Uncertainty in Intake Due to Portion Size Estimation in 24-Hour Recalls Varies Between Food Groups

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Abstract

Portion size estimation is expected to be one of the largest sources of uncertainty in dietary assessment of the individual. Therefore, we demonstrated a method to quantify uncertainty due to portion size estimation in the usual intake distributions of vegetables, fruit, bread, protein, and potassium. Dutch participants of the European Food Consumption Validation study completed 2 nonconsecutive 24-h recall interviews. In short, the uncertainty analysis consists of Monte Carlo simulations drawing values for portion size from lognormal uncertainty distributions. The uncertainty of the usual intake distribution and accompanying parameters (IQR and the shrinkage factor) were estimated. For the food groups, portion size uncertainty had the greatest effect for vegetables and the least for fruit: the relative 95% uncertainty interval (UI) of the IQR of the usual intake distribution was 0.61–1.35 for vegetables, 0.77–1.24 for bread, and 0.99–1.10 for fruit.

For protein and potassium, the resulting relative width of the UI of the IQR for portion size uncertainty are similar: 0.88–1.14 for protein and 0.86–1.14 for potassium. Furthermore, a sensitivity analysis illustrated the importance of the specified uncertainty distributions. The examples show that uncertainty in portion sizes may be more important for some foods such as vegetables. This may reflect differential quantification errors by food groups that deserve further consideration. In conclusion, the presented methodology allows the important quantification of portion size uncertainty and extensions to include other sources of uncertainty is straightforward. J. Nutr. doi: 10.3945/jn.111.139220.

Introduction

The 24-h recall method is a short-term dietary assessment method, where a respondent is asked to accurately recall, describe, and quantify the food items and ingredients of mixed dishes that were consumed the previous day. Dietary intake data are often associated with misreporting (1), i.e. food items were consumed but not reported, food items were reported but not consumed, the amount of food consumed was not equal to the amount reported, or a specific feature of the food was wrongly specified (e.g. baked potatoes instead of cooked potatoes) (2–4). Overall, incorrect estimation of portion sizes is, together with deletion errors, considered to be the major source of reporting error for foods in 24-h recalls (2).

For the assessment of food quantity, different portion size estimation aids (PSEA)7 may be used. These may be 2-dimensional (such as food photographs or computer graphics) or 3-dimensional (e.g. food models, household measures, food replicas, or real food samples) (5,6). Validation studies investigating the estimation error when using specific PSEA such as photographs show that estimation errors of portion sizes can be substantial and are highly variable between individuals (7–13).

The ability of a respondent to quantify an amount consumed is influenced by a complex cognitive process. The cognitive constructs that influence the portion size estimation are the perception of foods, the conceptualization of foods, and the memory of amounts eaten (5,14). Perception of foods refers to a participant’s ability to relate an amount of food that is shown in reality to an amount of food shown in a PSEA.
alization concerns the ability of a participant to translate a mental construct of an amount of food to an amount depicted by a PSEA. Memory is especially important for the recall of the amounts consumed and will affect the precision of the conceptualization.

The uncertainty in the reported amount will affect the final results, such as usual intake distributions, obtained from the 24-h recall data. Uncertainty analysis is a method for the quantitative assessment of the uncertainty in a measurement and thus it may be used to quantify the confidence in the results given the uncertainties surrounding portion size estimation. Therefore, the aim of this study is to demonstrate a method to quantify uncertainty due to portion size estimation using 24-h recall data from the European Food Consumption Validation (EFCOVAL) study. First, we determined how portion sizes were estimated during the 24-h recall interview. Second, the usual intake model was changed to explicitly include the primary information from the 24-h recall interview. Third, we defined how to calculate the uncertainty in the usual intake distribution due to the uncertainty in the portion size estimation. Finally, the uncertainties in the primary portion size data are specified quantitatively.

Materials and Methods

Portion size estimation. During the EFCOVAL study, dietary intake data were collected with EPIC-Soft, a standardized, computerized, 24-h recall method (15). For each reported food or mixed dish, respondents were asked to quantify the amount consumed. Depending on the type of food or mixed dish, the respondent chooses 1 quantification method from up to 6 different methods. These 6 quantification methods are: a picturebook containing photographs (P) of dishes and shapes of breads, household measures (H), standard units (U), standard portions (S), the gram/volume method (G) and unknown (?) (Table 1). In addition, for the P, H, and U, the respondent may indicate a standardized fraction or multiple of a selected portion size. Here, we define these primary data as unitweights \( u_{w} \) in gram and amounts \( a \) in gram for \( G \) and \( \frac{a}{i} \), in number of units for \( P, H, \) and \( U \) (Table 1). Quantification methods \( P, H, \) and \( U \) use both \( u_{w} \) and \( a \), method \( S \) uses only \( u_{w} \), and methods \( G \) and ? use only \( a \). The \( u_{w} \) is unique for a specific food item-quantification method combination, but the same for all persons in the survey, whereas \( a \) is potentially different for each food item on each eating occasion for each day of a person.

Adapted model of usual intake assessment. We extend the methodology of usual intake estimation to include an explicit account of the calculation of portion size and its uncertainty. We start with a short description of the estimation of usual intake from 24-h recall data. Usual intake models typically assume the availability of the consumed quantity of a specific food or food group \( Q_{ijk} \) or nutrient \( I_{ij} \) for each individual \( i = 1,...,n \) individuals for each day \( j = 1,...,N_{day} \). To obtain this quantity from the primary data, first \( u_{w} \) and \( a \) are multiplied for each food to obtain the quantity of each reported item \( Q_{ijkm} \) and then these quantities are summed over all eating occasions and, if necessary, over all foods in a food group.

\[
Q_{ijkm} = \sum_{k=1}^{N_{food}} a_{ijkm} \times u_{w} \]

where \( k (k = 1,...,N_{food}) \) indicates all foods belonging to a food group and \( m (m = 1,...,N_{occ ij}) \) indicates the eating occasions of individual \( i \) on day \( j \).

For foods that are ingredients in mixed dishes, \( Q_{ijkm} \) is calculated as the sum over all relevant mixed dishes \( d (d = 1,...,N_{mix d}) \) of the multiplication of the quantity of the mixed dish \( Q_{Id} \) and the proportion of food \( k \) to the mixed dish \( F_{dk} \):

\[
Q_{ijkm} = \sum_{d=1}^{N_{mix d}} Q_{ijdm} \times F_{dk} = \sum_{d=1}^{N_{mix d}} a_{ijkdm} \times u_{w} \times F_{dk},
\]

where \( a_{ijkdm} \) is the \( a \) of the mixed dish and \( u_{w} \) in the \( uv \) of the mixed dish.

When interested in the usual intake of nutrients, the procedure is the same, but now a food group consists of all foods containing the nutrient of interest. The intake of a specific nutrient for individual \( i \) on day \( j \) \( (I_{ij}) \) is then calculated by:

\[
I_{ij} = \sum_{k=1}^{N_{food}} \sum_{m=1}^{N_{occ ij}} a_{ijkm} \times C_{k},
\]

where \( C_{k} \) is the quantity of that nutrient (gram per gram) in food \( k \).

For reasons of clarity, conversion factors that were used (e.g. conversion from raw to cooked) have not been included in the equations above. These conversion factors have been used to calculate consumption per person per day in the examples presented in this paper, but no uncertainty was attributed to them.

\( Q_{ij} \) and \( I_{ij} \) are then used to estimate the usual intake distribution, which is the between-individual distribution, thus eliminating the within-person variation. Usual intake is defined as the average daily intake over a prolonged period of time. Most methods operate by transforming the data to a scale where normality can be assumed and then estimate variance components between and within persons. The shrinkage factor is the ratio of between person:total variance, which is used to correct the distribution for within-person variation. The results of both parts are used to obtain the final estimate of the usual intake distribution.

Uncertainty analysis. The uncertainty in \( a \) and \( u_{w} \) is modeled by lognormal distributions where the mean \( (m) \) is the nominal value (i.e. the value used in an analysis without uncertainty) and where a CV is specified to describe the amount of uncertainty. In practice, a lognormal distribution with mean \( m = 1 \) may be used to generate an uncertainty factor that is multiplied with the nominal value. On a logarithmic scale, the lognormal distribution becomes a normal distribution, characterized by 2 values, usually the mean (M) and the SD. The lognormal distribution can be characterized by specifying the M and SD of the corresponding normal distribution, or, more conveniently, by values on the natural scale (back-transformed). If the natural logarithm is used then common

<table>
<thead>
<tr>
<th>Method (abbreviation)</th>
<th>( uv )</th>
<th>( a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photographs (P)</td>
<td>Standard portion in grams (photograph of broccoli is 78 g)</td>
<td>Proportion or multiple of standard portion (1 times photograph of broccoli)</td>
</tr>
<tr>
<td>Household measures (H)</td>
<td>Standard portion in grams (a glass of tea is 150 g)</td>
<td>Proportion or multiple of standard portion (2 glasses of tea)</td>
</tr>
<tr>
<td>Standard units (U)</td>
<td>Standard portion in grams (a can of corn is 285 g)</td>
<td>Proportion or multiple of standard portion (1/2 a can of corn)</td>
</tr>
<tr>
<td>Standard portion (S)</td>
<td>Standard portion in grams (onion along with fries weighs 10 g)</td>
<td>—</td>
</tr>
<tr>
<td>Gram/volume (G)</td>
<td>—</td>
<td>Amount in grams (75 g of potato salad)</td>
</tr>
<tr>
<td>Unknown (?)</td>
<td>—</td>
<td>Amount in grams (an average portion of salad dressing weighs 15 g)</td>
</tr>
</tbody>
</table>
parameters are $m = \exp(M + 1/2SD^2)$ and the CV = $100/\sqrt{(\exp(SD^2) - 1)}$ (expressed as a percentage). In this work, we followed the convention of the MCRA program to use the CV for specifying an input uncertainty.

To assess the uncertainty, values for $a$ and $uw$ are sampled from the uncertainty distributions (Fig 1) and the usual intake distribution is estimated. This process is repeated in 500 iterations to obtain uncertainty distributions of selected intake percentiles. For $uw$ in each iteration, 1 single value for each relevant combination of food and unit is drawn from an uncertainty distribution with $CV_{uw}$. For $a$, values are drawn from an uncertainty distribution with $CV_{a}$. Here, in each iteration for each food, as many values are sampled as there are simulated persons in the consumption dataset. This is based on the idea that between-person differences in estimating an amount of a food are more important than the within-person variation (across different eating occasions of the same person). So we ignore the latter variation in estimation quality. See Supplemental Table 1 for an example on how this was implemented.

In addition, the uncertainty in $a$ and $uw$, the sampling uncertainty of the set of persons interviewed on their consumption, is addressed as in MCRA 6.2 by bootstrapping the set of participants (18,19). Sampling uncertainty refers to the uncertainty associated with the fact that the study population is only a sample from the overall target population.

**Specification of portion size uncertainties.** For quantification methods P, H, and U, the uncertainty in $uw$ as well as the uncertainty in $a$ needs to be specified; for quantification methods G and ?, the uncertainty in $a$ needs to be specified; and for method S, the uncertainty in $uw$ needs to be specified (Table 1). The uncertainty CV specifications were based on limited expert opinion to provide estimated upper values for $a$ and $uw$, and equating these to the p97.5 of the (log)normal uncertainty distribution (the best estimates are interpreted as the mean $m$).

The uncertainty CV for $a$ was based as much as possible on information from publications (7,11,13,20,21), resulting in a $CV_{a}$ of 50% for quantification method P, a $CV_{a}$ of 4.9% for quantification methods S, H, and G, and a $CV_{a}$ of 20.9% for quantification method ?.

The uncertainty CV of $uw$ was obtained as follows. P were considered an ordered series, where the lognormal CV was derived from the assumption that the p97.5 of the lognormal uncertainty distribution is equal to the nominal $uw$ value of the next photograph in the series. For the last photograph, the CV was set to be identical to that of the preceding picture. The CV for H were generalized from CV taken from a report on vegetables (22) (for spoons, $CV_{uw} = 27\%$ and for bowls and glasses, $CV_{uw} = 19\%$). The CV for U and S were assigned by placing the item into 1 of 4 categories, namely: 1) ordered series; the same method as for P was used; 2) small uncertainty: the p97.5 of the lognormal uncertainty distribution was set to 1.1 times the nominal value; items that were prepacked and reported as whole products were placed in this category; 3) medium uncertainty: the p97.5 of the lognormal uncertainty distribution was set to 1.5 times the nominal value; items reported as whole products were in this category; and 4) large uncertainty: the p97.5 of the lognormal uncertainty distribution was set to twice the nominal value; items that were part of a product or manmade were placed in this category. Supplemental Table 2 summarizes which items were placed into which categories.

**Application of the uncertainty methodology.** Data on dietary consumption of 122 healthy Dutch men and women aged between 45 and 65 y were collected as part of the EFCOVAL validation study, which aimed to further develop and validate a European food consumption method (23). Two nonconsecutive, 24-h recall interviews were conducted by trained dieticians. The interviews were scheduled at least 1 mo apart and covered all days of the week. The data collection took place from April to July 2007. Participants were recruited by convenience sampling through, e.g., advertisements and mailing lists. The study was approved by the ethics committee of Wageningen University and written informed consent was obtained from each participant.

The usual intake distributions were estimated by the BBN model using the MCRA software (18,19). To illustrate the method, usual intake distributions of 3 food groups (i.e. vegetables, fruit, and bread) and 2 nutrients (i.e. protein and potassium) were estimated using an adapted version of MCRA as described above. The food groups were chosen because they were marked as relevant to health in the EFCOSUM project (24) and the nutrients because of the possibility in the EFCOVAL project to compare the recalled intake with a recovery biomarker.

For each food group or nutrient, the best estimate and the 95% uncertainty interval (UI) of several of the percentiles (i.e. all percentiles between the 5th and the 95th by steps of 5) of the estimated usual intake distribution were obtained. To characterize the between-subject variability, the IQR of the usual intake distribution was calculated and the uncertainty of this estimate was represented with a 95% UI. The relative 95% UI was defined as the boundaries of the UI of the IQR divided by the estimated IQR. In addition, the shrinkage factor and its 95% UI were calculated. The usual intake distributions were estimated: 1) without uncertainty (denoted none); 2) with only sampling uncertainty (denoted Subject); 3) with only $uw$ and $a$ uncertainty (denoted Portion); and 4) with sample, $uw$ and $a$ uncertainty (denoted Subject+Portion). All these scenarios included uncertainty due to Monte Carlo sampling, which is a result of the Monte Carlo simulation process. A sensitivity analysis for the CV of the portion size uncertainty distributions was performed by comparing the results using the best estimates for the CV based on expert opinion and using twice these best CV estimates.

**Results**

Figure 2 shows the usual intake distribution (the solid line) of vegetables, fruit, bread, protein, and potassium with UI (the broken lines). The plots show the range of the usual intake distribution when considering portion size uncertainty, as well as the results of the sensitivity analysis. For instance, the estimate for the P50 of vegetable consumption was 178 g/d but ranged from 177 to 179 g/d when uncertainty in portion size and sampling were ignored and from 166 to 188 g/d when portion size uncertainty was considered. The sensitivity analysis showed that using twice the best CV estimate for portion size uncertainty increased the UI as expected: for the P50 of vegetable consumption, the resulting 95% UI ranged from 156 to 196 g/d.

For vegetables and bread, the plot also clearly showed that the uncertainty increased the UI as expected: for the P50 of vegetable consumption was 178 g/d but ranged from 166 to 188 g/d when portion size uncertainty was considered. The sensitivity analysis showed that using twice the best CV estimate for portion size uncertainty increased the UI as expected: for the P50 of vegetable consumption, the resulting 95% UI ranged from 156 to 196 g/d. For vegetables and bread, the plot also clearly showed that the UI in the tails of the distribution were wider than those in the...
This was also the case for fruit consumption, but it was much less visible from the plot.

The estimates of the IQR of the usual intake distribution with the 95% UI and the relative 95% UI, as well as the shrinkage factor and the 95% UI, are shown in Table 2. The value of the IQR characterizes in a crude way the variability between participants’ usual intake. For example, for vegetable consumption, the IQR was estimated at 60 g/d, but due to portion size uncertainty, the IQR could be as low as 37 or as high as 81. Also, the shrinkage factor for vegetables is highly uncertain, ranging between 0.05 and 0.25 when portion size uncertainty is taken into account. The uncertainty of the IQR and shrinkage factor is somewhat smaller for both fruit and bread.

The results show that the subject uncertainty was larger than the portion size uncertainty for vegetables (95% UI of IQR was 10–86 for subject, 37–81 for portion) and fruit (95% UI: 79–145 for subject, 99–123 for portion), but this difference was less pronounced for bread (95% UI: 48–74 for subject, 49–78 for portion). Relatively, portion size uncertainty had the largest effect in vegetables and the smallest in fruit (relative 95% UI was 0.61–1.35 for vegetables, 0.77–1.24 for bread, and 0.99–1.10 for fruit). Also, using twice the best CV estimate in the analysis instead of the best CV estimate increased the UI more for vegetables (relative UI increased from 0.61–1.35 to 0.61–1.35) than for fruit (relative UI increased from 0.88–1.10 to 0.81–1.24).

In general, both the IQR and the shrinkage factor were somewhat better estimated for the nutrients than for the food groups. For example, the protein intake IQR was estimated at 26 g/d with uncertainty limits of 17–33 g/d, and the shrinkage factor was estimated to be between 0.20 and 0.57.

For nutrients, the relative width of the UI of the IQR for portion size uncertainty were similar for protein and potassium for the best CV estimate (0.88–1.14 for protein, 0.86–1.14 for potassium) and twice the best CV estimate (0.80–1.30 for protein and 0.81–1.33 for potassium). Portion size uncertainty was relatively less important for these 2 nutrients than for vegetables and bread but comparable to that for fruit.

Discussion
In this paper, we present a method to quantify the uncertainty that is due to portion size estimation in 24-h recall. Several assumptions of the presented methodology warrant further discussion. First, assumptions of the modeling will be highlighted and second, points about the specification of the uncertainty distributions will be discussed.

Estimating usual intake from 24-h recall data requires assumptions regarding the data. Besides uncertainty in portion size estimation, other sources of uncertainty also exist in 24-h recalls. Examples of these sources are uncertainty associated with deletion error, addition error, and misclassification error, daily and seasonal variation, including variation caused by episodically consumed foods, and uncertainty in conversion factors (e.g. density to convert volume to weight or the conversion factor used to convert cooked foods to raw foods are vice versa). In addition, uncertainty in the nutrient levels reported in food composition tables will be important when looking at the usual intake of nutrients. These sources were not included in the presented methodology. However, the chosen approach allows a straightforward extension to include other sources of uncertainty.

Regarding the statistical model used to calculate the usual intake, it is assumed that the data have identical distributions for all person-days and that both the between-person variation and the within-person (between-day) variation can be approximated.
TABLE 2 Uncertainty and sensitivity analysis for usual intake of vegetables, fruit, bread, protein, and potassium

<table>
<thead>
<tr>
<th>Food group</th>
<th>Source(s) of uncertainty</th>
<th>IQR</th>
<th>95% UI, relative</th>
<th>Shrinkage factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>[95% UI]</td>
<td></td>
<td>[95% UI]</td>
</tr>
<tr>
<td>Vegetables,</td>
<td>None</td>
<td>60 [58, 61]</td>
<td>0.96; 1.01</td>
<td>0.17; 1.17</td>
</tr>
<tr>
<td>g/d</td>
<td>Subject</td>
<td>60 [10, 88]</td>
<td>0.17; 1.45</td>
<td>0.17; 0.00; 0.37</td>
</tr>
<tr>
<td></td>
<td>Portion</td>
<td>60 [37, 81]</td>
<td>0.61; 1.35</td>
<td>0.17; 0.05; 0.25</td>
</tr>
<tr>
<td></td>
<td>Subject+Portion</td>
<td>60 [2, 94]</td>
<td>0.04; 1.59</td>
<td>0.17; 0.00; 0.35</td>
</tr>
<tr>
<td></td>
<td>Portion2</td>
<td>60 [13, 106]</td>
<td>0.21; 1.76</td>
<td>0.17; 0.00; 0.26</td>
</tr>
<tr>
<td></td>
<td>Subject+Portion2</td>
<td>60 [2, 138]</td>
<td>0.03; 1.23</td>
<td>0.17; 0.00; 0.35</td>
</tr>
<tr>
<td>Fruit, g/d</td>
<td>None</td>
<td>112 [108, 114]</td>
<td>0.97; 1.02</td>
<td>0.36; 0.38; 0.36</td>
</tr>
<tr>
<td></td>
<td>Subject</td>
<td>112 [79, 145]</td>
<td>0.70; 1.29</td>
<td>0.36; 0.16; 0.53</td>
</tr>
<tr>
<td></td>
<td>Portion</td>
<td>112 [99, 123]</td>
<td>0.88; 1.10</td>
<td>0.36; 0.29; 0.41</td>
</tr>
<tr>
<td></td>
<td>Subject+Portion</td>
<td>112 [74, 149]</td>
<td>0.66; 1.33</td>
<td>0.35; 0.15; 0.54</td>
</tr>
<tr>
<td></td>
<td>Portion2</td>
<td>112 [91, 138]</td>
<td>0.81; 1.24</td>
<td>0.36; 0.22; 0.42</td>
</tr>
<tr>
<td></td>
<td>Subject+Portion2</td>
<td>112 [69, 162]</td>
<td>0.62; 1.45</td>
<td>0.36; 0.09; 0.53</td>
</tr>
<tr>
<td>Bread, g/d</td>
<td>None</td>
<td>63 [61, 64]</td>
<td>0.97; 1.02</td>
<td>0.44; 0.44</td>
</tr>
<tr>
<td></td>
<td>Subject</td>
<td>63 [48, 74]</td>
<td>0.76; 1.18</td>
<td>0.44; 0.29; 0.54</td>
</tr>
<tr>
<td></td>
<td>Portion</td>
<td>63 [49, 78]</td>
<td>0.77; 1.24</td>
<td>0.44; 0.19; 0.44</td>
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<tr>
<td></td>
<td>Subject+Portion</td>
<td>63 [36, 88]</td>
<td>0.58; 1.37</td>
<td>0.44; 0.10; 0.51</td>
</tr>
<tr>
<td></td>
<td>Portion2</td>
<td>63 [32, 97]</td>
<td>0.49; 1.49</td>
<td>0.44; 0.04; 0.39</td>
</tr>
<tr>
<td></td>
<td>Subject+Portion2</td>
<td>63 [32, 106]</td>
<td>0.03; 1.70</td>
<td>0.44; 0.00; 0.45</td>
</tr>
<tr>
<td>Protein, g/d</td>
<td>None</td>
<td>25.8 [25.0, 26.2]</td>
<td>0.97; 1.01</td>
<td>0.46; 0.46</td>
</tr>
<tr>
<td></td>
<td>Subject</td>
<td>25.8 [18.6, 30.2]</td>
<td>0.72; 1.17</td>
<td>0.46; 0.28; 0.59</td>
</tr>
<tr>
<td></td>
<td>Portion</td>
<td>25.8 [22.7, 29.3]</td>
<td>0.88; 1.14</td>
<td>0.46; 0.32; 0.49</td>
</tr>
<tr>
<td></td>
<td>Subject+Portion</td>
<td>25.8 [17.2, 32.7]</td>
<td>0.67; 1.28</td>
<td>0.46; 0.20; 0.57</td>
</tr>
<tr>
<td></td>
<td>Portion2</td>
<td>25.8 [20.3, 33.0]</td>
<td>0.80; 1.30</td>
<td>0.46; 0.19; 0.45</td>
</tr>
<tr>
<td></td>
<td>Subject+Portion2</td>
<td>25.8 [15.2, 36.8]</td>
<td>0.59; 1.43</td>
<td>0.46; 0.11; 0.53</td>
</tr>
<tr>
<td>Potassium, mg/d</td>
<td>None</td>
<td>942 [915, 957]</td>
<td>0.97; 1.02</td>
<td>0.40; 0.40</td>
</tr>
<tr>
<td></td>
<td>Subject</td>
<td>942 [720, 1119]</td>
<td>0.76; 1.19</td>
<td>0.40; 0.27; 0.52</td>
</tr>
<tr>
<td></td>
<td>Portion</td>
<td>942 [814, 1078]</td>
<td>0.86; 1.14</td>
<td>0.40; 0.26; 0.44</td>
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<tr>
<td></td>
<td>Subject+Portion</td>
<td>942 [614, 1172]</td>
<td>0.65; 1.25</td>
<td>0.40; 0.17; 0.50</td>
</tr>
<tr>
<td></td>
<td>Portion2</td>
<td>942 [746, 1220]</td>
<td>0.81; 1.33</td>
<td>0.40; 0.16; 0.42</td>
</tr>
<tr>
<td></td>
<td>Subject+Portion2</td>
<td>942 [511, 1357]</td>
<td>0.55; 1.47</td>
<td>0.40; 0.09; 0.48</td>
</tr>
</tbody>
</table>

1 Except Monte Carlo uncertainty, which contributes in all calculations.
2 Subject and Portion are the 2 sources of uncertainty.
3 Portion2x denotes the sensitivity analysis scenario where the portion size uncertainty coefficients of variation are set twice the best estimates.

by a normal distribution after a suitable data transformation. These assumptions create additional uncertainty, but this was not considered, because the focus was on presenting a new methodology for quantifying uncertainty of portion size estimation. General guidelines to address uncertainty in exposure calculations have been issued (25).

One of the assumptions made in the present methodology was that between-person differences in estimating an amount of a food are more important than the within-person variation, implemented by the fact that uncertainty in amount is modeled to be different for each (simulated) person but the same across different eating occasions of the same person. Even though consumed portion sizes are regularly more variable within individuals than between individuals (26,27), portion size estimation skills are influenced by the individual’s cognitive skills and memory (14). However, when 2 persons use the same quantification method, the CV of the uncertainty distribution from which amount is drawn is identical for both participants. Another option may be to specify the CV of the uncertainty distribution for amount not only on quantification method but also differently depending on certain characteristics of the participant (e.g., age or BMI).

The CV of the uncertainty distribution for H were generalized from a report on vegetables. Although this was done for practical reasons, it is unclear to what extent these CV are comparable for different foods. It is, for instance, conceivable that the CV of household measures is different for solid, amorphous, and liquid foods. Even though the sensitivity approach was limited to the scenario of doubling the best estimate of the CV, it shows the importance of providing good estimates of the CV of uw and a. Doubling the best estimate of the CV resulted in considerably larger uncertainty for all examples. On the other hand, the influence on the estimated uncertainty of the categorization of U and S in “medium” and “large” was small. This was checked by analyzing the data without separating these categories into 2 different categories (data not shown). However, providing optimal estimates of the CV of the uncertainty distributions was not the purpose of the presented research and therefore the CV are solely based on limited expert opinion and the sensitivity analysis was conducted only to show the influence of the specified CV on the results. To obtain better estimates of uncertainty in a and uw experiments are needed. For instance, the uncertainty in uw of a tomato could be obtained from well-designed experiments on weighing tomatoes and calculating the mean and variance of these data. Nevertheless, expert opinion will always be needed and should be obtained from meetings of experts to obtain consensus on these estimates. Formal statistical methods for eliciting expert opinion have been described (28).

Regarding the example provided, we conclude that the uncertainty due to portion size was relatively small compared with the sample uncertainty in our examples. This is because only a relatively small sample of 122 participants was available from the Dutch part of the EFCOVAL validation study. Future national dietary surveys will include larger sample sizes, thus reducing sampling uncertainty. Portion size uncertainty will then become relatively more important. Furthermore, the uncertainty of the vegetable example seemed larger than for the other examples. Both the variability between persons and the shrinkage factor are not very well estimated. A possible reason for this is that vegetables are often reported as pieces to which a large uncertainty was attributed or that different quantification methods are used. This will require further consideration.

The presented methodology is not a method to correct for potential bias. When bias is present, this should be corrected using, e.g., the methodology described by Freedman et al. (29). This correction would then represent another source of uncertainty that should be taken into account. One of the main advantages of uncertainty analysis is that it may give quantitative insight into uncertainties for all foods and nutrients, where bias correction methods are for now only applicable for those nutrients for which recovery biomarkers are available.

In the present paper, we focused on portion size uncertainty in 24-h recalls. Other methods to assess dietary intake at the individual level, such as FFQ, are also associated with sources of uncertainty. Uncertainty in FFQ will, for instance, be associated with the reported frequency, the portion sizes used to calculate amounts, the grouping of certain food items together into 1 question, and the assignment of nutrient content to foods and groups of foods. FFQ are especially used in epidemiological studies. The methodology presented in this paper can be applied with alterations to quantify the uncertainty in the FFQ in any diet-disease association of interest. Most importantly, the sources of uncertainty in the FFQ need to be specified and the uncertainty distributions of these sources need to be quantified. Then an iterative procedure estimating the diet-disease association can be applied. Quantifying the uncertainty in nutritional epidemiological...
studies may provide new insight in the spurious associations that are often found in this field (30).

In summary, the methodology presented in this paper provides a starting point to quantify sources of uncertainty in dietary surveys, thus allowing a better interpretation of the results. The MCRA program (19) was adapted to allow this uncertainty analysis of portion sizes and the methodology is part of release 7 of MCRA (31). The methodology can be extended to more sources of uncertainty and research effort needs to be put into supplying optimal estimates of uncertainty distributions.

Acknowledgments
O.W.S., H.v.d.V., M.F., and P.v.t.V. designed research; A.G. and J.d.V. conducted research; O.W.S. and W.d.B. analyzed data; O.W.S. and H.v.d.V. wrote the paper; and P.v.t.V. had primary responsibility for final content. All authors read and approved the final manuscript.

Literature Cited