade, cola, diet cola, multi-vitamin juice, apple juice, orange juice, grape juice, grapefruit juice, elder juice, beer without alcohol, malt beer
Hot beverages	Coffee, black tea, green tea, herbal tea, fruit tea
Additions for hot beverages	Sugar, sweetener, milk, honey
Alcoholic beverages	Beer, beer shandy, strong beer/malt liquor, red wine, white wine, rosé wine, sparkling wine, wine spritzer, hot wine punch, spirit drinks, liqueur, mixed drinks



Brot, Getreideprodukte, Brotaufstriche und Beilagen

Haben Sie gestern Brot oder Brötchen gegessen ?

○ Nein ☒ Ja

Welche Brotsorten haben Sie gegessen?	☐ Mischbrot, Mischbrotbrötchen	☐ Vollkornbrot, Vollkornbrötchen	☐ Weizenbrot, Weizenbrötchen, Baguette
	☐ Mehrkornbrot, Mehrkornbrötchen	☐ Vollkorntoastbrot	☐ Laugenbrezel, Laugengebäck
	☐ Roggenbrot, Roggenbrötchen	☐ Toastbrot	☐ Fladenbrot
	☐ Dinkelbrot, Dinkelbrötchen	☐ Croissant, Splitterbrötchen	☐ Sonstiges
Welche Aufstriche auf Brot oder Brötchen haben Sie gegessen?	☐ Butter	☐ Honig	☐ Fleischsalat
	☐ Margarine	☐ Marmelade, Konfitüre	☐ Heringssalat, Matjessalat
	☐ Halbfettmargarine	☐ Nougatcreme, Schokoaufstrich	☐ Sonstiges
	☐ Schmalz	☐ Zuckerrübensirup	☐ Keine
	☐ Pflanzlicher Brotaufstrich, vegetarische Paste	☐ Eiersalat	

Figure III-1. Exemplary screenshot of the 24-h food list for the food group bread and buns

2 Determinants of consumption-day amounts (Objective 2)

The characteristics of the NVS II study population are presented in Table III-5. Overall, the mean age of the study population was 48 years, and 53% of the study participants were women.

Table III-5. Characteristics of participants of the National Nutrition Survey II, n=8,522

	Age group (years)		
	20 to ≤34	>34 to ≤64	>64 to 80
n	1,526	5,603	1,393
Female, %	54.9	53.6	49.6
Age, years (mean, SD)	27.6 (4.4)	48.0 (8.3)	70.0 (4.2)
BMI, kg/m^2 (mean, SD)	24.2 (4.5)	26.1 (4.4)	27.3 (4.1)
Years of education[1], %			
9 to 10 years	5.9	4.8	17.1
12 to 13 years	53.5	50.4	48.0
14 to 16 years	22.2	21.0	16.4
17 to 18 years	18.4	23.8	18.5
Employed, %	78.0	76.9	5.9
Smoking status, %			
Never	52.7	45.1	61.4
Former	11.9	25.5	28.7
Current	35.5	29.3	9.9
Living together with a partner, %	57.0	82.9	76.9
Household net income, %			
<1,500 €	30.4	17.3	32.0
1,500 to <3,000 €	47.9	49.4	52.9
≥3,000 €	21.7	33.4	15.1

Abbreviations: BMI, body mass index; SD, standard deviation

[1] according to the International Standard Classification of Education 1997 [66]

The results of the linear mixed-effects analysis for associations between determinants and consumption-day amounts for 15 food groups and seven beverage groups are shown in Table III-6. Sex was a major determinant of the amount consumed: compared to women, men consumed statistically significantly larger amounts of 20 food and beverage groups except for water and tea. For vegetables and fresh fruits, no statistically significant association was observed. With higher age, the amount consumed was significantly lower for eight food groups: breakfast cereals, pasta, rice, milk and dairy products, cheese, processed meat, meat, sweets and salty snacks; and four beverage groups: water, soft drinks, fruit and vegetable juice and beer. On the contrary, the amount consumed was higher for fresh fruits, vegetables and coffee. This also points to age being a major determinant for consumption-day amounts. No statistically significant association between age and consumption-day amounts was observed for bread and buns, potatoes, fish and shellfish, soup and stew, cake and cookies, tea and wine. An one-unit increase in BMI was statistically significantly associated with larger consumption-day amounts of pasta, rice, processed meat, meat, water, fruit and vegetable juice, coffee, wine and beer. On the other hand, study participants with a higher BMI consumed less bread and buns, and potatoes. Current compared to never smokers consumed larger amounts of all beverage groups except for tea, and of milk and dairy products, processed meat, meat and sweets and salty snacks. In contrast, current smokers consumed less bread and buns, and fresh fruits compared to never smokers. With a higher educational level (17 to 18 vs. 9 to 10 years of education), the amount consumed was significantly lower for milk and dairy products, processed meat, soup and stew, soft drinks, fruit and vegetable juice, coffee and beer, but higher for cheese, fresh fruits, vegetables and tea. A high household net income (≥3,000 vs. <1,500 €) was associated with lower consumption-day amounts of bread and buns, pasta, milk and dairy products and soft drinks. In contrast, a high household net income was associated with higher amounts of cheese and water consumed. Study participants who lived together with a partner consumed lower amounts of milk and dairy products, cheese, sweets and salty snacks, water, tea and beer compared to participants not living together with a partner. Employed compared to unemployed study participants consumed statistically significantly higher amounts of bread and buns, processed meat, fruit and vegetable juice, coffee, tea and wine.

Table III-6. Regression coefficients (g/day) for consumption-day amounts in mutual adjusted linear mixed-effects models, n=8,522

			Sex	*Age*	*BMI*	*Smoking status*		*Years of education*			*Household net income (€)*		*Living with a partner*	*Employ-ment*
Food group			Male[1]	Years	kg/m²	Former[2]	Current[2]	12-13[3]	14-16[3]	17-13[c]	1,500-<3,000[4]	≥3,000[4]	Yes[5]	Yes[5]
	n	IC	ß (SE)											
Bread and buns	15,425	127.34	45.51*** (1.45)	-0.01 (0.06)	-0.45** (0.16)	-1.12 (1.74)	-11.08*** (1.71)	0.27 (2.81)	-1.05 (3.12)	-3.22 (3.17)	-0.94 (1.94)	-7.20** (2.33)	3.07 (1.87)	9.34*** (1.74)
Breakfast cereals	1,998	61.01	12.18*** (1.67)	-0.19** (0.07)	-0.02 (0.21)	-0.73 (1.97)	1.00 (2.19)	-2.87 (3.97)	-2.42 (4.17)	-5.21 (4.17)	-1.92 (2.44)	-3.91 (2.74)	-1.08 (2.17)	3.43 (2.05)
Pasta	3,448	177.10	35.91*** (3.38)	-0.86*** (0.14)	0.97** (0.37)	3.37 (4.22)	4.87 (3.88)	3.26 (6.92)	-5.51 (7.52)	3.79 (7.74)	-4.16 (4.74)	-11.03* (5.38)	-1.69 (4.35)	0.01 (4.08)
Rice	1,536	93.36	30.03*** (3.05)	-0.33** (0.12)	1.18** (0.34)	2.51 (3.73)	-6.75 (3.61)	0.47 (6.32)	-7.04 (6.87)	-4.54 (6.81)	-9.02* (4.21)	-4.03 (4.85)	-5.17 (3.83)	4.80 (3.72)
Potatoes	6,818	171.41	30.49*** (1.97)	-0.14 (0.08)	-0.50* (0.23)	-3.55 (2.38)	-0.19 (2.34)	-5.12 (3.66)	-3.50 (4.13)	-3.52 (4.20)	-2.24 (2.60)	-5.47 (3.18)	-0.63 (2.55)	-1.52 (2.38)
Milk and dairy products	7,731	358.52	64.04*** (5.29)	-1.61*** (0.21)	-0.06 (0.60)	-9.06 (6.29)	20.09** (6.42)	-8.95 (10.64)	-3.47 (11.68)	-28.66* (11.81)	-14.93* (7.14)	-18.00* (8.49)	-32.69*** (6.71)	3.02 (6.39)

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Table III-6. Regression coefficients (g/day) for consumption-day amounts in mutual adjusted linear mixed-effects models, n=8,522 *(continued)*

			Sex	*Age*	*BMI*	*Smoking status*		*Years of education*			*Household net income (€)*		*Living with a partner*	*Employ-ment*
Food group			Male[1]	Years	kg/m²	Former[2]	Current[2]	12-13[3]	14-16[3]	17-18[3]	1,500-<3,000[4]	≥3,000[4]	Yes[5]	Yes[5]
	n	IC	ß (SE)											
Cheese	9,880	44.60	4.81*** (0.75)	-0.13*** (0.03)	-0.11 (0.08)	1.31 (0.89)	-0.24 (0.91)	1.23 (1.53)	2.92 (1.67)	5.03** (1.69)	1.20 (1.03)	4.26** (1.22)	-3.28** (0.99)	0.46 0.92
Fresh fruits	9,722	247.74	3.27 (4.44)	0.88*** (0.18)	-0.33 (0.51)	3.35 (5.12)	-18.94** (5.47)	2.43 (8.59)	10.00 (9.53)	30.30** (9.62)	-8.25 (5.98)	-10.75 (7.13)	-10.29 (5.77)	9.24 (5.33)
Vegetables	12,102	127.42	-0.04 (2.18)	0.22* (0.09)	0.04 (0.25)	7.90** (2.60)	-3.57 (2.60)	2.68 (4.31)	12.95** (4.76)	22.81*** (4.80)	1.07 (2.95)	-0.28 (3.50)	-2.70 (2.82)	1.65 (2.61)
Processed meat	11,356	81.58	41.93*** (1.64)	-0.56*** (0.07)	0.70** (0.18)	-0.58 (1.97)	4.70* (1.93)	-4.87 (3.23)	-10.09** (3.57)	-17.12*** (3.66)	0.01 (2.23)	-0.82 (2.67)	-2.99 (2.15)	5.51** (2.02)
Meat	6,192	103.46	44.26*** (2.47)	-0.41*** (0.10)	1.27*** (0.28)	1.60 (3.06)	16.85*** (2.85)	-4.14 (4.92)	-1.27 (5.46)	-9.93 (5.57)	-4.06 (3.39)	-5.92 (4.01)	-1.46 (3.26)	4.96 (2.99)
Fish and shellfish	2,384	105.72	30.29*** (4.00)	0.02 (0.17)	0.63 (0.47)	0.01 (4.71)	3.57 (4.87)	-8.15 (8.09)	-17.79* (8.92)	-14.14 (8.86)	5.14 (5.50)	1.68 (6.53)	-1.75 (5.21)	-1.33 (4.94)

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Table III-6. Regression coefficients (g/day) for consumption-day amounts in mutual adjusted linear mixed-effects models, n=8,522 *(continued)*

Food group			*Sex*	*Age*	*BMI*	*Smoking status*		*Years of education*			*Household net income (€)*		*Living with a partner*	*Employ-ment*
			Male[1]	Years	kg/m²	Former[2]	Current[2]	12-13[3]	14-16[3]	17-18[3]	1,500-<3,000[4]	≥3,000[4]	Yes[5]	Yes[5]
	n	IC	ß (SE)											
Soup and stew	2,609	380.50	74.26*** (8.76)	-0.02 (0.35)	-0.14 (1.00)	27.08** (10.27)	10.51 (10.45)	-16.28 (16.41)	-6.21 (18.27)	-37.16* (18.56)	-6.98 (10.98)	-18.18 (13.54)	-5.67 (11.02)	6.09 (10.62)
Cake and cookies	7,124	112.81	26.46*** (2.41)	-0.14 (0.10)	0.06 (0.27)	-5.11 (2.87)	-0.61 (2.93)	-1.60 (4.74)	-4.86 (5.25)	-5.29 (5.33)	-3.47 (3.22)	-5.50 (3.91)	2.47 (3.16)	3.64 (2.90)
Sweets and salty snacks	5,089	78.20	13.41*** (1.47)	-0.62*** (0.06)	-0.07 (0.17)	4.35* (1.78)	13.74*** (1.74)	2.61 (3.23)	-3.67 (3.46)	-5.80 (3.51)	-1.24 (2.06)	-0.65 (2.39)	-3.86* (1.91)	1.51 (1.82)
Water	13,863	1217.87	-30.52* (14.51)	-8.83*** (0.59)	12.79*** (1.61)	129.68*** (17.23)	130.91*** (17.24)	14.04 (28.65)	10.61 (31.64)	-56.65 (32.09)	26.39 (19.53)	60.98** (23.21)	-48.97** (18.49)	2.50 (17.40)
Soft drinks	2,690	745.51	161.71*** (19.96)	-6.49*** (0.86)	1.48 (2.09)	23.69 (27.26)	111.09*** (21.53)	-0.97 (39.48)	-67.22 (43.66)	-146.70** (46.45)	-36.21 (26.24)	-79.49* (31.08)	-3.63 (23.80)	23.93 (25.77)
Fruit and vegetable juice	6,671	743.01	115.00*** (12.47)	-6.03*** (0.50)	4.93** (1.43)	-11.71 (15.24)	36.73* (14.96)	-73.06** (26.37)	-123.69*** (28.57)	-188.71*** (28.67)	-13.85 (17.17)	24.24 (19.93)	-25.44 (16.12)	30.07* (14.93)

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Table III-6. Regression coefficients (g/day) for consumption-day amounts in mutual adjusted linear mixed-effects models, n=8,522 *(continued)*

Food group	n	IC	*Sex* Male[1]	*Age* Years	*BMI* kg/m²	*Smoking status* Former[2]	*Smoking status* Current[2]	*Years of education* 12-13[3]	*Years of education* 14-16[3]	*Years of education* 17-18[3]	*Household net income (€)* 1,500-<3,000[4]	*Household net income (€)* ≥3,000[4]	*Living with a partner* Yes[5]	*Employment* Yes[5]
			ß (SE)											
Coffee	13,811	378.59	35.61*** (7.12)	1.25*** (0.31)	3.21*** (0.80)	70.16*** (8.46)	206.16*** (8.31)	-11.56 (13.83)	-11.33 (15.38)	-31.58* (15.66)	-7.72 (9.64)	10.42 (11.53)	9.00 (9.41)	59.50*** (8.70)
Tea	7,045	736.86	-79.47*** (14.19)	0.65 (0.56)	-0.38 (1.57)	4.39 (16.57)	20.65 (17.79)	73.54** (26.94)	153.53** * (29.87)	111.13** (29.93)	-27.07 (18.24)	-11.68 (22.28)	-113.81*** (17.59)	46.96** (16.71)
Wine	2,727	109.99	61.23*** (8.46)	-0.43 (0.39)	4.30*** (1.05)	31.68** (9.27)	63.59*** (10.19)	38.06 (19.45)	29.26 (20.82)	37.25 (20.66)	8.11 (12.82)	24.85 (14.39)	-17.33 (11.57)	23.91* (10.45)
Beer	3,894	475.13	381.03*** (25.21)	-6.39*** (0.98)	17.75*** (2.79)	62.97* (25.52)	169.16*** (25.83)	-68.65 (56.35)	-59.14 (59.34)	-124.04* (59.68)	2.35 (31.16)	19.95 (36.20)	-107.33** (29.85)	-37.31 (27.77)

Abbreviations: BMI, body mass index; IC, intercept; SE, standard error

*** p<0.0001; ** p<0.01; * p<0.05

[1]Reference category: female; [2]Reference category: never smoker; [3]Reference category: 9-10 years; [4]Reference category: <1,500€; [5]Reference category: no

Both the variance inflation factor and the phi coefficient indicated a correlation of the determinants years of education and household net income in the linear-mixed effects models (VIF>2 for all food groups; r_{φ}=0.37).

The results of the LASSO variable selection using the BIC as selection strategy are shown in Table III-7. Sex and years of education were selected for the model for all groups of foods and beverages. In contrast, BMI and living with a partner were selected for 16 out of 22 food groups, respectively. Determinants of consumption-day amounts were shown to be less relevant for the food groups ‘fish and shellfish’ and ‘soup and stew’.

Table III-7. Relevant determinants for consumption-day amounts of selected food groups in order of importance

Determinant	*No. of food groups with positive selection*[1]	*Food group that determinant was not selected for*
Sex	22	-
Years of education	22	-
Smoking status	21	Fish and shellfish
Age	20	Fish and shellfish, soup and stew
Household net income	20	Milk and dairy products, fish and shellfish
Employment	18	Pasta, vegetables, fish and shellfish, soup and stew
BMI	16	Breakfast cereals, milk and dairy products, fresh fruits, vegetables, sweets and salty snacks, soup and stew
Living with a partner	16	Pasta, potatoes, fish and shellfish, cake and cookies, soup and stew, water

Abbreviation: BMI, body mass index

[1] Bayesian information criterion was used for selection of the most suitable LASSO model

The relevance of determinants of consumption-day amounts varied across groups of foods and beverages (Table IX-2, Appendix). For 11 out of 22 food groups all investigated factors were selected for the respective model. These food groups included bread and buns, rice, cheese, processed meat, meat, soft drinks, fruit and vegetable juice, wine, beer, coffee and tea. For the food group ‘soup and stew’, four out of eight determinants were selected for the model including sex, smoking status, household net income and years of education. Only three determinants were relevant for consumption-day amounts of the food group ‘fish and shellfish’: sex, BMI and years of education.

3 Feasibility and evaluation study of the 24-hour food list (Objective 3)

Among all GNC pilot study subjects, 36% of individuals did not participate in the feasibility and evaluation study. About 28% refused or were unable to participate, primarily because of lack of access to the Internet (Table III-8). Non-participation was higher for women than for men and it was higher for older than for younger individuals. Another eight percent of individuals who initially agreed to participate did not respond to the first online invitation. Overall, at least one 24-h FL was obtained from 323 study participants, corresponding to an overall response proportion of 64%. Response proportions were largest in Berlin-South (86%), Berlin-North (74%), and Kiel (72%). The response proportion in study centers using comparable recruitment and prompting procedures was 63%.

Of the study population, 52% were female and 51% were younger than 50 years of age (Table III-8). Differences between study centers with respect to sex were marginal except for the study center in Berlin-South, which recruited a greater proportion of women (79%). Differences between study centers regarding age resulted from different approaches of selecting the study sample, as described in the method section. Compliance was highest for the first application of the 24-h FL and lower for the second and third applications. Among all participants, 100%, 85%, and 68% completed the 24-h FL one, two, or three times, respectively. Moreover, 90% filled in at least one 24-h FL and the FFQ.

Table III-8. Characteristics of participants and non-participants of the 24-h food list's feasibility study, n=505

	Total	Study center					
		Augs-burg	*Berlin-North*	*Berlin-South*	*Frei-burg*	*Kiel*	*Regens-burg*
	n (%)						
Individuals invited to 24-h FL	505	74	27	44	157	102	101
Non-participants	140 (28)	27 (36)	0 (0)	3 (7)	40 (25)	21 (21)	49 (49)
Female	85 (61)	19 (70)	-	0 (0)	24 (60)	11 (52)	31 (63)
Age <50 years[1]	44 (31)	9 (33)	-	1 (33)	13 (33)	7 (33)	14 (29)
Reason: no web access	97 (69)	15 (56)	-	3 (100)	30 (75)	18 (86)	31 (63)
No reaction after online invitation	42 (8)	0 (0)	7 (26)	3 (7)	24 (15)	8 (8)	0 (0)
Participants	323 (64)	47 (64)	20 (74)	38 (86)	93 (59)	73 (72)	52 (51)
Female	169 (52)	22 (47)	8 (40)	30 (79)	44 (47)	40 (55)	25 (48)
Age <50 years[1]	164 (51)	25 (53)	8 (40)	22 (58)	46 (49)	44 (60)	19 (37)
BMI ≥25 kg/m²[2]	171 (53)	28 (60)	10 (50)	17 (45)	50 (54)	33 (45)	33 (63)
High School[2]	185 (57)	19 (40)	10 (50)	24 (63)	63 (68)	43 (59)	26 (50)
Never Smoker[3]	221 (68)	28 (60)	16 (80)	26 (68)	71 (76)	40 (55)	40 (77)
Married[4]	212 (66)	37 (79)	11 (55)	21 (55)	63 (68)	41 (56)	39 (75)
No. of 24-h FLs completed							
1 24-h FL	323 (100)	47 (100)	20 (100)	38 (100)	93 (100)	73 (100)	52 (100)
2 24-h FLs	275 (85)	42 (89)	17 (85)	36 (95)	77 (83)	67 (92)	36 (69)
3 24-h FLs	219 (68)	26 (55)	14 (70)	35 (92)	53 (57)	64 (88)	27 (52)
At least 1 24-h FL and FFQ	294 (90)	35 (74)	19 (95)	37 (97)	79 (85)	72 (99)	52 (100)

Abbreviations: BMI, body mass index; FFQ, food frequency questionnaire; 24-h FL, 24-hour food list

[1]Age categories: 20-49 years vs. 50-70 years; [2]Education categories: secondary school vs. high school; [3]Smoking categories: never smoker vs. ever smoker; [4]Family status categories: married vs. single, divorced

Considering each administration separately, a total of 817 24-h FLs were completed (Table III-9). The median completion time was nine minutes and this was very similar across study centers. On average, women required two minutes more to complete the questionnaire than men. Older individuals required four minutes more than younger participants. Of all 24-h FLs, 57% were completed on the day the participant was prompted. The lowest number of 24-h FLs completed on time was found in Berlin-North and Regensburg.

Table III-9. Duration and timeliness of 24-h food lists completed, n=817

		Study center					
	Total	*Augs-burg*	*Berlin-North*	*Berlin-South*	*Freiburg*	*Kiel*	*Regens-burg*
Total 24-h FLs completed, n (%)	817 (100)	115 (14)	51 (6)	109 (13)	223 (27)	204 (25)	115 (14)
Duration per 24-h FL (min), median (IQR)	9 (7-13)	9 (7-12)	8 (7-14)	9 (7-14)	9 (7-12)	9 (7-12)	9 (7-15)
Female	10 (7-13)	9 (8-12)	9 (7-14)	9 (6-14)	10 (8-12)	10 (7-12)	10 (8-15)
Male	8 (7-13)	8 (6-13)	8 (7-14)	8 (7-12)	8 (7-12)	8 (7-18)	9 (7-11)
Age 20-49 years	8 (6-10)	8 (6-10)	7 (7-8)	8 (6-9)	7 (6-10)	8 (6-10)	8 (7-9)
Age 50-70 years	12 (8-16)	11 (8-34)	12 (8-16)	13 (9-16)	12 (8-15)	12 (8-19)	11 (8-15)
24-h FL on time[1], n (%)	467 (57)	72 (63)	5 (10)	65 (60)	160 (72)	146 (72)	19 (17)
24-h FL not on time[2], n (%)	350 (43)	43 (37)	46 (90)	44 (40)	63 (28)	58 (28)	96 (83)

Abbreviations: IQR, interquartile range; 24-h FL, 24-hour food list

[1]24-h FL completion on the day of prompting the study participant; [2]24-h FL completion not on the day of prompting the study participant

The evaluation form was completed by 78% of participants (Figure III-2). Over 90% of participants rated the understandability, usability, and visual presentation of the 24-h FL as good or very good. At least 80% reported good or very good perceived completeness of the list of food items and confirmed that the questionnaire reflected their diet of the previous 24 hours. Approximately 90% had no difficulties in finding the foods they had consumed and matching them to the item list (data not shown). Also, no difficulties were reported in recalling what was consumed the day before. Additional assistance in navigating the questionnaire in terms of the need for supplementary legends etc. was stated as not being necessary. About 95% of participants indicated they would be willing to repeat the web-based version of the 24-h FL.

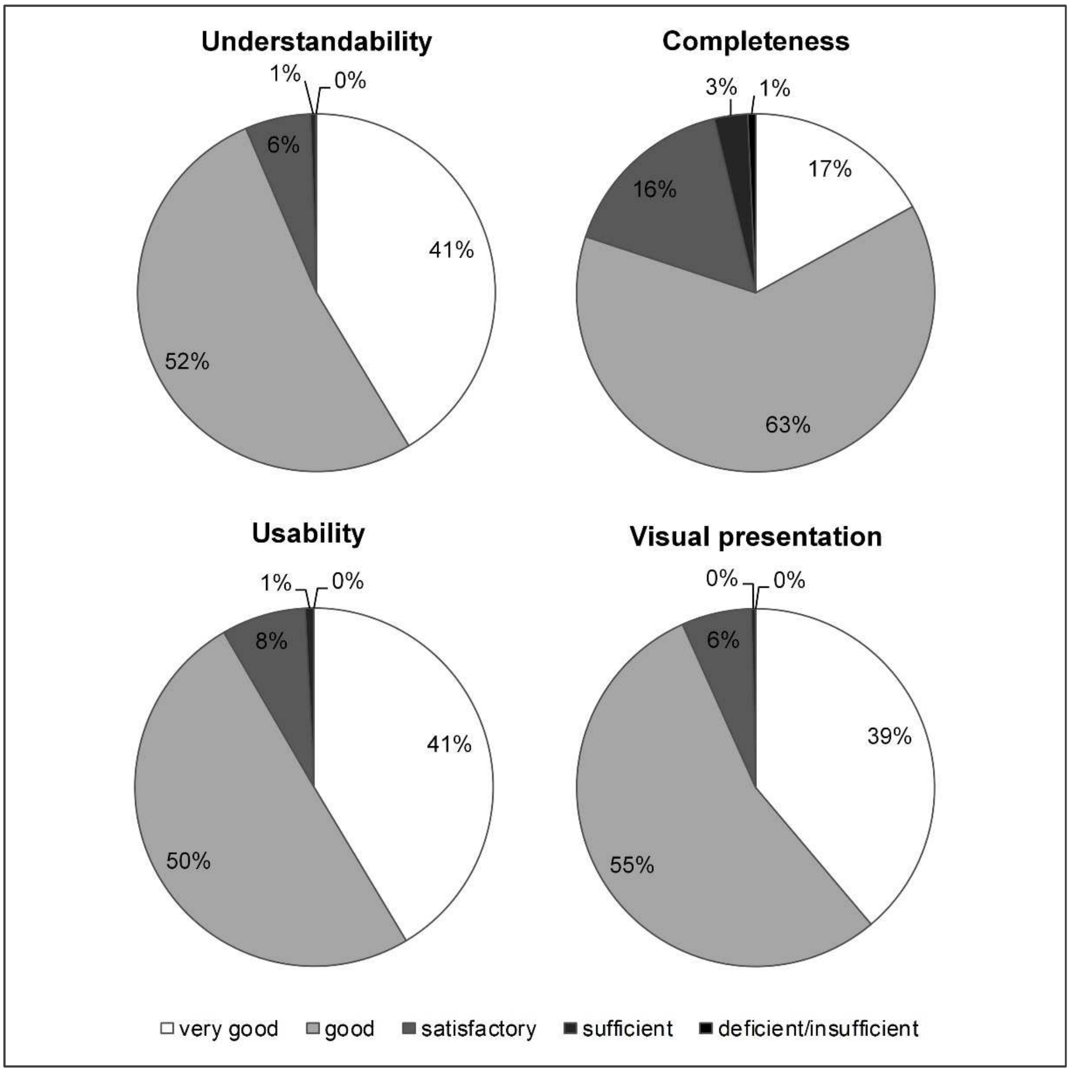

Figure III-2. Acceptance of the 24-hour food list among participants who completed the evaluation form, n=252

Only few food items were declared missing on the 24-h FL. Missing food items predominantly included regional specialties or were foods assignable to existing food items. All but four food items including hot smoked herring, eel, groats, and strong beer/malt liquor were chosen by at least one study participant.

Compared to an FFQ, the proportion of participants consistently classified as consumers or non-consumers of selected food groups by the 24-h FL increased with an increasing number of 24-h FLs completed (Table III-10). Food groups for which almost all participants were consistently classified irrespective of the number of 24-h FLs completed were ‘bread and buns’, ‘non-alcoholic beverages’, and ‘coffee and tea’ (93 to 100%). The proportion of participants that was misclassified as non-consumers by the 24-h FL increased with a lower number of 24-h FLs completed. In total, seven out of 24 food groups misclassified a high proportion of participants with three 24-h FLs completed (40 to 60%) with fish, desserts, and soup and stew showing the highest misclassification rates. Food groups with a high proportion of true non-consumers according to the FFQ were breakfast cereals, dried fruits, and tofu (data not shown). These food groups showed a correct classification of 57 to 76% in the 24-h FLs. Misclassification as consumers by the 24-h FL was rare, with breakfast cereals, dried fruits, and nuts and seeds showing misclassification rates of about two percent.

Table III-10. Classification proportions of participants comparing food group intake data according to the 24-h food list and the food frequency questionnaire, n=294

Food group	*Consistently classified as consumer or non-consumer*[1]			*Inconsistently classified in 24-h FL as non-consumer*[2]			*Inconsistently classified in 24-h FL as consumer*[3]
	No. of 24-h FL completed						
	3	2	1	3	2	1	
	%						
Bread and buns	100	99	93	0	1	7	0
Non-alcoholic beverages	100	99	95	0	1	5	0
Coffee and tea	98	98	95	2	2	5	0
Fruits	94	90	77	6	10	23	0
Cheese	89	81	62	11	19	38	0
Milk and dairy products	86	80	65	14	18	34	1
Cooked vegetables	85	71	54	15	29	46	0
Meat	83	76	57	17	24	43	0
Processed meat	82	79	67	16	20	32	1
Cookies, sweets	82	74	52	17	25	47	0
Raw vegetables	80	74	49	20	26	51	0
Rice, pasta and other grains	79	61	44	21	39	56	0
Tofu	76	75	74	24	24	25	0
Potatoes	74	58	37	25	41	63	0
Alcoholic beverages	73	66	48	27	34	52	0
Cake	63	51	36	36	48	64	1
Gravy	63	50	32	35	49	66	1
Breakfast cereals	58	55	45	40	43	52	2
Dried fruits	57	54	45	41	45	53	2
Eggs	55	42	23	45	58	77	0
Nuts and seeds	52	48	32	43	48	64	3
Fish	44	32	20	56	67	80	0
Desserts	43	35	23	57	65	76	1
Soup and stew	39	27	15	61	73	84	0

Abbreviation: 24-h FL, 24-hour food list

[1]Consumer in at least one 24-h FL and FFQ or non-consumer in all 24-h FLs and FFQ; [2]Non-consumer in all 24-h FLs and consumer in FFQ; [3]Consumer in at least one 24-h FL and non-consumer in FFQ.

4 An application example for the estimation of usual dietary intake (Objective 4)

The characteristics of the GNC pilot study population are presented in Table III-11 (after exclusion of non-participants and participants with missing information on relevant baseline characteristics). Overall, the mean age of the study population was 48 years and 52% of the study participants were women.

Table III-11. Characteristics of pilot study participants of the German National Cohort, n=306[1]

	Age group (years)		
	20 to ≤34	>34 to ≤64	>64 to 80
n	54	215	37
Female, %	53.7	52.1	46.0
Age, years (mean, SD)	26.9 (4.4)	50.6 (8.2)	67.6 (1.4)
BMI, kg/m^2 (mean, SD)	24.7 (4.6)	26.2 (4.9)	27.6 (6.7)
Years of education[2], %			
9 to 10 years	0	1.9	8.1
12 to 13 years	31.5	36.3	27.0
14 to 16 years	27.8	24.2	24.3
17 to 18 years	40.7	37.7	40.5
Smoking status, %			
Never	63.0	44.7	37.8
Former	16.7	31.2	56.8
Current	20.4	24.2	5.4
Household net income, %			
<1,500 €	42.6	9.3	10.8
1,500 to <3,000 €	38.9	37.2	43.2
≥3,000 €	18.5	53.5	46.0

Abbreviations: BMI, body mass index; SD, standard deviation

[1]After exclusion of non-participants (n=182) and participants with missing information on relevant baseline characteristics (n=20); [2]According to the International Standard Classification of Education 1997 [66]

For model A (i.e., inclusion of sex, age and BMI as explanatory variables), the determination of a valid regression equation was not possible for the food item hot smoked herring (buckling) because there were too little observations in the NVS II data

(data not shown). Applying model B (i.e., inclusion of sex, age, BMI, smoking status, years of education and household net income as independent variables), no prediction model could be calculated for six food items: filled potatoes, mirabelle plum, cape gooseberry, roast pork, hot smoked herring (buckling), and sprat. For some study participants, the food items soured milk, kefir, cabanossi, roast pork, calamari, chocolate mousse, and elder juice revealed negative values for the usual dietary intake, suggesting unreliable regression equations.

Table III-12 exemplarily shows the usual dietary intake distributions for selected food items on the 24-h FL (i.e., most frequently and fewest consumed food item for each food group) (n=49). The number of consumers ranged from one for the food items gooseberries, Bavarian veal sausage, other offal, and waffles to 283 for mineral water/drinking water. For the presented food items, the lowest difference in means between model A and model B was found for sour milk cheese (0.0002 g/day), whereas coffee/espresso showed the highest difference in means (4.3498 g/day). With respect to all food items on the 24-h FL, the highest difference in means was observed for soured milk (7.6583 g/day). The highest maximum value of usual intake was observed for mineral water/drinking water. For 17 out of 49 food items presented, statistically significant differences in distributions between the two prediction models were found. Overall, for 31% of food items, the distribution differed statistically significantly between model A and model B.

For most of the food items that were statistically significantly different in their distribution, the percentage difference in means was less or equal than 10% except for seven food items including cold sweet soup with fruits, blueberries, crème fraiche, codfish, orange juice, cola and pollock (Table III-13). Except for orange juice (n=52) and cola (n=42), those food items were less frequently consumed in the GNC pilot study population (n≤14). Overall, the percentage difference in means ranged from 0.4% for multigrain bread and buns to 69.8% for the item cold sweet soup with fruits (data not shown).

Table III-12. Distribution of usual dietary intake (g/day) across food items using two different prediction models[1], n=306

Food item	*No. of consumers*	*Model*	*Mean*	*SD*	*Median*	*P25*	*P75*	*Min*	*Max*	*p-value*[2]
Mineral water, drinking water	283	A	995.68	369.63	1110.18	933.90	1231.15	0.00	1557.43	0.9994
		B	995.53	374.99	1118.15	899.58	1243.37	0.00	1620.10	
Coffee, espresso	259	A	498.69	236.26	600.44	429.94	654.66	0.00	729.88	0.0331
		B	494.34	247.48	562.51	396.39	649.85	0.00	852.43	
Butter	194	A	11.68	10.81	10.36	0.00	19.02	0.00	30.47	<0.0001
		B	11.40	10.68	10.51	0.00	18.85	0.00	35.73	
Semi-hard and hard cheese	193	A	12.09	11.36	10.32	0.00	21.65	0.00	35.40	0.0079
		B	12.18	11.42	10.56	0.00	21.93	0.00	34.72	
Raw tomatoes	155	A	23.84	28.27	23.28	0.00	41.72	0.00	100.70	0.2820
		B	23.78	28.19	23.30	0.00	42.68	0.00	101.93	
Pasta, noodles	146	A	44.96	57.80	0.00	0.00	65.39	0.00	219.53	0.0050
		B	44.54	57.16	0.00	0.00	65.12	0.00	218.23	
Wheat bread and buns, baguette	141	A	21.73	27.94	0.00	0.00	39.42	0.00	108.22	<0.0001
		B	21.43	27.60	0.00	0.00	36.77	0.00	110.27	
Milk	139	A	89.94	116.66	0.00	0.00	175.25	0.00	379.58	0.0015
		B	86.41	115.84	0.00	0.00	165.32	0.00	436.38	

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Table III-12. Distribution of usual dietary intake (g/day) across food items using two different prediction models[1], n=306 *(continued)*

Food item	*No. of consumers*	*Model*	*Mean*	*SD*	*Median*	*P25*	*P75*	*Min*	*Max*	*p-value*[2]
Potatoes	112	A	28.46	43.72	0.00	0.00	54.27	0.00	180.51	<0.0001
		B	28.23	43.38	0.00	0.00	53.89	0.00	180.56	
Nuts	106	A	8.37	13.88	0.00	0.00	13.87	0.00	61.10	0.6944
		B	8.37	14.11	0.00	0.00	13.50	0.00	69.06	
Apple	104	A	112.91	98.43	86.65	0.00	180.92	0.00	278.64	0.2844
		B	113.04	98.56	87.27	0.00	182.32	0.00	278.94	
Salami	100	A	6.15	10.37	0.00	0.00	11.22	0.00	46.14	<0.0001
		B	5.92	10.13	0.00	0.00	10.59	0.00	44.06	
Beer	89	A	137.72	256.57	0.00	0.00	205.11	0.00	1164.00	0.0632
		B	136.11	260.52	0.00	0.00	196.85	0.00	1242.93	
Boiled egg	85	A	8.59	15.91	0.00	0.00	20.88	0.00	71.54	<0.0001
		B	8.37	15.45	0.00	0.00	19.74	0.00	73.15	
Chocolate bar	85	A	6.33	11.60	0.00	0.00	12.80	0.00	52.53	0.0144
		B	6.19	11.38	0.00	0.00	11.88	0.00	55.25	
Muesli	73	A	7.55	15.41	0.00	0.00	0.00	0.00	67.14	0.0216
		B	7.44	15.18	0.00	0.00	0.00	0.00	72.99	

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Table III-12. Distribution of usual dietary intake (g/day) across food items using two different prediction models[1], n=306 *(continued)*

Food item	*No. of consumers*	*Model*	*Mean*	*SD*	*Median*	*P25*	*P75*	*Min*	*Max*	*p-value*[2]
Cooked tomatoes	71	A	6.82	14.02	0.00	0.00	0.00	0.00	72.81	0.0047
		B	7.29	15.28	0.00	0.00	0.00	0.00	70.36	
Tart, pie	69	A	16.97	35.35	0.00	0.00	0.00	0.00	180.77	0.1417
		B	16.92	35.16	0.00	0.00	0.00	0.00	176.90	
Pork	66	A	12.56	28.57	0.00	0.00	0.00	0.00	155.25	0.0108
		B	12.10	28.29	0.00	0.00	0.00	0.00	168.40	
Crisps, crackers	65	A	6.10	13.57	0.00	0.00	0.00	0.00	62.75	0.6720
		B	6.08	13.72	0.00	0.00	0.00	0.00	69.59	
Fruit tea	49	A	56.86	148.69	0.00	0.00	0.00	0.00	701.06	0.8793
		B	57.27	151.08	0.00	0.00	0.00	0.00	763.59	
Pizza, baguette	45	A	17.68	48.65	0.00	0.00	0.00	0.00	334.29	0.3345
		B	17.62	48.56	0.00	0.00	0.00	0.00	338.24	
Vegetable stew	40	A	24.21	67.74	0.00	0.00	0.00	0.00	431.16	<0.0001
		B	25.94	71.93	0.00	0.00	0.00	0.00	445.95	
Tomato sauce	38	A	4.92	14.08	0.00	0.00	0.00	0.00	89.48	0.7815
		B	4.91	14.10	0.00	0.00	0.00	0.00	98.23	

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Table III-12. Distribution of usual dietary intake (g/day) across food items using two different prediction models[1], n=306 *(continued)*

Food item	*No. of consumers*	*Model*	*Mean*	*SD*	*Median*	*P25*	*P75*	*Min*	*Max*	*p-value*[2]
Ice cream	31	A	5.09	17.37	0.00	0.00	0.00	0.00	112.01	0.2151
		B	5.04	17.07	0.00	0.00	0.00	0.00	110.64	
Cream pie. cake with butter crème or custard filling	27	A	5.41	19.37	0.00	0.00	0.00	0.00	165.78	0.0167
		B	5.26	18.63	0.00	0.00	0.00	0.00	158.74	
Filled chocolates	25	A	1.50	5.57	0.00	0.00	0.00	0.00	38.46	0.0097
		B	1.35	5.11	0.00	0.00	0.00	0.00	37.91	
Salmon	22	A	2.90	11.85	0.00	0.00	0.00	0.00	92.08	0.1951
		B	2.90	11.77	0.00	0.00	0.00	0.00	91.18	
Flax seeds	18	A	0.46	2.08	0.00	0.00	0.00	0.00	14.68	0.8986
		B	0.44	2.07	0.00	0.00	0.00	0.00	17.08	
Crème of vegetable soup	15	A	7.51	34.91	0.00	0.00	0.00	0.00	264.26	0.0103
		B	7.28	33.87	0.00	0.00	0.00	0.00	264.02	
Pancakes	10	A	4.05	22.80	0.00	0.00	0.00	0.00	194.23	0.1602
		B	3.85	21.42	0.00	0.00	0.00	0.00	164.39	
Lasagna	8	A	3.09	19.58	0.00	0.00	0.00	0.00	166.56	0.8438
		B	3.11	19.91	0.00	0.00	0.00	0.00	177.44	

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Table III-12. Distribution of usual dietary intake (g/day) across food items using two different prediction models[1], n=306 *(continued)*

Food item	*No. of consumers*	*Model*	*Mean*	*SD*	*Median*	*P25*	*P75*	*Min*	*Max*	*p-value*[2]
Flatbread	8	A	2.03	13.84	0.00	0.00	0.00	0.00	164.56	0.0781
		B	1.73	11.60	0.00	0.00	0.00	0.00	134.75	
Flavored milk (drinks)	6	A	3.84	28.86	0.00	0.00	0.00	0.00	325.40	0.0625
		B	4.47	33.55	0.00	0.00	0.00	0.00	351.92	
Avocado	6	A	0.67	5.00	0.00	0.00	0.00	0.00	57.80	0.2188
		B	0.72	5.42	0.00	0.00	0.00	0.00	65.85	
Hot wine punch	6	A	1.89	13.42	0.00	0.00	0.00	0.00	108.44	0.1563
		B	1.72	12.40	0.00	0.00	0.00	0.00	110.95	
Sugar beet molasses	5	A	0.27	2.31	0.00	0.00	0.00	0.00	24.93	0.3125
		B	0.33	2.77	0.00	0.00	0.00	0.00	29.48	
Vegetable, cereal patty	5	A	1.51	12.26	0.00	0.00	0.00	0.00	141.94	0.3125
		B	1.85	16.10	0.00	0.00	0.00	0.00	195.10	
Potato pancake	5	A	1.80	14.30	0.00	0.00	0.00	0.00	131.77	0.0625
		B	1.65	13.14	0.00	0.00	0.00	0.00	122.76	
Soy sauce	5	A	0.09	0.71	0.00	0.00	0.00	0.00	8.05	0.8125
		B	0.09	0.70	0.00	0.00	0.00	0.00	7.67	

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Table III-12. Distribution of usual dietary intake (g/day) across food items using two different prediction models[1], n=306 *(continued)*

Food item	*No. of consumers*	*Model*	*Mean*	*SD*	*Median*	*P25*	*P75*	*Min*	*Max*	*p-value*[2]
Puffed rice	4	A	0.38	3.60	0.00	0.00	0.00	0.00	49.84	1.0000
		B	0.45	4.74	0.00	0.00	0.00	0.00	59.98	
Sour milk cheese	3	A	0.20	2.22	0.00	0.00	0.00	0.00	34.78	1.0000
		B	0.20	2.29	0.00	0.00	0.00	0.00	36.19	
Kale, borecole	3	A	0.33	3.31	0.00	0.00	0.00	0.00	35.85	0.5000
		B	0.31	3.10	0.00	0.00	0.00	0.00	35.59	
Collared pork	3	A	0.42	4.61	0.00	0.00	0.00	0.00	69.11	0.5000
		B	0.33	3.88	0.00	0.00	0.00	0.00	56.99	
Mackerel	2	A	0.29	3.52	0.00	0.00	0.00	0.00	45.91	1.0000
		B	0.35	4.83	0.00	0.00	0.00	0.00	79.69	
Diet lemonade	2	A	1.84	22.87	0.00	0.00	0.00	0.00	312.35	1.0000
		B	1.90	23.45	0.00	0.00	0.00	0.00	307.77	
Gooseberries	1	A	0.33	5.69	0.00	0.00	0.00	0.00	99.56	1.0000
		B	0.19	3.36	0.00	0.00	0.00	0.00	58.79	

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Table III-12. Distribution of usual dietary intake (g/day) across food items using two different prediction models[1], n=306 *(continued)*

Food item	*No. of consumers*	*Model*	*Mean*	*SD*	*Median*	*P25*	*P75*	*Min*	*Max*	*p-value*[2]
Bavarian veal sausage	1	A	0.11	1.92	0.00	0.00	0.00	0.00	33.65	1.0000
		B	0.10	1.82	0.00	0.00	0.00	0.00	31.86	
Waffles	1	A	0.24	4.16	0.00	0.00	0.00	0.00	72.70	1.0000
		B	0.22	3.84	0.00	0.00	0.00	0.00	67.19	

Abbreviation: BMI, body mass index; P, Percentile; SD, standard deviation

[1]Model A: parsimonious prediction model with sex, age and BMI as independent variables, Model B: comprehensive prediction model with sex, age, BMI, smoking status, years of education, and household net income as independent variables; [2]Differences between models were tested using the Wilcoxon signed-rank sum test

Table III-13. Percentage difference in means of usual dietary intake[1] across two prediction models[2]

Percentage difference in means	*No. of food items*	*Food items (no. of consumers on 24-h FL)[3]*
≤ 1%	7	Multigrain bread and buns (n=91), pasta/noodles (n=146), potatoes (n=112), semi-hard and hard cheese (n=193), soft cheese (n=66), banana (n=103), coffee (n=259)
> 1 to ≤ 5%	45	Rye bread and buns (n=69), brown bread and buns (n=88), wheat bread and buns (n=141), whole grain bread and buns (n=137), butter (spread) (n=194), honey (spread) (n=67), marmalade/jam (n=173), muesli (n=73), corn flakes (n=21), chips/French fries (n=24), milk (n=139), flavored yoghurt (n=82), mozzarella (n=23), tangerine (n=72), kiwi (n=36), raw carrots (n=86), raw turnip cabbage (n=16), lettuce (n=145), cooked capsicum / pepper, cauliflower (n=21), broccoli (n=36), red cabbage (n=19), mushrooms (n=43), salami (n=100), ham sausage (n=54), bologna/polony (n=51), liver sausage (n=43), raw ham (n=45), cooked ham (n=67), pork (n=66), poultry (n=50), boiled egg (n=85), crème of vegetable soup (n=15), vegetable pie (n=28), pound cake/muffin (n=53), cream pie/cake with butter crème or custard filling (n=27), cookies or biscuits with (n=70)/ without (n=69) chocolate icing, other chocolate or sweets with chocolate (n=79), chocolate bar (n=85), sweets without chocolate (n=50), apple juice (n=80), black tea (n=69), herbal tea (n=92), red wine (n=76)
> 5% to ≤ 10%	11	Margarine (spread) (n=61), half-fat margarine (spread) (n=40), plum (n=30), olives (n=30), cooked tomatoes (n=71), bratwurst (n=18), vegetable stew (n=40), filled chocolates (n=25), lemonade (n=36), other fruit juice (n=29), liqueur (n=8)
> 10%	7	Crème fraiche (n=14), blueberries (n=7), codfish (n=9), saithe / pollock (n=12), cold sweet soup with fruits (n=8), orange juice (n=52), cola (n=42)

Abbreviation: BMI, body mass index; 24-h FL, 24-hour food list

[1]Food items were statistically significantly different in their distribution between models; [2]Model A: parsimonious prediction model with sex, age and BMI as independent variables, Model B: comprehensive prediction model with sex, age, BMI, smoking status, years of education, and household net income as independent variables; [3]Food items are sorted by food groups

For food items with less than two observations (n=4; gooseberries, Bavarian veal sausage, other offal, waffles), no Kappa statistic could be calculated. In addition, it was not possible to determine the strength of agreement for another nine food items that were either not consumed by GNC pilot study participants (n=4; hot smoked herring, eel, groats, strong beer/malt liquor) or did not reveal reliable prediction models (n=6; filled potatoes, mirabelle plum, cape gooseberry, roast pork, hot smoked herring, sprat).

Table III-14 shows the strength of agreement between the two prediction models for 220 food items with respect to ranking of study participants according to individual usual dietary intake of the respective food item. For about 65% of food items, a substantial to almost perfect agreement was found, indicating that study participants were ranked into the same quantile irrespective of the applied prediction model. In contrast, 29 food items showed a slight to poor agreement (Table III-15). These food items comprised less frequently consumed foods in the study population. Related food groups predominantly included fish and shellfish, sausages and ham, meat and meat products, cooked vegetables, and fruits.

Table III-14. Strength of agreement between two prediction models[1] for 220 food items on the 24-h food list, n=306[2]

Kappa statistic[3]	*Strength of agreement[4]*	*No. of food items (%)*
<0.00	Poor	7 (3)
0.00 – 0.20	Slight	22 (10)
0.21 – 0.40	Fair	14 (6)
0.41 – 0.60	Moderate	34 (15)
0.61 – 0.80	Substantial	74 (34)
0.81 – 1.00	Almost perfect	69 (31)

Abbreviation: BMI, body mass index

[1]Model A: parsimonious prediction model with sex, age and BMI as independent variables, Model B: comprehensive prediction model with sex, age, BMI, smoking status, years of education, and household net income as independent variables; [2]Only positive intakes of 24-h FL items; [3]Unweighted Cohen's Kappa coefficients; [4]According to [68]

Table III-15. Food items with poor to slight agreement across prediction models[1]

Food item	*No. of consumers*	*Kappa statistic*[2]	*Strength of agreement*[3]
Mackerel	2	-1.0000	Poor
Rolled pickled herring (rollmops)	2	-1.0000	
Tiramisu	2	-1.0000	
Kale, borecole	3	-0.5000	
Trout	5	-0.2500	
Soy sauce	5	-0.2500	
Herring	11	-0.1000	
Sour milk cheese	3	0.0000	Slight
Pork goulash	6	0.0000	
Codfish	9	0.0000	
Chocolate mousse	9	0.0000	
Hot wine punch	6	0.0000	
Cold sweet soup with fruits	8	0.0476	
Tofu	13	0.0714	
Kefir	7	0.1250	
Blueberries	7	0.1250	
Aspic	7	0.1250	
Gyros	7	0.1250	
Calamari	7	0.1250	
Strawberries	9	0.1667	
White cabbage	18	0.1667	
Rosé wine	9	0.1667	
Cabanossi	11	0.1750	
Puffed rice	4	0.2000	
Asparagus	4	0.2000	
Shashlik, meat skewer	4	0.2000	
Fish sticks	4	0.2000	
Fish bake	4	0.2000	
Malt beer	4	0.2000	

Abbreviation: BMI, body mass index

[1]Model A: parsimonious prediction model with sex, age and BMI as independent variables, Model B: comprehensive prediction model with sex, age, BMI, smoking status, years of education, and household net income as independent variables; [2]Unweighted Cohen's Kappa coefficients; [3]According to [68]

IV DISCUSSION

The overall objective of this thesis was to develop and evaluate an innovative approach for dietary assessment in large-scale epidemiological studies for Germany to overcome some of the dietary assessment problems that are inherent to large-scale settings. The 24-h FL included 246 food items and was designed to assess information on the consumption of selected food items during the previous 24 hours (O1). The overall response proportion in the feasibility study was 64%. The completion time of the 24-h FL was nine minutes on average and acceptance by study participants was high as shown by the positive results of the evaluation form (O3). Relevant determinants for the consumption-day amount across selected food groups were sex, age, BMI, smoking status, years of education, household net income, living with partner and employment status (O2). With respect to usual dietary intake distributions, however, the application of a comprehensive prediction model compared to a parsimonious prediction model seemed to be important for less frequently consumed food items only (O4).

1 Results in the context of current knowledge

1.1 General aspects

Various innovative approaches are currently addressing the methodological challenges faced in dietary assessment in epidemiological studies. Some focus on new methodologies, such as combining different assessment instruments by statistical modeling [11, 16, 20], while others address new technologies, such as dietary assessment using mobile phones [36] or web-based 24-h DR applications [21, 22].

With respect to large-scale epidemiological studies, web-based instruments are of particular relevance as their application offers several potential advantages. Innovative technologies of conventional instruments are promising to enhance dietary assessment through lower costs and more efficient data collection. Moreover, they offer the possibility for data collection at a time and location that is convenient for the study participant [10]. Recent developments of new technologies prefer short-term dietary assessment instruments such as the 24-h DR [10, 21, 22, 24]. In general, available instruments differ with respect to the number of foods assessed, the collection of information on portion size, and the inclusion of probes, but all are stand-alone instruments. For example, the ASA24 represents a detailed automated self-administered 24-h DR. It collects and codes dietary intake data and includes detailed questions about portion sizes and food preparation methods [22, 53]. Likewise, the web-based 24-h DR DietDay contains 9,349 foods, assesses information on portion sizes and preparation methods, and was designed for repeated administrations [21]. The Oxford WebQ is a low-cost, web-based method for assessing previous 24-hour dietary intakes. It obtains information on the amount consumed of 21 food groups, and the mean time for self-completion is 14 minutes [24]. Thus, with a finite food list and brief application time, the 24-h FL can be regarded similar to the Oxford WebQ. However, the 24-h FL assesses the probability of consumption of 246 food items without requesting information on the amount consumed. This approach is backed by the notion that the frequency of food intake represents a larger contribution to inter-individual variation in food and nutrient intake than inter-individual variation in portion sizes [25, 26]. The 24-h FL is by definition intended for the use in a combined approach using statistical modeling and not as a stand-alone instrument.

Of the various statistical methods for estimating usual dietary intake distributions, two deserve particular consideration: the NCI Method [11, 13], and the MSM [16, 49]. Both methods rely on repeated 24-h DR information and follow a two-step approach. The first step includes an estimation of the probability of consumption and the second step entails an estimation of the amount consumed. The NCI Method directly estimates the usual intake distribution of the study population. In contrast, MSM first estimates usual intake data for each individual and uses that information to calculate usual intake distributions of the population. Person specific covariates such as age and BMI can be included in both steps of the model for NCI and MSM. Moreover, frequency information from an FFQ can be used as a covariate to enhance the estimation of usual intakes from 24-h DR data [18]. For MSM, the FFQ can further be used to identify true consumers among those considered non-consumers according to the 24-h DR. More recently, the *Statistical Program to Assess Dietary Exposure* (SPADE) was introduced [69]. Like the NCI Method and MSM, SPADE can model usual dietary intake of daily or episodically consumed foods from repeated short-term dietary intake data. Moreover, usual intake from dietary supplements can be incorporated. Usual intake is modeled as a function of age. SPADE can also consider true non-consumers and participants having zero intakes on recall days, but are not true non-consumer. The combined use of different dietary assessment instruments to provide information on the probability of consumption, the consumption-day amount and true non-consumption is to-date the most promising approach to dietary assessment in large-scale epidemiological studies. Because the 24-h FL lent itself to quick and potentially frequent applications for a given study participant, it may represent a superior tool for estimating the probability of consumption in large-scale cohort studies compared to a conventional detailed 24-h DR. Moreover, in an effort to reduce demands on time in dietary assessment, the individual amount consumed as determined by 24-h DRs could be replaced by standard consumption-day amounts depending on person-specific covariate information such as sex, age, BMI and further socio-economic factors. In this scenario, usual dietary intake of a subject is estimated by three entities: 1) repeated application of the 24-h FL assesses the probability of consumption; 2) a single application of an FFQ assesses true non-consumption and provides further information on the frequency of consumption as covariate information; and 3) survey data is used to calculate the consumption-day amount depending on further covariate information (Table IV-1.).

Table IV-1. Proposed combination of dietary assessment instruments for statistical derivation of usual dietary intake distributions in large-scale cohort studies

Information	*Instrument*	*Study participants*
Probability of consumption	24-h-FL	All
True non-consumption, frequency	FFQ	All
Consumption-day amount	Detailed 24-h DR	Subgroup or survey data

Abbreviations: FFQ, food frequency questionnaire; 24-h DR, 24-hour dietary recall; 24-h FL, 24-hour food list

Evidence is needed as to whether or not the combined use of the 24-h FL, an FFQ and standard consumption-day amounts provides valid estimates of individual usual dietary intake. Both the measurement error structure and its implications on diet-disease associations should be investigated. In this context, both the overall concept and the 24-h FL itself could be validated. For validation of the 24-h FL, a reference instrument would be needed that also provides an estimate of the probability of consumption, but with an uncorrelated error structure [70]. The Oxford WebQ, for instance, has been tested against an interviewer-administered 24-h DR and similar mean estimates of energy and nutrient intakes were found [24]. The validity of the ASA24 was assessed through a feeding study and a good performance was found [54]. Compared to three meals with known true intake, the ASA24 captured approximately 80% of the foods and drinks actually consumed and therewith performed as good as a conventional 24-h DR.

The validity of the DietDay was tested using the doubly labeled water method [44]. To assess the validity of the 24-h FL, a diet record would be a suitable and feasible comparison method as records are likely to have the least correlated errors. To test the 24-h FL in terms of accuracy, the correlation between this tool and a diet record could be compared regarding the probability of consumption, e.g. on food group level. To test the overall concept for the estimation of usual dietary intake, a well-designed validation study using biomarkers would be optimal [10]. Such a study could be complemented by a diet record to apply the method of triads as proposed by Rosner and colleagues [71]. To assess the validity and accuracy of dietary assessment methods, recovery biomarkers such as doubly labeled water and urinary nitrogen are mainly applied as reference instruments [72]. Due to their costs and complexity, however, these biomarkers are largely inapplicable for widespread epidemiological use and are most often used in post hoc analyses only. It has been previously stated that there is a need for recovery biomarkers which can be directly used to validate dietary assessment instruments [9]. Recently, a new class of biomarkers has been defined, the so-called predictive biomarkers, which have been also proposed to be used as reference instrument [72]. Like recovery biomarkers, predictive biomarkers are sensitive, time-dependent and show a dose-response relationship with intake levels but they have a lower overall recovery. Up to now, 24-h urinary sucrose and fructose are the only examples [73]. To be a valid reference marker for the 24-h FL approach, the biomarker would have to assess a similar time window compared to the dietary assessment methods, i.e., usual dietary intake of the previous year. Further research is needed to identify suitable biomarkers and a cost-effective study design for the validation of the overall 24-h FL concept.

1.2 The 24-hour food list

The appropriateness of the food item list is crucial to close-ended dietary assessment methods. The food item selection for the 24-h FL was conducted using stepwise linear regression analysis, a method that identifies foods that discriminate the most between individuals and is typically used for FFQ development [31]. Along with previous studies [31, 74], for nutrients with few major sources such as vitamin A and alcohol only few items were selected to explain 75% of variance in intake whereas the number required for nutrients with many minor sources such as macronutrients and iron was up to 97. In addition, contribution analysis was applied which yielded only four additional items for the item list. The food items selected, differed between the two different approaches. It has been already shown previously that foods contributing to variance in intake are not necessarily those contributing to absolute nutrient intake [31]. Thomas and coworkers proposed an alternative strategy for the selection of subsets of foods for the development of short questionnaires [75]. By maximizing the correlation coefficient, Max_r selects a subset of foods that best preserves the inter-individual variance in nutrient intake. However, it has been shown that this method produces results similar to the stepwise procedure [31, 76]. In addition, the purpose of food item selection was not to obtain the shortest item list possible, as evidenced by the decision to include a large number of nutrients (n=27) and four major food groups. Moreover, to account for possibly different food consumption among men and women as well as among different ages, stratified analyses were performed. Food items selected for each nutrient overlapped considerably, reducing the possibility that a particular food item may have been missed. The Oxford WebQ, which is conceptually comparable to the 24-h FL, has not been developed based on statistical concepts. Food groups and foods were chosen to cover the major foods consumed in the UK and to address current hypothesis about certain foods and diseases [24]. Likewise, the food list on the DASH Online Questionnaire that also requires individuals to recall intakes over the previous 24 hours captured commonly eaten foods not derived by statistical methods [23]. However, compared to stepwise regression analysis, this approach ignores the fact that foods with high inter-individual variation in their use are more informative than those that are consumed by almost everyone [31].

To assess whether all relevant food items were included in the 24-FL, participants were asked to declare missing items on the evaluation form. This resulted in the addition of two items to a revised item list created subsequently to the feasibility study. This finding is not surprising given that a finite list of food items cannot capture an individual's diet in all detail because that may include many different foods, brands, and preparation practices [27]. In the present study, all but four food items were chosen by at least one study participant, suggesting that the item list was appropriate. Moreover, at least 80% of study participants reported a good or very good perceived completeness of the list of food items on the evaluation form, and confirmed that the questionnaire reflected their diet of the previous 24 hours. The developers of the Oxford WebQ modified their tool according to data of the EPIC-Oxford study. They randomly selected a single day of a seven day dietary record (N=101) and food items were entered into the Oxford WebQ by blinded personnel. In the case that food items had been entered as free text, modifications were applied [24]. This approach might have been feasible for the 24-h FL as well (e.g. using the NVS II data), but was beyond the scope of the present thesis.

To apply data-based approaches such as stepwise regression analysis and contribution analysis, it is important to use adequate source data [31, 50, 77]. In general, survey data, dietary information of a subsample of the study population, or information on typical food consumption obtained from health professionals are appropriate. In the present study, recent German survey data was analyzed [64]. Of note, application of recent data is required to also cover new foods [77]. The NVS II provides representative intake data of the German population and was thus suitable to identify commonly eaten foods and recipe dishes to be included on the 24-h FL. More precisely, 24-h DR data was used for analysis in the present thesis. This is advantageous in terms of not missing important contributors to nutrient intake [31]. To apply statistical selection methods, however, for some food items, grouping of foods was necessary, which might not correspond to the perceptions of individuals that complete the questionnaire. To avoid this problem, only food items similar in composition or usage, such as green and red peppers or different types of margarines, were combined. Likewise, the item list development of the Oxford WebQ was conducted using information from population surveys [24]. Unfortunately, the authors did not report as to whether or not open-ended data was used for the development of the item list.

The present feasibility study of the web-based 24-h FL found an overall response proportion of 64%. Non-participants tended to be older and of female sex with the main reason for non-participation was lack of Internet access. These findings are in line with previous studies of web-based questionnaires [78]. It has been suggested that those study participants who completed web-based questionnaires have certain characteristics such as young age, high education, or being familiar with using the Internet [78, 79]. In the last years, Internet access rapidly increased in Germany [80]. Still, it is important to apply easy and understandable tools, especially for large-scale cohorts investigating the relationship between diet and chronic diseases, in order to reduce selection bias [81, 82].

The simple structure of the 24-h FL has been designed to decrease participant burden and thereby increase the willingness to participate. It has previously been shown that design issues such as layout and length of the questionnaire affect response rates [83]. Compared to FFQs that typically contain between 50 to 150 food items [38], the 24-h

FL included 246 food items. However, FFQs typically include similar foods in a single question such as beef, pork, or lamb, which can create a cognitively complex question [27]. In contrast, the item list on the 24-h FL was compiled without grouping of single items and study participants were asked whether a selected food item had been consumed on the previous day or not. To further simplify the questionnaire, a drop-down menu appeared only in reply to positive answers to a food group question which than contained a list of individual food items related to that particular food group. This advantage of computer technology was also taken by the Oxford WebQ [24]. The assignment of single items to food groups might, however, not necessarily correspond to the perceptions of individuals that complete the questionnaire. Further research is needed to test the accuracy of food grouping on the 24-h FL.

Moreover, ease of use and a rapid completion time are important because multiple applications of the 24-h FL are required, which itself bears a risk of affecting participant compliance and, thus, of reducing the applicability for repeated self-administration in large-scale cohort studies. Indeed, the median completion time of the questionnaire was nine minutes, which can be considered an acceptable duration. However, the findings show that compliance declined with an increasing number of 24-h FLs completed. About 68% of study subjects completed the questionnaire three times as required. It is unclear how many administrations of a short-term instrument can be reasonably expected to be completed and with which level of quality [20]. One study found a high compliance (92%) for completion of eight non-consecutive automated 24-h DRs [21]. With each additional recall, however, a decline in mean energy estimates was observed. There appears to be a point in time at which the gain in accuracy due to multiple administrations of a 24-h DR is offset by loss of participants due to the high burden [20]. The present study indicated that even with a relatively short completion time of the 24-h FL, not more than three repetitions seem to be feasible. Of note, the feasibility study covered a period of three to six months only and thus, for longer durations more administrations might be possible. Further research is needed to investigate the effect of the number of 24-h FL's administrations on response rates.

For all but three food groups, three 24-h FLs completed were not sufficient to correctly classify all study participants as consumer or non-consumer of a food group as compared to an FFQ. In accordance with another study, a higher agreement between the 24-h FL and the FFQ was observed for foods consumed daily, such as bread and buns, coffee, tea or non-alcoholic beverages [16]. Furthermore, study participants were classified correctly with agreement greater than 80% for eight other food groups often consumed, such as fruits, and milk and dairy products. Haubrock and colleagues showed that bread, water, and milk and dairy products represented food groups with a low proportion of non-consumers in the 24-h DR [16]. In the same study, higher proportions of non-consumption were found for the food groups breakfast cereals and fish, which also showed higher proportions of misclassification in the present study. In contrast to 24-h DRs, the food frequency method is able to reflect long-term dietary intake and is thus more suitable to identify true non-consumers of foods. Consequently, the MSM allows taking into account true non-consumption as identified by an FFQ through assignment of a usual intake of zero [16]. The additional use of an FFQ to identify non-consumers of foods therefore seems warranted.

Several investigators calculated the number of 24-h DRs needed to capture nutrient intakes. Those studies showed different results for different nutrients depending on the consumption frequency. Mennen and coworkers reported that at least eight days were necessary to capture intake of most nutrients [84]. For ß-carotene, however, 16 administrations were needed. Another study found three 24-h DRs as being optimal for estimating energy intake in middle-aged women [85]. Few studies looked at the number of 24-h DRs needed to estimate food intakes. Palaniappan and colleagues showed that there was a greater variability in the intake of specific foods compared with food groups [86]. They discussed the possibility that two days of measured intake for each individual are insufficient to obtain a true picture of variability in some less frequently eaten foods. With respect to statistical modeling of usual dietary intake, the additional use of an FFQ has been suggested to level out the weakness of the 24-h DR method in estimating the probability of consumption for episodically consumed foods [11, 16, 18, 20]. Although those results are not generalizable to the 24-h FL, they indicate the need for two or more repeated administrations of the 24-h FL as well as the additional use of an FFQ to enhance the estimation of the consumption probability.

1.3 Standard consumption-day amounts

The findings of the present thesis indicated that all demographic and socio-economic factors investigated were of relevance for the consumption-day amount of specific food groups. In the Australian National Nutrition Survey, an FFQ was applied, and irregular and regular consumers of foods (i.e., consumption of a food less or more than once per month) were compared according to education and income [87, 88]. The Dietary and Nutritional Survey of British Adults and the Dutch National Food Consumption Survey used dietary records to assess food consumption and compared mean daily intakes of food groups across different socio-demographic factors and smoking behavior [89-91]. Likewise, the Portuguese National Health Survey calculated mean daily intakes of selected food groups and compared consumption across smoking categories [92]. According to this previous research in surveys, socio-demographic factors such as education [88], income [87], family status [89] and socio-economic status [91] as well as smoking status [90, 92] were associated with food and beverage consumption. One study comprising a sample of the EPIC-Potsdam study observed that amounts consumed differed across groups of sex, age and BMI [25]. Thus, various factors exist that are associated with both the frequency of consumption and consumption-day amounts. However, despite these studies, it remains unclear as to whether or not the factors have a joint impact on the consumption-day amount and whether there are correlations among them. To the best of the author’s knowledge, this is the first study that investigated the joint impact of possibly relevant factors for the consumption-day amount across groups of foods and beverages. The present findings show that socio-demographic and health-related factors in combination are associated with consumption-day amounts. Similar to previous results, differences in relevance of explanatory variables across food groups were observed in a way that different combinations of determinants were found for different food groups. Thus, for 11 out of 22 food groups all investigated factors were of relevance for the consumption-day amount whereas for ‘soup and stew’ and for ‘fish and shellfish’, four and three out of eight determinants were selected for the model, respectively. However, a food group specific prediction of standard consumption-day amounts does not seem to be advisable as determinants have to be assessed anyway. Of note, it was observed that household net income and years of education were correlated. Thus, for the application of person-specific consumption-day amounts, both factors either have to be included or excluded for calculation.

Information on standard consumption-day amounts may be derived from different sources of data. First, national dietary survey data such as the NVS II in Germany can be used [64] as it has been done in the present study. Second, the application of 24-h DRs in a subgroup of the population under study can be conducted. National survey data might provide representative data of the population of a country. Moreover, survey sample sizes are typically large and thus, the variety in the pictured diet might be high.

This may lead to more reliable data for the computation of standard consumption-day amounts. In contrast, the application of 24-h DRs in a subgroup of the population under study might be preferable for specific populations such as multicultural populations.

To take into account covariates that were shown to be predictive of the consumption-day amount, two general strategies are possible. First, standard consumption-day amounts could be derived using stratified mean or median intakes of the respective food items as it has been done previously [25, 47]; and second, amounts could be estimated by using appropriate statistical models [11, 16, 49]. Tooze and colleagues stated that using statistical models may result in a more efficient estimation than does stratification [11]. Especially when applying a number of person-specific factors, as it has been suggested by the present findings, stratification may lead to very small samples for specific strata combinations. Therefore, the application of prediction models seems to be advantageous for the proposed 24-h FL approach.

As a precondition, standard consumption-day amounts depending on person-specific covariates can only be used if the determinants actually have been assessed in the respective study. All of the proposed determinants are nowadays typically assessed in nutritional epidemiological studies [61, 93] meaning that no additional assessment effort would be necessary. However, for household net income, which was one of the factors proposed to be important for consumption-day amounts, no general standards are available for the generation of categories. Even if prediction models are applied instead of stratification, this variable needs to be categorized for analysis. Thus, future research should evaluate the application of different strata according to the estimation of usual dietary intake.

The implementation of determinants of consumption-day amounts may lead to more precise estimates of usual dietary intakes in a study population by reducing inter-individual variation of intake [11]. The comparison of food item specific usual intake distributions derived by either a parsimonious (i.e. sex, age, BMI) or a comprehensive model (i.e. sex, age, BMI, smoking status, years of education and household net income) found that 31% of usual intake distributions statistically significantly differed between the two models. Of these, the percentage difference in means was less than 10% for most items. Food items with a higher percentage difference in means predominantly included less frequently consumed foods. Moreover, the present findings showed that for rarely consumed foods, the ranking of study participants according to their usual intake distribution of foods significantly differed between a parsimonious and a comprehensive prediction model. Thus, based on these results, the inclusion of all investigated socio-demographic and health-related factors seemed to be advantageous for the prediction of standard consumption-day amounts, especially for rarely consumed foods. However, only a simplified calculation was applied in the present thesis. Previous studies that focused on single person-specific factors suggested that stratified portion sizes did not markedly improve the variance explained [25]. Thus, for a more informed decision as to whether or not the determination of person-specific standard consumption-day amounts is worth the effort, the application should be repeated using statistical models and a larger study population as the 24-h FL approach is intended for large-scale cohort studies.

2 Strengths and limitations

This study has several general and specific strengths and limitations that warrant consideration.

2.1 General aspects

The 24-h FL approach has some general limitations. Using the 24-h FL to estimate the probability of consumption on the one hand, and standard consumption-amounts derived by survey data on the other hand assumes that the two parts of the model, i.e., the probability of consumption and the consumption-day amount, are independent and can be estimated separately. However, it has been shown that for some food groups there is a correlation between the probability of consuming a food and the consumption-day amount [11]. Those individuals who eat a food most frequently tend to eat more of it. Tooze and coworkers used the Eating at America`s Table Study data to determine how often this happens [11]. They found that about 80% of the analyzed food groups showed a positive correlation between the probability of consumption and the mean consumption-day amount. Thus, to further improve the proposed 24-h FL approach in terms of statistical modeling, this correlation needs to be estimated using both an appropriate procedure (e.g. the MIXTRAN macro developed by the NCI) and reference population (e.g. the NVS II study population), and should be incorporated as a standard correlation in the statistical model.

The currently available statistical models are limited in terms of that they require a sufficient number of people consuming a given food on at least two recalled days [11]. This might also be true for the 24-h FL if it is used for estimating the probability of consumption. For foods that are consumed episodically in a population, such as offal, this condition may not be satisfied. The findings of the present study already suggested that for some food items on the 24-h FL, the number of consumers on at least two days was insufficient for a valid estimation of usual intake. The 24- FL, however, is intended for the use in large-scale cohort studies while the feasibility study comprised only a sample of 326 study participants. Therefore, this might not be a problem in larger samples. Another major limitation is that the statistical models are based on the assumption that the 24-h DR is an unbiased instrument for the measurement of usual dietary intake [11]. However, studies on the validity of 24-h DRs using biomarkers have found underreporting for both energy and protein [34, 42-44]. It has been suggested that underreporting may differ by food [94]. As it is not possible, however, to determine the foods and the effect, statistical models have to assume that the 24-h DR is unbiased [11]. With respect to the 24-h FL, both the structure of measurement error and the impact on the estimation of usual dietary intake need to be investigated in future studies.

As a further limitation, the application of the proposed 24-h FL approach with respect to populations of varying age warrants consideration. For the elderly, functional impairments may require specific adaptions to dietary assessment methods [27]. It has been suggested that older people experience more difficulties in recalling short-term dietary intake than long-term dietary intake, and have, moreover, problems with open-ended methods than with structured questionnaires using a finite list of food items [95]. Therefore, FFQs might be a superior tool compared to 24-h DRs in this age group. However, evidence is missing for this hypothesis. Regarding the 24-h FL, it has to be tested as to whether or not the application of such a short-term method provides accurate information on dietary intake of the general elderly population. As the 24-h FL includes some characteristics of an FFQ such as a finite item list and a food-group based structure, the questionnaire might still be feasible for application in older study participants. In addition, the tool omits portion size questions and frequency techniques which are cognitively more complex. Another issue in the elderly, but also in children might be the mode of administration of the 24-h FL. Due to cost and logistic issues in large-scale epidemiological studies, the 24-h FL is intended to be self-administered on the Internet. Self-administered tools may be inappropriate in the elderly if physical impairments such as poor vision are present. As an alternative, interviewer administration of the 24-h FL could be applied. This might, however, outweigh the advantages of the 24-h FL with respect to the logistics of data collection. Moreover, it was shown that interviews might also be difficult in older study participants if hearing problems are present [96]. Furthermore, web-based questionnaires might be a problem in older age groups due to lack of access to the Internet and low computer skills. Hence, younger study participants are more likely to complete web-based questionnaires [78, 97]. However, studies indicate that knowledge about computers and the Internet also exists among the elderly [82]. Thus, further research is needed to evaluate the impact of web-based administrations on non-response in older age groups. For children and adolescents, several self-administered and web-based questionnaires have been tested and it has been found that these tools tend to underestimate food intake as compared to traditional instruments [27]. The 24-h FL has not yet been tested in children and adolescents and thus, further research is needed to investigate the ability of the 24-h FL for adequate dietary assessment in this age group. Finally, the appropriateness of the food list might be a concern for specific age groups. For the development of the 24-h FL, different age strata in adults were considered, also taking into account the elderly (i.e., 65 to 80 years of age). One other study found that the foods selected for an FFQ to be applied in an elderly population were similar to those identified for younger adults [95]. The authors concluded that there was no need to adapt the food list for an elderly population. In contrast, the adaption of the food list for the use of the 24-h FL in children and adolescents might be important.

Strengths of the present thesis are that this is the first study characterizing a new methodological approach for dietary assessment in large-scale prospective studies and that several constraints inherent to large-scale settings such as cost and logistic issues were taken into account. The underlying study populations were recruited from the general population and thus, the results are applicable to the German population independent of region.

2.2 The 24-hour food list

The feasibility and evaluation study of the 24-h FL has some limitations. The strategies used for prompting and reminding participants differed between study centers. This may explain the observed differences in the timeliness and number of 24-h FLs completed between study centers. Furthermore, the time frame for repeated assessments varied between three and six months, limiting the ability to directly compare participant compliance between study centers. Thus, one of the implications of the feasibility study was to develop an automated system for prompting and reminding study participants. The feasibility study tested a web-based application of the 24-h FL; a paper-based version was not available. This may limit the generalizability of the findings to persons with Internet access. Therefore, an additional implication of the feasibility study was to develop a paper-based version of the 24-h FL. Moreover, participants may have been prone to reactivity because the questionnaire was accessible throughout the entire duration of the study. To minimize the potential for reactivity, participants were asked to complete the 24-h FL the day they were prompted. However, because it was not possible to monitor the date participants actually checked their e-mail, the proportion of participants who failed to complete their 24-h FL on time (43%) should be interpreted with caution.

Strengths of the feasibility study are that the 24-h FL represents a novel tool that assesses the probability of consumption of 246 food items. Ease of use and a rapid completion time may facilitate repeated administration and thereby may lead to an improved estimation of the probability of consumption for large-scale settings. The list of food items was based on representative contemporary German dietary survey data and is thus suitable for application in different study regions throughout Germany. Further, formal statistical procedures were used for food item selection. Moreover, strengths of the 24-h FL include general advantages of web-based dietary assessment instruments such as reduced costs and improved quality assurance due to skipping routines [21].

2.3 Standard consumption-day amounts

The study on determinants for consumption-day amounts has also some limitations. To identify factors that explain variation in consumption-day amounts, food items of different serving size were combined into commonly used food groups (e.g. cake and cookies), reducing some of the data variation. However, not the quantitative amount consumed was important but the impact of determinants across groups of foods and beverages. Another limitation is that although a broad range of possible informative socioeconomic and anthropometric factors were pictured, there may be other important determinants such as physical activity additionally influencing consumption-day amounts. It was, however, not possible to include this variable in the analysis since information on physical activity in the NVS II was assessed for a subgroup of participants only. Further studies are thus needed to investigate their importance. The present study did not explicitly take into account variation of consumption-day amounts by season. In the NVS II, the two 24-h DR interviews were conducted within 35 days for each participant, which can be expected to have no seasonal influence on the individual reporting [56]. On the group level, seasonal consumption was balanced as the NVS II interviews encompassed an entire year. For the present study participants with special conditions or missing values on important determinants had to be excluded for analysis. Overall, this may have led to seasonal distortions of consumption-day amounts. It is, however, assumed that seasons make a relatively small contribution to variation in intake in industrialized countries [31]. Moreover, it is more likely that seasons influence the probability of consumption than the consumption-day amount.

With respect to the application of person-specific standard consumption-day amounts for the estimation of usual dietary intake, further limitations have to be considered. First, the approach is limited by the availability of data in a study population. There is a need for imputation procedures to be used in the case of missing information. For instance, a higher proportion of missing data was found for the variable household net income in the present study. Second, another limitation was observed with respect to the application of prediction models to estimate person-specific consumption-day amounts. Using sex, age and BMI as prediction variables, the determination of a valid regression equation was not possible for one food item on the 24-h FL. Applying smoking status, household net income and years of education as further prediction variables, another 5 food items did not reveal a regression equation. In addition, for seven food items negative usual intake values were predicted for some study participants, also suggesting unreliable regression equations. These findings might be caused by too little observations in the underlying NVS II data. For instance, the food item hot smoked herring (buckling) was named by four NVS II study participants and moreover, on one of the two recalled days only, respectively. If the consumption-day amount is predicted applying 24-h DRs in a subgroup of the population under study, the proportion of food item specific consumption-day amount that cannot be predicted might be even higher. It has to be considered if a combined standard consumption-day amount for equally consumed food items would solve this problem.

The fact that representative contemporary German dietary survey data was used to analyze determinants of consumption-day amounts can be considered a strength. Thus, the results are suitable for use all over Germany. The application of person-specific standard consumption-day amounts may lead to more precise estimates of usual dietary intake in large-scale settings that are limited by the costs and logistics of data collection.

3 Implications for future directions in dietary assessment

The reliance on self-reported dietary intake remains an essential issue for dietary assessment, especially with respect to large-scale study settings. Improving the estimation of usual dietary intake is essential to determine accurate associations between diet and health. The results of the present study have some implications for future directions in dietary assessment.

The combination of traditional 24-h DRs and FFQs as it is currently predominantly applied in dietary surveys is proposed to be replaced by frequent applications of the 24-h FL and an FFQ for usage in large-scale cohort studies. The 24-h FL may represent a superior tool for the estimation of the probability of consumption in large-scale cohort studies in comparison to a conventional detailed 24-h DR. Moreover, in an effort to reduce demands on time in dietary assessment, the individual amount consumed as determined by 24-h DRs could be replaced by standard consumption-day amounts depending on person-specific covariate information such as sex, age, BMI and further socio-economic factors.

The present study provides evidence to support the feasibility of using a web-based 24-h FL in a population-based study sample. The food list was shown to be suitable for study participants in different regions of Germany. Further modifications, however, have been carried out since the feasibility study and might further be necessary to best reflect the diet of German study populations. In addition, the 24-h FL requires further testing under a variety of circumstances to ensure that the questionnaire is convenient for as many study participants as possible. A paper-based version of the 24-h FL has already been developed but might pose new problems such as handling of missing values and appropriate interview methods that need to be addressed.

The current available statistical methods promise to improve the accuracy of usual dietary intake estimations. For the use of a 24-h FL instead of detailed 24-h DRs, the underlying statistical concepts have to be adopted and need further exploration with respect to known limitations. The use of person-specific standard consumption-day amounts seemed to be advantageous for some less frequently consumed foods. Further research is necessary to evaluate the extent to which detailed person-specific standard consumption-day amounts influence usual dietary intake distributions. Moreover, there might be a need for the evaluation of suitable imputation procedures in the case of missing values.

As an alternative to the use of survey data for the determination of standard consumption-day amounts, the application of 24-h DRs in a subgroup of the study population was proposed. It is, however, not clear what study size would be needed and if the variety in the diet would be sufficient for the application of statistical models. The EPIC study, for example, collected additional dietary intake data using detailed 24-h DRs in a representative subsample of 5-12% of study participants in each of the sub-cohorts (n=36,900) [93]. Further research should address the question if such a scenario would be appropriate for the proposed 24-h FL approach as well and if additional collection of detailed 24-h DR data would outweigh the advantages of the 24-h FL in terms of costs and time.

In recent years, research has addressed the development of innovative technologies to automate dietary assessment as they offer the potential for reduced costs and decreased burden to participants and researchers [10, 98, 99]. Next to web-based dietary assessment technologies, whose potential benefits are well known and have been already discussed in the present thesis, the use of mobile phones in aiding dietary assessment has gained importance [98]. The usage of mobile phones largely increased in the recent years [100] and, moreover, mobile phones have a variety of technological features that are promising to facilitate dietary assessment [98]. Up to now, this technology has been mainly used for real-time recording of food intake due to the advantage of portability [10, 99]. Recently, smartphone applications have been developed allowing self-monitoring of food and beverage intake [99]. Intake data can be directly transferred to nutrient output for analysis. With respect to the 24-h FL, it seems worth to consider converting the web-based questionnaire to a smartphone-based application. Such an approach would further enhance participant's mobility for dietary assessment. In Germany, 90% of households declared to have at least one mobile phone in 2012 [101]. Moreover, the number of mobile Internet users increased by about 43% in 2013 [102]. Smartphones are typically carried around so that they can be conveniently used throughout the day [99]. Another promising feature of smartphone-based dietary assessment is the possibility to take pictures of food and beverages. A recent review on the feasibility and validity of mobile phones to assess dietary intake identified eight studies with food photograph analysis by trained dieticians and six applications with automated photograph analysis [98]. However, the authors came to the conclusion that methods using food photographs still suffer from natural and technological limitations. In theory, a smartphone-based application of the 24-h FL could be complemented by a food photograph option to later aid participants' memory or to report food items missing on the questionnaire. In this context, however, the impact of taking real-time pictures on reactivity needs to be evaluated. One study that used passively captured food photographs to aid in a 24-h DR reported that this may have influenced eating behavior [103].

Despite the potential advantages of the proposed 24-h FL approach as compared to conventional assessment methods in large-scale studies, the 24-h FL and the FFQ rely on self-reporting, which itself is prone to measurement error. In contrast, dietary biomarkers can provide an objective assessment method of nutritional exposure [104]. Thus, dietary biomarkers are assumed to be independent of bias and errors associated with study subjects and dietary assessment methods [72]. Direct measurement of biomarkers in human specimen therefore has been established as an alternative approach compared to self-reported dietary assessment [9]. The use of biomarkers for the estimation of diet-disease risk associations has attracted a lot of attention in the past years and has found application in prospective large-scale studies, where biological samples were collected before disease onset [72]. In general, nutritional biomarkers can be categorized into short-term (i.e., reflecting intake over past hours/days), medium-term (i.e., reflecting intake over past weeks/months) and long-term biomarkers [105]. In this context, the type of specimen used determines the time window of assessment (e.g. serum/plasma, urine, hair) [104, 105]. Several biomarkers are available correlating with intakes of specific foods, food groups or nutrients as well as with dietary patterns [72, 106]. Regarding the proposed 24-h FL approach in the present thesis, however, it might not be feasible to substitute one of the components with dietary biomarkers. There still is a lack of any biomarker for many dietary factors of major interest [70]. In addition, there are still open questions regarding the feasibility and validity of dietary biomarkers, especially with respect to gene-diet or gene-gene interactions [72, 105]. Nevertheless, it could be argued as to whether or not dietary biomarker information can complement the 24-h FL approach, e.g. in terms of biomarker calibration [107].

V CONCLUSION

Taking into account the short completion time of nine minutes on average, the web-based 24-h FL represents a potentially promising tool to estimate the probability of consumption of a finite number of food items in future large-scale cohort studies. However, an increasing number of repeated administrations of the 24-h FL may lower participant compliance. In combination with an FFQ and information on person-specific standard consumption-day amounts, the 24-h FL can be employed as part of a blended approach combining multiple data sources for the estimation of usual dietary intake in prospective epidemiological settings. The application of the proposed combined 24-h FL approach needs to be tested in future research. In this context, the development of statistical algorithms and the application in larger study populations are of particular relevance. Moreover, future research should address the measurement error structure in the 24-h FL approach and its implications for diet-disease risk associations.

VI SUMMARY

The validity of dietary assessment in large-scale cohort studies has been questioned. Combining different instruments for the assessment of consumption probability and amounts consumed might be feasible and improve the estimation of usual dietary intake in such studies. Thus, the objectives were (a) to develop a web-based 24-hour food list (24-h FL) for Germany to assess the consumption probability of foods during the previous 24 hours, (b) to evaluate the performance of the new questionnaire in a feasibility study, (c) to identify determinants of consumption-day amounts in order to derive person-specific standard consumption-day amounts and (d) to evaluate their relevance for the estimation of usual dietary intake distributions.

Data from the German National Nutrition Survey II (NVS II) was used to develop a finite list of food items for the 24-h FL applying stepwise linear regression analysis. In addition, NVS II data was analyzed for determinants of consumption-day amounts across 22 food groups. A total of 508 individuals participating in the pilot study for the German National Cohort (GNC) were invited to fill in the 24-h FL via Internet up to three times during a three to six month period. In addition, GNC pilot study participants were asked to evaluate the questionnaire using a brief online evaluation form. Finally, usual intake distributions were compared that were either derived by using a parsimonious or a comprehensive prediction model.

In total, 246 items were identified for the item list of the 24-h FL, reflecting more than 75% of variation in intake of 27 nutrients and four major food groups. Among individuals of the GNC pilot study invited, 64% participated in the feasibility study. Of these, 100%, 85%, and 68% of participants completed the 24-h FL one, two, or three times, respectively. The average time needed to complete the questionnaire was nine minutes and its acceptability in terms of understandability, usability, completeness and visual presentation was rated as high. Relevant determinants for consumption-day amounts of food groups were sex, age, body mass index (BMI), smoking status, years of education, household net income, living with a partner and employment status. However, the use of a comprehensive prediction model (sex, age, BMI, smoking status, years of education, household net income) compared to a parsimonious prediction model (sex, age, BMI) seemed to be important for less frequently consumed foods only.

The 24-h FL represents a promising new dietary assessment tool, which can be employed as part of a blended approach combining multiple data sources for estimation of usual dietary intake in large-scale cohort studies.

VII ZUSAMMENFASSUNG

Die valide Ernährungserhebung in großen epidemiologischen Studien ist eine methodische Herausforderung. Die Kombination verschiedener Instrumente zur Erfassung der Verzehrswahrscheinlichkeit und der Verzehrsmenge stellt einen vielversprechenden Ansatz zur verbesserten Schätzung des üblichen Verzehrs dar. Ziele dieser Arbeit waren (a) die Entwicklung einer web-basierten 24-Stunden Food List (24-h FL) für Deutschland zur Erhebung der Verzehrswahrscheinlichkeit der am Vortag verzehrten Lebensmittel, (b) die Evaluierung der 24-h FL im Rahmen einer Machbarkeitsstudie, (c) die Ermittlung von Determinanten der Verzehrsmengen an einem Tag, um personenspezifische Standardverzehrsmengen zu bilden und (d) die Analyse deren Relevanz bezüglich der Schätzung des üblichen Verzehrs.

Daten der Nationalen Verzehrsstudie II (NVS II) wurden mittels schrittweiser Regression untersucht, um die Lebensmittelliste der 24-h FL zu erstellen. Außerdem wurden Daten der NVS II im Hinblick auf Determinanten für Verzehrsmengen von 22 Lebensmittelgruppen analysiert. Es wurden 508 Individuen, die an der Pilotstudie zur Nationalen Kohorte (NaKo) teilnahmen, gebeten, die 24-h FL im Internet bis zu drei Mal über einen Zeitraum von drei bis sechs Monaten auszufüllen. Zusätzlich erhielten die Teilnehmer einen Evaluierungsbogen zur 24-h FL. Ein sparsames und ein ausführliches Prädiktionsmodell zur Verteilung des üblichen Verzehrs wurden verglichen.

Für die Itemliste der 24-h FL wurden 246 Lebensmittel identifiziert, die mindestens 75% der Variation in der Aufnahme von 27 Nährstoffen und vier Lebensmittelgruppen erklärten. Von den eingeladenen NaKo-Studienteilnehmern nahmen 64% an der Machbarkeitsstudie teil. Davon füllten 100%, 85% bzw. 68% die 24-h FL je ein-, zwei- bzw. dreimal aus. Die durchschnittliche Ausfülldauer betrug neun Minuten und die 24-h FL erzielte eine hohe Akzeptanz bezüglich Verständlichkeit, Vollständigkeit, Anwendbarkeit und Optik. Wichtige Determinanten für Tagesverzehrsmengen der untersuchten Lebensmittelgruppen waren Geschlecht, Alter, Body-Mass-Index (BMI), Rauchverhalten, Bildungsjahre, Haushaltsnettoeinkommen, Wohnsituation und Beschäftigungsstatus. Allerdings war die Anwendung eines ausführlichen Prädiktionsmodells (Geschlecht, Alter, BMI, Rauchverhalten, Bildungsjahre, Haushaltsnettoeinkommen) im Vergleich zum sparsamen Modell (Geschlecht, Alter, BMI) nur für selten verzehrte Lebensmittel von Bedeutung.

Die 24-h FL stellt ein vielversprechendes neues Ernährungserhebungsinstrument dar, das als Bestandteil eines kombinierten Ansatzes zur Schätzung des üblichen Verzehrs in großen Bevölkerungsstudien eingesetzt werden kann.

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IX APPENDIX

Table IX-1. Assignment of food items to groups of foods and beverages

Food or beverage group	*Included food items*
Bread and buns	Brown (rye wheat) bread and buns, multigrain bread and buns, rye bread and buns, dinkel wheat bread and buns, whole grain bread and buns, whole grain toast, toast, croissant, wheat bread and buns/baguette, lye pretzel/breads, flatbread, other
Breakfast cereals	Muesli, corn flakes, wholemeal, rolled cereals/oat flakes, puffed rice, other
Pasta	Pasta/noodles, whole grain pasta
Rice	Rice
Potatoes	Potatoes, pan-fried potatoes, mashed potatoes, potato dumplings, potato salad, filled potatoes, potato pancake, chips/French fries, other
Milk and dairy products	Milk, soured milk, buttermilk, soy milk, hot/cold cocoa, flavored milk (drinks), cream, kefir, plain yoghurt, flavored yoghurt, crème fraiche, plain curd (quark), curd with herbs, other
Cheese	Cream cheese/cottages cheese, soft cheese, mozzarella, feta, semi-hard and hard cheese, sour milk cheese, other
Fresh fruits	Apple, pear, orange, tangerine, kiwi, cherries, plum, mirabelle plum, peach, apricot, nectarine, pomegranate, grapes, melon, banana, strawberries, blueberries, raspberries, gooseberries, fresh fig, physalis/cape gooseberry, pineapple, fruit salad, other
Vegetables	Lettuce, cucumber, tomatoes, capsicum/pepper, carrots, turnip cabbage (kohlrabi), pickled cucumber/gherkin, olives, avocado, broccoli, spinach, zucchini/courgette, aubergine/eggplant, cauliflower, white cabbage, kale/borecole, Brussels sprouts, red cabbage, sauerkraut, mushrooms, asparagus, legumes, mixed vegetables, other
Processed meat	Liverwurst, salami, mettwurst, cabanossi, bologna/polony, ham sausage, cooked ham, raw ham, poultry sausage, aspic, collared pork, blood sausage, frankfurter/wiener/hot dog, bratwurst, Bavarian veal sausage, Bavarian meat loaf, hamburger/meatball, other
Meat	Beef, poultry, veal, pork, lamb, venison, mixed ground meat, German beef roulade, beef goulash, chicken/turkey ragout, roast pork, pork goulash, gyros, shashlik/meat skewer, liver, other offal, bolognese sauce, other

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Table IX-1. Assignment of food items to groups of foods and beverages *(continued)*

Food or beverage group	*Included food items*
Fish and seafood	Salmon, mackerel, herring, salted herring, fried herring, rolled pickled herring, hot smoked herring, sprat, eel, redfish, trout, tuna, saithe/pollock, codfish, fish sticks, fish bake, calamari, craps/shellfish, other
Soup and stew	Vegetable stew, stew with meat, clear soup, crème of vegetable soup, other
Cake and cookies	Yeast cake and pastry, tart/pie, cream pie/cake with butter crème or custard filling, cheesecake, pound cake/muffins, cookies or biscuits with chocolate icing, cookies or biscuits without chocolate icing, other
Sweets and salty snacks	Filled chocolates, chocolate bar, other chocolate or sweets with chocolate, other sweets without chocolate, crisps and crackers, other
Water	Mineral water, drinking water
Soft drinks	Lemonade, diet lemonade, cola, diet cola
Fruit and vegetable juice	Multi-vitamin juice, apple juice, orange juice, grape juice, grapefruit juice, elder juice, other fruit juice, tomato juice, other vegetable juice
Coffee (additions included)	Coffee/espresso, coffee without caffeine, cappuccino/caffè latte
Tea (additions included)	Black tea, green tea, herbal tea, fruit tea
Wine	White wine, red wine, rosé wine, wine spritzer
Beer	Beer, beer shandy, strong beer/malt liquor

Table IX-2. Results of the variable selection with LASSO using the Bayesian information criterion as selection strategy

Food group	*No. of relevant determinants*	*Relevant determinants*
Bread and buns	8	Sex, age, BMI, smoking status, household net income, years of education, living with partner, employment
Rice	8	Sex, age, BMI, smoking status, household net income, years of education, living with partner, employment
Cheese	8	Sex, age, BMI, smoking status, household net income, years of education, living with partner, employment
Processed meat	8	Sex, age, BMI, smoking status, household net income, years of education, living with partner, employment
Meat	8	Sex, age, BMI, smoking status, household net income, years of education, living with partner, employment
Soft drinks	8	Sex, age, BMI, smoking status, household net income, years of education, living with partner, employment
Fruit and vegetable juice	8	Sex, age, BMI, smoking status, household net income, years of education, living with partner, employment
Wine	8	Sex, age, BMI, smoking status, household net income, years of education, living with partner, employment
Beer	8	Sex, age, BMI, smoking status, household net income, years of education, living with partner, employment
Coffee	8	Sex, age, BMI, smoking status, household net income, years of education, living with partner, employment
Tea	8	Sex, age, BMI, smoking status, household net income, years of education, living with partner, employment
Breakfast cereals	7	Sex, age, smoking status, household net income, years of education, living with partner, employment
Pasta	7	Sex, age, BMI, smoking status, household net income, years of education, employment
Potatoes	7	Sex, age, BMI, smoking status, household net income, years of education, employment
Fruits	7	Sex, age, smoking status, household net income, years of education, living with partner, employment
Cake and cookies	7	Sex, age, BMI, smoking status, household net income, years of education, employment
Sweets and salty snacks	7	Sex, age, smoking status, household net income, years of education, living with partner, employment

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Table IX-2. Results of the variable selection with LASSO using the Bayesian information criterion as selection strategy *(continued)*

Food group	No. of relevant determinants	Relevant determinants
Water	7	Sex, age, BMI, smoking status, household net income, years of education, employment
Milk and dairy products	6	Sex, age, smoking status, years of education, living with partner, employment
Vegetables	6	Sex, age, smoking status, household net income, years of education, living with partner
Soup and stew	4	Sex, smoking status, household net income, years of education
Fish and shellfish	3	Sex, BMI, years of education