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Biases and adjustments in nutritional assessments from dietary questionnaires

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Abstract

In nutritional epidemiology, it is essential to use Food Consumption Assessment Methods that have been validated and accepted by the international community for estimating food consumption of individuals and populations. This assessment must be made with the highest quality possible so as to avoid, as far as possible, sources of error and confusion in the processes.

The qualities that are required in a measurement method are validity and accuracy; validity being the main factor. Lack of validity produces biases, or systematic errors. These can reside in the process of subject selection, or processes of information gathering where the lack of accuracy produces random errors.

For many nutrients, the intra-individual variances are due to many factors such as day-of-the-week or season, and could create problems in the data analyses. Adjustments are needed to minimize these effects.

Confounding factors may over- or under-state the real magnitude of the observed association, or even alter the direction of the real association. Total energy intake can be a confounding variable when studying a relationship between nutrient intake and disease risk. To control for this effect several approximations are proposed such as nutrient densities, standard multivariate models and the nutrient residual model.

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SESGOS Y AJUSTES EN LA VALORACIÓN NUTRICIONAL DE LAS ENCUESTAS ALIMENTARIAS

Resumen

En la epidemiología nutricional es esencial la utilización de los Métodos Valoración del Consumo Alimentario validados y aceptados por la comunidad internacional para estimar el consumo alimentario de los individuos y grupos de población. Esta estimación debe hacerse con la mayor calidad posible, evitando, en la medida de lo posible, las fuentes de error y confusión en la medida del consumo alimentario.

Las cualidades que otorgan calidad a un método de medida son la validez y la precisión, siendo la validez la principal característica. La falta de validez produce sesgos o errores sistemáticos, los cuales pueden ser en el proceso de selección de los sujetos o en el proceso de obtención de la información; y la falta de precisión produce errores aleatorios.

Para muchos nutrientes, las variaciones intra-individuales debidas a muchos factores como el día de la semana o la estación del año, podrían crear problemas en los análisis de datos. Para minimizar este efecto se deben realizarse algunos ajustes en los análisis.

Los factores de confusión pueden exagerar o subestimar la verdadera magnitud de la asociación o incluso alterar la dirección de la asociación. El consumo total de energía puede ser una variable de confusión en el estudio de la relación entre la ingesta de nutrientes y el riesgo de enfermedad. Para controlar este efecto se proponen varias aproximaciones: la densidad de nutrientes, modelo multivariado estándar y el modelo residual de nutrientes.

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Palabras clave: *Métodos de valoración del consumo alimentario. Valoración nutricional errores sistemáticos. Sesgos. Errores aleatorios. Ajustes. Factores de confusión. Calidad. Exactitud. Validez. Precisión. Repetitividad.*

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Limitations in the correct assessment of the food consumption

In nutritional epidemiology, it is essential to correctly assess food consumption, to describe as well as to estimate its effect on health. Its measurement is complex and is not exempt from significant limitations. Therefore, to obtain data of quality special attention needs to be applied in minimizing errors of measurement. It is important to control the sources of error (systematic or random) and confounding factors that can occur at different stages of data acquisition in the research process, from the design of the study protocol to the publication of results. It is important to define clearly the goals of the study including: the design of the epidemiologic study; the selection, size and type of participants; the choice of methods for measuring the variables-of-interest under study.

Monitoring the correct implementation of the protocol during the fieldwork is fundamental if deviations from the previously-planned objectives are to be avoided and, if deviations do occur, to detect them early enough to introduce corrections. A further point in the research process is the analysis and interpretation of the results since it is vital to pay special attention to preventing and/or correcting for any errors, especially with respect to confounding factors.

Quality of methods of assessing food consumption: validity and accuracy

From among all the above factors, the method selected to assess food consumption is key to obtaining data of quality. However, there is no ideal method for assessing the habitual and/or spontaneous dietary intake of the subject. Indeed, there are various methods for assessing food consumption (MAFC) that have been internationally accepted as being appropriate in assessing individual food item consumption. These include: food records; 24h recalls; diet diaries; and food-frequency questionnaires. Each has its own strengths, weaknesses, and specific characteristics[1,2,3].

MAFC quality is reflected in two variables: validity and accuracy. Validity is the quality of measurement of what one really wishes to measure; accuracy reflects the concordance between several repeated measurements of the same variable with the same methodology. Lack of validity produces systematic errors and lack of accuracy produces random errors. Both errors can occur in intra- or inter-individually[4].

Bias, or systematic error, is distortion in the estimation that affects the measurement of the variable. These biases can be of selection, or of information. Selection bias is related to the type of epidemiologic study used in the investigation. The most common errors result from: the difficulties in obtaining a representative sample; the selection of the control group; controlling for loss-to-follow-up; selection of participants that excludes the ones with greater severity; an event occurring in one of the groups under greater surveillance; the detection bias; and the bias occurring because of volunteer involvement which is related to greater participation of cases[1,2,3].

Information biases occur in the data collection process. An important part of these biases are related to the skills and experience of the interviewer, or imprecision in quantifying the food portion size; or skills and motivation of the respondent. They can also result from the food composition tables used. Other errors can result from research data management throughout the process.

The validity of a method is assessed by comparing the results obtained by the method-of-study with those of a reference method, or gold standard. If the studied variable is quantitative, various statistical methods for the comparison of means can be used. If the variable is dichotomous, the sensitivity and specificity values of each method are compared. The method used as gold standard should estimate the intake in a different manner from the study-method in order to prevent the inclusion of the same type of error in both methods and, as such, erroneously assume that the method-of-study is valid[4].

In relation to accuracy, a random error is the difference due, simply, to chance between the value obtained from a subject's food consumption *vs*. the real value. Alternatively, it can be between the observed value in a sample compared to that corresponding to the overall population; which would increase the intra- and/or inter-individual variability. Random errors are caused by unknown factors affecting the measurement of the variable. This could include the mood of the interviewed subject on any of the assessment days artificially modifying the response. Whatever the cause, this random variability from unknown factors decreases the accuracy of the measurement and affects the mean and widens the confidence interval[1,2,3] (Fig. 1).

To estimate the variability of a method, the same measurement is repeated in the same individual and the correlation between the two measures is analyzed. The KAPPA Index is used if the variable is qualitative and, if the variable is quantitative, the intra-class correlation coefficient, or the graphical method of Bland and Altman, is used[4]. Some factors need to be considered in conducting this analysis of repeatability such as the real possibility that the events are repeatable. This can be difficult when assessing the diet at two different times since, although the method is very accurate, the accuracy could be affected due to the diet itself having been altered. It is advisable that the periods compared are not too close in time such that the interviewee remembers the previous measurement. Neither should the time interval be too distant that the dietary habits had changed. Willett et al. recommended spacing the measurements between 4 and 10 weeks[5]. Repeatability is also influenced by the degree of difficulty, or measurement variability. For example, a food frequency questionnaire (FFQ) that does not evaluate portion

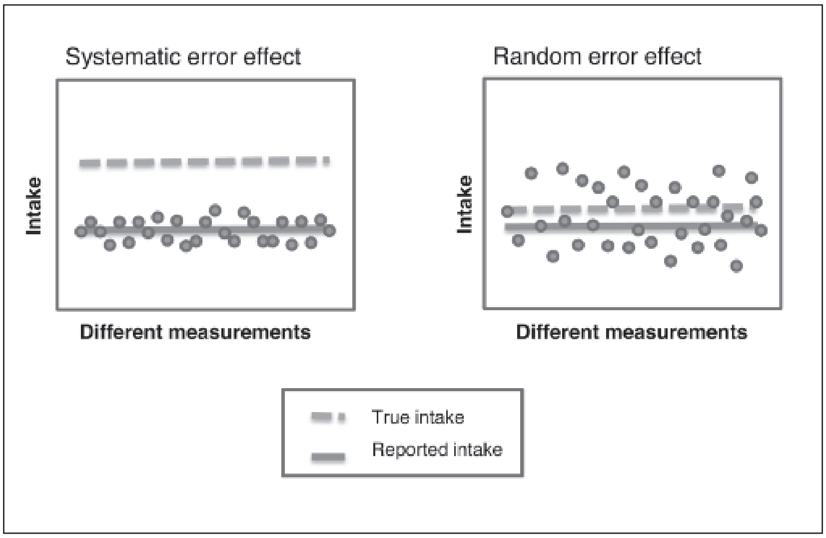

Fig. 1.—Representation of systematic and random errors.

size is more repeatable than one that does. Whether the design of the FFQ is clearer or more confusing for the understanding of the participant, the repeatability would change.

The most important error in the estimation of food consumption is the intra-individual random error. The variability caused by this error is greater the longer the time between measurements, since they include the intra-individual error and true dietary changes. This error can be decreased by increasing the number of days assessed. A comprehensive study addressing this issue indicated that the number of days depended on different situations. For example, in the assessment of different nutrients more days are needed in estimating the usual intake of some micronutrients than to estimate energy and macronutrients. In cross-sectional study designs aimed at obtaining mean intakes for groups of subjects, it is accepted that 1 or 2 days are needed. However, when evaluating the individual relationship between habitual intake and health concerns, more measurements are required. This can be between 3 and 7 days provided they are not consecutive and, as well, variability between days of the week and between seasons is taken into account. The decision on the number of days of measurement is limited in population studies since, if the number is high, the information recorded or reported by the subject may be modified due to the participant's tedium in response and, as well, the eating habits of the participants may change in order to simplify the consumption and ease the recording of intake[1,2,3].

It is important to highlight that, to confirm the method as being correct, the main feature to be considered is the validity i.e. good accuracy, by itself, is not enough.

Misclassification of the subjects; effect on results

Bias in the collection of information can lead to misclassification of the causal factor, the effect studied, or both. This misclassification between cases and controls or between exposed and non-exposed individuals may occur in analytical epidemiological studies; the outcomes may be modified. When misclassification occurs in a similar manner in all subjects or study groups, a non-differential misclassification may occur which could reduce the real difference, or association, between cause and effect. This bias is not related to either exposure or to the disease-under-study, but is inherent in the method of data collection itself. As such, the odds ratio, or the relative risk, tends to disappear and the studied effect can be lost. However, a differential misclassification will occur if the bias happens in only one of the study groups[1,2,3].

This bias is related to exposure and/or to the disease and may underestimate, or overestimate, the effect studied (Fig. 1). The result could be the observation of an apparent relationship when, in reality, it did not exist, or observing an apparent lack of relationship when, in reality, there is one. For example, if the relationship between consumption of cheese and the presence of migraine is to be assessed in an epidemiological case-control study and individuals with migraine respond with more interest regarding cheese consumption than controls, the effect would be overestimated. Similarly, when the dietary intake is assessed in obese and non-obese individuals, the effect may be underestimated since those with obesity tend to report lower consumption than the reality, as has been reported widely. The differential bias is not uniform[1,2,3].

Avoiding biases

To avoid these biases and, hence, to increase the validity and reliability of the results, control measures need to be included in the design of the study protocol, the conduct of fieldwork, as well as in the analysis and interpretation of results. In preparing the study protocol, it is essential to choose the most objective, and validated techniques of measurements. This decreases the variability caused by the method, taking into account the design and purpose of the study and the study population. Also, it is essential to include a standardization of how and when data are collected and, as well, standardization of the methodology among the interviewers since this would decrease the variability caused by the instrument of measurement and by the observer. Increasing the number of days on which the measurements are conducted would decrease intra-individual variability and increase the reliability of the data. Last but not least, we recommend the double entry of data into the database, data verification, database pruning, testing the quality of the collected data and, finally, using statistical procedures to adjust for measurement errors.

Recommendations for intra-individual variation control in dietary intake

The underlying assumption in assessing the nutritional status of a population is that, usually, individuals maintain their dietary habits and the population mean intake can be defined based on the usual intake of the individuals involved. Unfortunately, neither a single 24h dietary recall nor semi-quantitative frequency questionnaires accurately reflect an individual's true intake of a nutrient or dietary factor[5]. As a result, estimates of the population's mean intake or rate of nutrient deficiency (or excess) based on these data could be biased[6].

An individual intake varies from day to day and factors such as day of week or season contribute to this daily variation. A basic assumption is that the within-person variation is random, while the degree of random variation differs according to nutrient. One 24h dietary recall cannot characterize an individual's usual intake. For many nutrients, the intra-individual variances (within-person variance) are much larger than inter-individual variances (between-person variance) and could create problems in the analyses of data[7].

Analitical approach

In an approach to estimating the prevalence rate of nutrient deficiency of usual intakes, data from two or more daily consumption schedules for each person is needed, where the daily nutrient intake is the dependent variable[5,8].

The matrix format of the data should be organized following the format presented in Table I with repeated measurements for subjects considered as separate data.

The analysis can be summarized as follows:

- Firstly, analysis of data to ensure normality of distribution of intake. Logarithmic transformation is required if the data do not follow normal distribution.
- Estimate intra- and inter-individual variance.
- Compute the adjusted (for intra-individual variance) intake for each nutrient as:
  Estimate R as:
  (√Var between/Var between + Var intra) / (√Var between/0.5(Var between + Var intra)
  Secondly, create a new variable for each individual deviation from the mean value of the total, or a stratum
- Adjusted intake as:
  Adjusted intake = (observed intake-mean intake) * R value

Means of adjusted and unadjusted values must be the same (Fig. 2).

Confounding factors and adjustment for total energy intake in nutritional epidemiologic studies

In nutritional epidemiologic studies, misleading conclusions can be arrived-at if data are not properly analyzed and interpreted. In particular, the relationships between the diet (exposure) and disease risk can be distorted, or biased, by extraneous "confounding" factors. Failing to account for a confounding factor can lead to a spurious relationship being observed between exposure and disease risk i.e. a false correlation. The

Table I
Matrix format for analyses

Nutrient (N)	*Subject*	*Age group (factor)*	*Season*
V1	1	1	W
V2	1	1	S
V1	2	2	W
V2	2	2	S
V1	3	1	W
V2	3	1	S

W: Winter; S: Summer

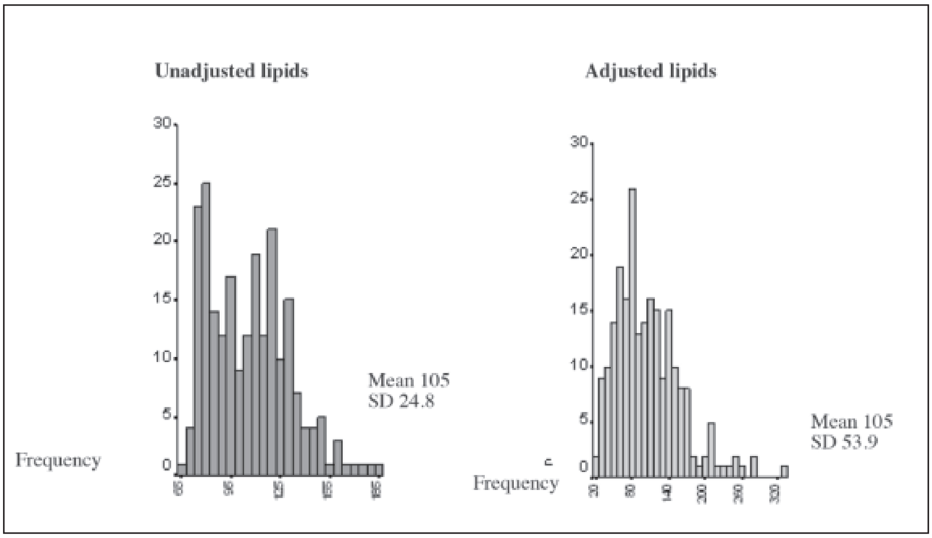

Fig. 2.—Example of unadjusted and adjusted values.

confounding factor can also cause an overestimate or underestimate of the real magnitude of the association, or even alter the direction of the real association.

A classic example of confounding factor effect was presented by Hulley and Cummings in 1993[9], in which the spurious association between drinking coffee and myocardial infarction was detected due to the confusion with the smoking habit effect. Specifically, this association was found because the number of smokers in the group of subjects who drank coffee was higher (380 *vs*. 120) than in the group that did not drink coffee (20 *vs*. 480). Further, the smokers had a higher incidence of myocardial infarction (10%) than non-smokers (1.7%). Hence, this different distribution of subjects according to the confounding factor (smoker status) in each group of coffee drinkers caused a spurious association between coffee-drinking and myocardial infarction.

Another example of confounding factor in which the real magnitude of the association is overstated was presented by Irala et al in 2001, when discussing the relationship between the neural tube defects of newborns and the mother's folic acid deficiency[10]. The effect of folic acid fortification was overestimated because mothers with normal values of folic acid also have several healthy behavior patterns such as a healthy diet, better genetic endowment, or lower prevalence of risk factors (tobacco or alcohol abuse) relative to mothers with folic acid deficiency.

In nutritional studies, the total energy intake can be a confounding variable when studying relationships between nutrient intake and disease risk. According to Willet et al in a studies in free-living human populations, the total energy intake is, largely, a consequence of variations in physical activity, body size and metabolic efficiency[11,12]. The confusion occurs when the total energy intake is associated with disease risk and nutrient intake. Total energy intake association with disease risk happens due to physical activity, body size or the metabolic efficiency being associated with disease probability. Total energy intake and nutrient intake are associated because either the nutrients directly contribute to the total energy or because the individuals who have a higher energy intake also have a higher intake of specific nutrients. The Willet et al study (1997) provided an example of total energy intake as a confounding factor in the relationship between nutrients and coronary artery disease[12].

Several approximations are proposed to adjust for the effect of the total energy intake. These include nutrient densities, standard multivariate models, and nutrient residual model.

Nutrient densities are computed by dividing the nutrient values by the total energy intake. As such, correlations between disease risk and nutrient densities, instead of the nutrient, are analyzed. The main problem in using these densities arises when the disease is also associated with the total energy intake. Under such circumstances, nutrient intake will be confounded (in opposite direction) by total energy intake because of it being divide by total energy.

If standard multivariate models are used, the total energy intake is included in a multivariable model along with the nutrient of interest. In such a model the association of nutrient intake and disease, measured by its regression coefficient, is controlled (or adjusted-for) by the total energy intake.

The nutrient residual model is calculated by using, as the independent variable, the residuals from the regression model of total energy intake, while absolute nutrient intake is the dependent variable. Since residuals have a mean value of zero, a constant to the residual is added. Willet et al[11] proposed the use of the mean of the nutrient as the constant value. Hence, the disease risk can be modelled as a function of the nutrient residual and the total. An advantage of this model is that both variables (nutrient residual and total energy) are uncorrelated, which is a desirable property for multivariable analysis in order to avoid problems of co-linearity.

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