Zeitschrift für
Ernährungswissenschaft Z Ernährungswiss 28:240–259 (1989)

Strategies for analyzing nutritional data for epidemiological purposes – Conceptual framework

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Summary: The relation between nutritional factors and health investigated in epidemiological studies are often inconsistent. One of the reasons for such findings can be the improper addressing of the multitude of nutritional dimensions in the specific study situation such as physiological individuality of human beings, different living conditions, or numerous interdependencies between nutritional variables.

Epidemiological research in nutrition and health should recognize such facts and work with appropiate study models and adequate data analyses. Instead of investigating heterogenous populations it is advisable to concentrate on specific "types" of people. Under consideration of the study goals such "types" can be compiled according to physiological properties, e.g., cholesterol sensitivity, or biological-constitutional factors such as body build, life-style entities, or other factors.

The variety of nutrition factors far beyond the commonly applied nutrient values can be expressed in integrated indices of "food patterns". Such "food patterns" can be derived in many ways. They can be deduced from theories by using specific criteria, but also explored by modern multivariate statistical analyses. The ways leading to "food patterns" are discussed.

The ideas presented and discussed in this paper lead to an improved model for research in the field of nutrition and health with integrated indices of "food patterns" as the critical point. It is assumed that using this approach will generate new insight in the relation of nutrition and health, a currently still diffuse research area.

Zusammenfassung: Die Beziehungen zwischen Ernährungsfaktoren und Gesundheit in epidemiologischen Studien sind oft inkonsistent. Eine der möglichen Ursachen für diese Gegebenheit kann darin liegen, daß die Vielzahl der potentiellen Ernährungsdimensionen in der spezifischen Untersuchungssituation in unzulänglichem Maße berücksichtigt wurden. Solche Dimensionsbereiche sind vor allem die physiologische Individualität von Menschen, deren verschiedenen Lebensumwelten und die zahlreichen Interdependenzen zwischen Ernährungsvariablen.

Diese Tatsachen sollten in ernährungsepidemiologischen Studien dadurch besser erfaßt werden, daß sowohl die Studienmodelle als auch die Datenanalysen entsprechend ausgerichtet werden. Anstelle von Untersuchungen an heterogenen Stichproben ist es ratsam, sich auf spezifische „Typen" zu konzentrieren, wobei gemäß dem jeweiligen Studienziel solche „Typen" aus den physiologischen Beson-

derheiten (z. B. Cholesterinempfindlichkeit), aus biologisch-konstitutionellen Faktoren (z. B. Körperbau-Typus), aus Lebensstil-Eigenschaften oder anderen Faktorenbereichen abgeleitet werden können.

Die Variationsbreite der Ernährungsfaktoren geht über die üblicherweise verwendeten Nährstoffdimensionen hinaus, doch sie läßt sich durch integrierte Indizes – die „Nahrungsmuster" – zusammenfassen. Zu solchen „Nahrungsmustern" kann man auf verschiedene Weise kommen. Sie können aus Theorien abgeleitet werden und zu bestimmten Bewertungsrastern führen. Man kann sie aber auch mittels multivariater statistischer Analyse suchen. Die prinzipiellen Wege, die zu „Nahrungsmustern" führen, werden dargestellt und diskutiert.

Die hier vorgestellten und diskutierten Ideen leiten zu einem verbesserten Untersuchungsmodell für ernährungsepidemiologische Studien über. Die „Nahrungsmuster" nehmen dabei eine wichtige Position ein. Man kann annehmen, daß durch diesen Untersuchungsansatz neue Erkenntnisse über die Beziehungen zwischen Ernährung und Gesundheit sichtbar werden, die helfen, den bisher noch diffusen Untersuchungsbereichen klare Konturen zu geben.

Key words: Data analysis; health status; food pattern; nutrition behavior; research strategy

Schlüsselwörter: Gesundheitsstatus; Ernährungsverhalten; Forschungsstrategie; Datenanalyse; Nahrungsmuster; Ernährungsepidemiologie

1 Introduction

It is the main objective of etiologically oriented epidemiology to identify factors affecting human health. From all life-style factors under suspicion, nutrition can be regarded as potentially important. In many epidemiological studies that examined the relationship of nutritional factors to diseases, in particular the important chronic diseases of the western world, nutrition proved to be a significant risk factor (1, 3, 7, 9, 33, 92). The same holds true for populations living in the Third World. There, food is also an important factor in the web of causes of diseases and mortality (13, 17).

Basically, research on the relation of human nutrition to health is started from a relatively simple study model (Fig. 1) which, however, can become complex in the concrete case. The study model presented in Fig. 1 envisages that human nutrition expressed in food consumption or nutrient intake, as an independent variable, changes a dependent health variable, which is either an indicator variable for a changed metabolism, e.g., hypertension, or a disease itself.

A close consideration of the individual constituents shows that human nutrition consists of highly complex variables. Scientists have difficulty in identifying the single causative agents out of this mixture. Therefore in recent years several nutritionists began to characterize "nutrition", not with a bundle of single and isolated variables, but rather with indices called a "pattern", a specific constellation of variables among or within individuals that includes many single aspects in one index. But until now a generally accepted definition of "pattern" has been missing and there has been a lack of agreement about if and when "pattern" indices should be used in nutrition research and nutrition epidemiology (8, 10, 22, 26, 37, 52, 56, 59, 78, 85, 86, 96, 108).

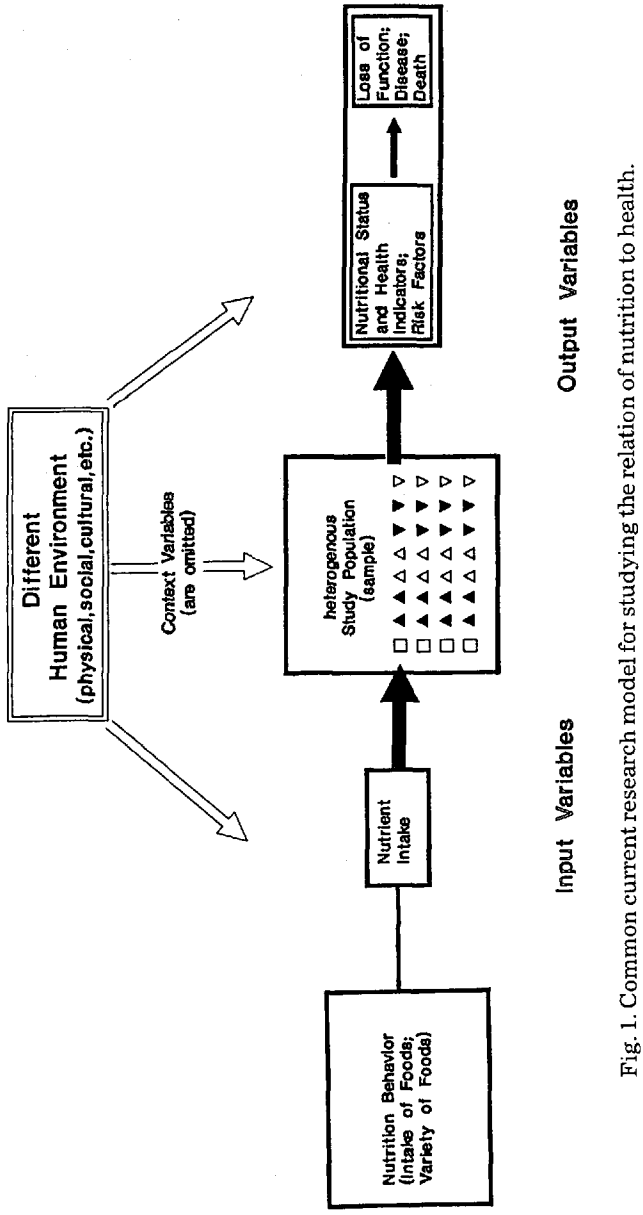


Fig. 1. Common current research model for studying the relation of nutrition to health.

We feel that it is necessary to start a discussion about the role of food patterns in etiological research. In this article we introduce a comprehensive research strategy including food patterns for analyzing nutritional data for the purpose of relating nutritional variables (risk factors as well as protective factors) to health. Most of the ideas presented were developed during a pilot project – EMSIG (Ernährungsmodell-Studie in Gießen) – performed by the authors in 1981–1983 (19, 20). Among our group it was

the strongly felt that human food intake contains more relevant information than is described by using consumption indices for nutrients. Future analysis of this complex structure and its influence on health status may show much stronger effects than before; yet this presumption has to be empirically proven.

2 Problems occurring when nutrition is related to health

In the first part of this paper problems are described which are associated with variables important in the nutrition disease model. Studies analyzing such relationships have to take these problems into account when results are interpreted. This list of problems is far from complete, but may be helpful for understanding the difficulties nutrition epidemiologists are faced with.

2.1 Physiological individuality

Man is a system which is open to its environment. If he wants to survive, he will have to find a dynamic balance with his environment. The manifestation of this balance not only depends upon a physiological standard, but also individual qualities are important. As an example, for the extent of this biological individuality we can use genetic disorders registered so far. Of the roughly 3 000 known genetic disorders, 250 alone are biochemically defined e.g., by disorders in aminoacid-, vitamin-, mineral-, carbohydrates- and lipid-metabolism (67, 70, 81, 101). There are also many examples of inter-individual differences in response to dietary intake, e.g., to cholesterol (58, 73), sodium chloride (30, 76), alcoholic beverages (41), or to general or specific food items known as food intolerances or food allergies (11, 25, 54, 98). This biological variability will definitely play a role, not only with obvious defects, but also it is of importance when establishing individual states of balance. In a study it is difficult to separate these individual characteristics from effects caused by independent factors. Thus, for instance, it is unclear whether being moderately overweight constitutes a function of caloric intake or whether it is partly due to biological variability.

In this context it is perhaps illustrative to revert to the system idea in man. We know of systems that, as a rule, can be kept in balance by several independent feedback mechanisms. Shifting a factor does not, therefore, necessarily mean that the system will break down, but can mean that it will simply find its balance on a different level. The human energy balance, for instance, may follow such principles. It is known that the distribution of body fat affects metabolic reactions (2, 16, 40, 53, 87). The manifestation of the individual feedback control systems in man himself may, therefore, lead to differing reactions. It is thus not surprising that monocausal assumptions do not apply and a considerable inter-individual variability is to be found.

This inter-individual variability should, however, not be seen fixed under any circumstances and it must be assumed that an individual does not always respond in the same manner to an exterior stimulus. According to the situation of the individual, perhaps also depending upon the biologi-

cally fixed rhythm of life, different manifestations may be observed (33, 35, 93, 105, 114). Physiological individuality has to be recognized during sampling in nutrition epidemiological studies. Instead of investigating heterogeneous population (Fig. 1) it is advisable to concentrate on specific "types" of people. The "types" have to be selected in recognition of the specific goals of the planned study and includes all individuals who show similar physiological properties, i.e., body fat distribution or salt sensitivity. But such types can also be selected according to non-physiological variables such as similarities in socio-psychological characteristics, i.e., life-style (112), stress-coping behavior (66, 84), biological-constitutional types such as pyknic and leptosomic (45, 74), or food habits, which will be discussed later on (see 3.1).

2.2 Interdependencies between nutritional variables

Nutrition is not a single factor, but consists of a variety of variables often highly correlated to each other. The available technique such as food diaries or retrospective questionnaires is limited in assessing food intake (14, 18, 27, 32, 48, 69, 79, 94, 100). Based on these techniques it will be nearly impossible to differentiate between causal factors and correlates. In epidemiological field studies where individual nutrition is recorded, no single variable is measured, but instead only a complex mixture of variables. Knowledge about the composition of this mixture is more or less limited. Identifying the causal factor will be nearly impossible by means of these techniques because they are unable to adequately describe the complex factor for causal inferences. Additionally, other risk factors associated with the variable of interest may confound the results. Confounding variables are usually not fully identified or can only be measured incompletely (44). It will be nearly impossible in the field situation to control nutrition behavior; the selection according to one nutrient variable will necessarily interfere with other nutritional factors. The limitations in food intake per day by amount or energy content restricts the intake of certain food items which contain minerals and vitamins as well. In the following an outline of the range of possible interactions will be presented.

2.2.1 Diversity of food

It is evident that the potential of possible foodstuffs almost reaches the total number of the known vegetables and animals including their subgroups. Kunkel, in a list of all eatable plants, arrived at a figure of 12 850 species (62). Even with a restriction to food items, which can be acquired at an average cost, we still come to 10 000 products, which are to be considered. An average supermarket today contains 12 000 different food products (68). In addition to this selection, there are series of variation, e.g., by biological variables, processes during ripening and storage, or variations caused by different industrial processing or different preparations within households.

If we only consider the substances contained in foodstuffs, this multitude of food items becomes very much restricted. However, as a matter of principle, the term "substance contained in foods" should go beyond

Table 1. Classification scheme of compounds in food.

A)	*Natural compounds*	*Example*
	– essential nutrients	vitamin
	– non-essential nutrients	sugar
	– positive acting non-nutrients	fiber
	– negative acting non-nutrients	mycotoxines
B)	*Man-made compounds*	
	– intended (additives)	conservatives
	– accidential (contaminents, reaction products)	pesticides browning products (Maillard reaction)

the term "essential nutrients" of which there are about 40, and should also include the non-nutrients (Table 1). Though little is known so far about the physiological effect of the non-nutrients, there have always been surprising pieces of knowledge in the past (24, 97). Thus, for example, the observation that cabbage plays a protective role against the development of colon carcinoma was ascribed to the presence of certain indole compounds which stimulate the formation of enzyme systems (106).

2.2.2 Interactions between nutrients

There are a number of observations which prove that multiple interactions exist between substances contained in foodstuffs (4, 111). On the basis of projections it can be proved that it will never be possible to completely clear up this complex network of interactions. Abrams, for instance, calculated that the combinations of the 40 essential nutrients with two manifestations alone, if one endeavored to examine them for all interactions of first order, would each exceed the size of the present world population 250 times (5). If, in addition, non-nutrients are included, it can easily by seen that the number of these interactions is inconceivable, although, as many examples, show, they certainly exist (47, 75).

2.2.3 Purified food compounds often have a different effect from that exerted by crude foods

Lately, results of experimental investigations, where – as a rule – the substance to be examined is administered in a pure form, do not coincide with observations made when the examined substance was administered in the form of a foodstuff. For instance, the blood sugar reaction is different with the administration of isolated carbohydrates, e.g., starch, than with the administration of starch in the form of potatoes, rice, or pulse. In the same way, different effects can be evoked with different foods or menu components (12, 28, 55, 61).

2.2.4 A homogenous nutrient intake can produce different physiological effects by different modes of nutrition

In spite of an arithmetically equal quantity of substance intake, the physiological effect of the substances can be rather different. For example,

the physiological value of a quantity of protein is not equal but corresponds to the composition of the amino acids. There are so-called "optimal" protein mixtures which can cover the overall human requirement even with a low intake and combinations where, in spite of high protein intake, the biological demand is not met (38, 105, 113). In the same way, situations might be thought out for other fields where, in spite of an arithmetically equal intake, varying physiological reactions occur conditioned by differing modes of nutrition. As to the overall energy supply, it is, for instance, known that the number of meals plays an essential role as to how the energy supplied is used (6, 30). During the process of calculation of nutrient intake from data of dietary surveys the observed individual dietary variability becomes "smoothed". The variations in nutrient intakes are small compared with variations in intakes of specific foods (109, 110). Individuals can easily avoid the intake of disliked foods, but none of the essential nutrients should be ignored. Myres and Kroetsch, in analysis of the Nutrition Canada data, found few major differences in the nutrient intake of children among different income groups, although differences in food consumption patterns were evident (72).

2.2.5 The study models are tested in different environments

It must always be taken into consideration that studies about the connection between nutrition and health often take place in societies with different cultural backgrounds. Although the basic mechanism of an effect must certainly be the same for all men as long as it is not influenced by different genetic manifestations, the question must be asked whether the different environments of man might not exert an influence on the result of the study. Neither the nutrition nor the state of health of man can be separated from his environment. We must remember just how different human environments may be, e.g., different climatic zones, from tropical rain forests to deserts, moderate climates on to the arctic, or even the different economic structures by which nutrition as well as health is manifested, such as developing and industrial nations, town and country regions, workers and the unemployed, or single households versus multiple family-member households.

3 Consequences

The groups of problems shown lead us to recognize that the objects of investigation-nutrition, health, and their relation are highly complex. The simpler we render the study model, the less reality-oriented the knowledge gained from it will be from the viewpoint of the entire problem. As an interested scientist one will have to ask how the observations are connected within the framework of the complex entity. Research in this field means that variables from the complex entity are chosen, because of their assumed essential importance, without knowing exactly whether this is the case. Contrary to earlier times, the choice of variables will be greater due to the use of electronic data processing. In this decision process a methodical procedure is helpful when the research goal is first defined, a study model derived, then the corresponding sample chosen and appropriate statistical methods are established. If this procedure is

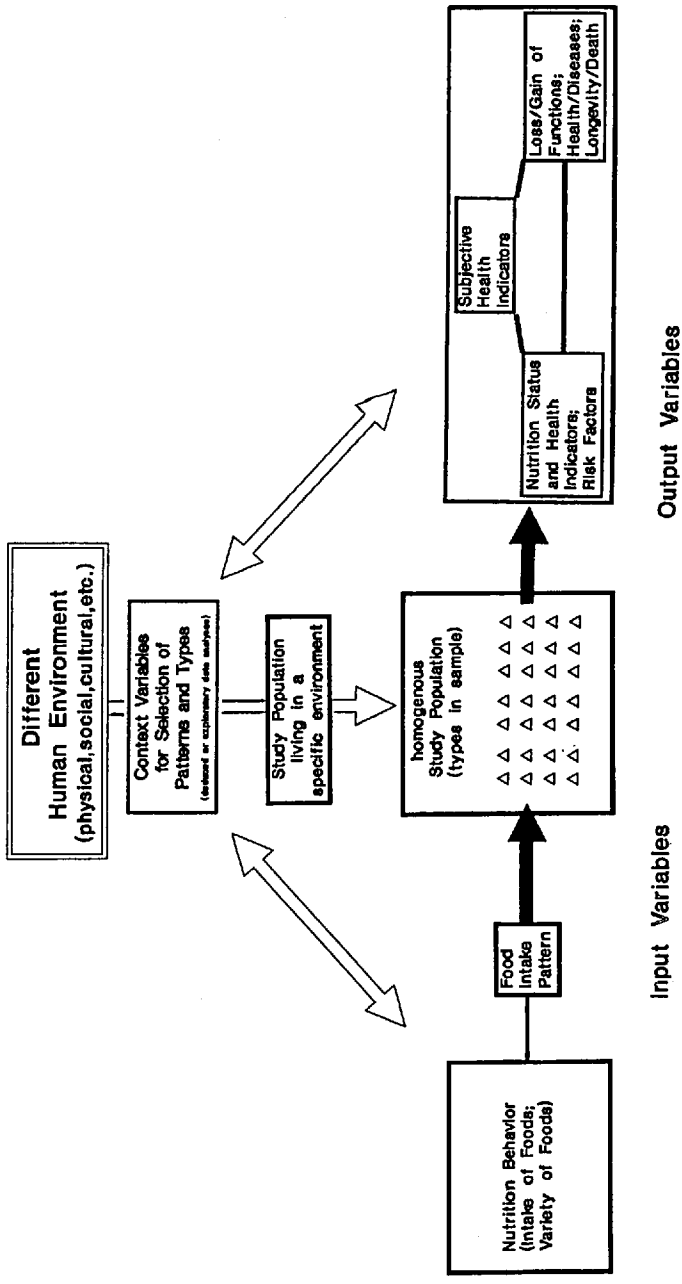


Fig. 2. A new improved research model for studying the relation of nutrition to health.

put down in written form, the reduction of reality is carried out in a reconstructable manner. It will not be possible to work out general guidelines as to how the process of reduction must take place. But today it can be said that in the future we will definitely not be able to work with simple

models, but that simple models will have to be replaced by multifactorial study models. Some working groups have attempted to reduce this complex happening and to turn it into models (12, 23, 31, 64). Starting from the system idea (kybernetics) one endeavors to represent observations of reality by such reduced models, including observations of further environmental variables. These models would have to include those variables which have proved to be of essential importance.

3.1 Extended research model

For the further systematization of the discussion and to render the scientific procedure more precise, we want to present a study model going beyond the simple model shown in Fig. 1. This study model is suitable for defining the corresponding groups of problems and for showing the connections between individual research areas. In particular, Fig. 2 illustrates where multivariate procedures can or should be used and how far results of multivariate procedures can be seen in the overall context of the object of the study.

Our considerations are concentrated on the intake of foodstuffs. The intake information should be covered and described in seperate dimensions, i.e., where, when, what, by whom (see 3.2). Many individual observations can be combined and described as a pattern. Food (dietary) patterns can be defined as: "Repeated arrangements of food and beverages that can be observed in food consumption records, including the combination of foods into meals or into recipes for prepared items in meals or snacks. More loosely, types of foods consumed by people in a country, culture or locale emerges as a result of food habits" (63). Determination of food patterns should possibly consider different dimensions in food consumption in the form of integrating indices. The indices can be obtained by using a certain pattern of criteria (see 3.3) or by identifying the structural elements of consumption by means of explorative data analysis. In so doing, explorative data analysis with the inclusion of many factors is a way to order nutritional consumption without the burden of previously existing criteria.

Another possibility to describe the variable nutrition consists in the evaluation of food consumption which has taken place. In most cases, the calculation of nutrients is an evaluation procedure used to describe food consumption of individuals or groups. However, depending upon the research problem, not only may the substances be of interest, but there are also many different possibilities of evaluation in order to derive indices from food consumption. Figure 3 shows the different disciplines which may be interested in human nutrition and their standards of evaluation. Principally, all of them may contribute valuable information to the determinants of observed food behavior, and thus, how they are related to individual health status. On the level of the indices derived by evaluating food intake according to evaluation standards, it will, in many cases, be opportune to identify essential structures by means of explorative data analysis or preformed patterns of criteria and to reduce the wealth of data by using more highly derived variables.

This aspect at present appears to be of secondary interest, since food consumption is the variable from which the other variables are derived. A concentration on food consumption appears to be the most promising

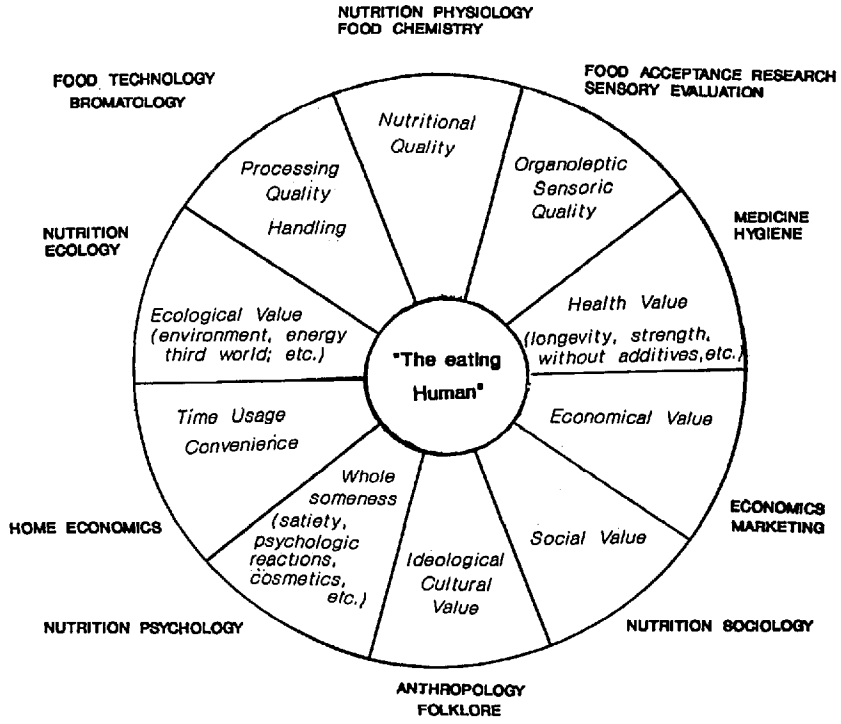
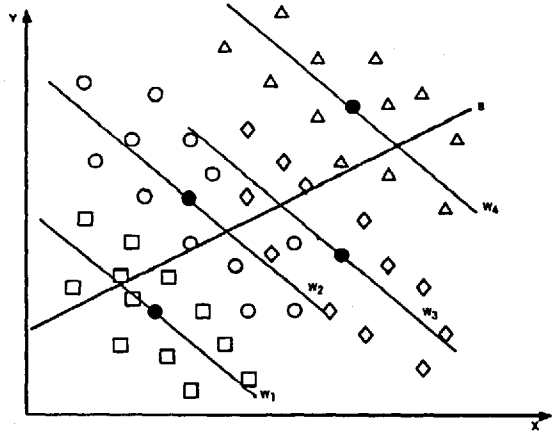


Fig. 3. The scientific disciplines involved in human nutrition research and their different evaluation standards.
(Oltersdorf, U.: Die Problematik der Bewertung von Lebensmitteln und von Ernährungsweisen. Hauswirtschaft und Wissenschaft 35(4):184–196 (1987))

approach on account of the limited resources, since, within the framework of the groups of problems already described, a systematic research as to the derived indices will lead to inexplicable phenomena without a good knowledge of the basic variable, the food intake.

The relation of nutritional variables to health status should not be established without further context variables. These context variables can act as additional filter variables throughout which the individual health status is further defined. From the past it is known that, for instance, sex and age exert an influence upon the investigation model. However, not only should the classic sociodemographic variables be included but also other factors which are known to influence nutritional behavior. In terms of statistical analysis introducing these factors will lead to more homogenous subgroups from which conclusions are drawn. It is known that the heterogeneity of study groups can evoke or veil results. An example is found in Fig. 4. The context variables can also be used to describe the members of a pattern more precisely and to develop specific "types" for which a pattern is characteristic. In many cases, these factors can be designated as lifestyle factors. Hendrichs succeeded in giving an accurate description of nutritional patterns including such lifestyle factors as



B: Between Groups (4 means) Regression Line; Positive Correlation
$W_1 \ldots W_4$: Within Groups Regression Lines; Negative Correlation

Fig. 4. Graphic representation of hypothetical values of heterogenous groups and the influence of grouping on correlation analyses. (Adapted from: Munoz-Box, R.: Statistical evaluation of nutritional, neurochemical and behavioral data: a case study. Int. J. vit. Nutr. Res., Suppl. 29:83–97 (1986))

attitudes or mental state (49). There are only few other studies which investigate nutrition-related "types", such as restrained non-restrained eaters, health-conscious dieters, fastfood devotees, finicky eaters, or high-calorie traditionalists (8, 50, 82, 95).

There are as yet no exact number of context variables to be included in the study model. However, within the framework of this paper, we wanted to introduce the concept in which context variables factors are a necessary constituent of the investigation.

Analogous to setting up a catalog of context variables permitting division of the population to be investigated into homogeneous groups or to describe specific patterns, it should be considered how nutrition in its various aspects is to be covered.

3.2 Choice of dimensions of food intake

When enumerating the different aspects of nutrition, we want to differentiate between the dimensions of food intake simultaneously recorded by the measurement techniques and the enlistment of evaluation standards. The intake of foods basically shows different dimensions: the substantial dimension (the respective foodstuff), the temporal dimension (the respective eating time), and the spatial dimension (the respective eating situation). It is in this multidimensional pattern that the individual food intake takes place; it could thus be infinitively varied. However, daily experience shows that food intake does not take place unstructured in these three dimensions but that partly individual structures are formed, some of which become nutritional habits.

The individual food intake or rather the individualized recurring pattern shown as an average figure per day, can be judged by evaluation standards. According to the way the nutritional information is collected these

evaluation standards can differ greatly. For instance, food intake, can be judged according to its nutritional value. Other evaluation standards are economy, ecology, enjoyment, wholesomeness, repleteness or stimulation offered by the consumption of a foodstuff (see Fig. 3).

One has to recognize that the evaluation standards are not evident to the acting subject – the eating person – but we can try to use the recorded food intake data for such an evaluation. Since food intake belongs to the daily actions, man would rather conform with habits and experiences in the selection of his foods instead of some scientific evaluation standards. For instance, the knowledge about nutritional science definitely belongs to those experiences considered to set the standards for the execution of eating. But the frequently negative experiences collected when including the consideration of knowledge about nutrition into the action of nutritional intake point to the fact that knowledge about nutrition plays but a very subordinate role as a parameter of judgment.

The nutritional researcher is faced with a situation where he has information on the object of investigation with regard to the context variables which enable him to form homogeneous subgroups from the study population. On the other hand, he can observe how individual persons consume their nourishment within the framework of this multidimensional network (e.g., what, when, and how). In addition, he can validate what he observes. On the other side there is the object to be investigated – the human being ("The eating human" – Fig. 3), who acts almost entirely independently of the scientific point of view – he simply rats. We only know with certainty that the interest of the researcher in aspects of nutrition does not coincide with the factors which determine the nutritional behavior of man.

3.3 The role of food patterns

We have seen that food intake can be multidimensionally represented and that, for this purpose, certain criteria of evaluation can be used at the same time. If "nutrition" is to be described, it is important to present the combination or constellation of foodstuffs dependent upon time and space since these are the dimensions which can, for example, be objectively established by means of food records.

With the keyword "food pattern" a concept is to be introduced by which food intake can be structured in multidimensional space. We start by assuming that while nutritional action takes place individually, the individual persons are more or less common in their nutritional behavior. This can be anticipated since nutritional behavior as such must be manifested by structures, otherwise it would operate in an entirely unstructured manner. In describing food patterns, we want to concentrate essentially on food intake behavior and leave the evaluation standards out of consideration at this time. The standards of evaluation are judgments of this behavior and reduce the manifold food intake actions to certain aspects which might likewise be of interest for a consideration of patterns. Thus, for example, it is extraordinarily interesting to compare individual persons with regard to their provision with nutrients. However, in so doing it should be taken into account that the consideration of the level of action constitutes a further differentiation (see 2.2.4).

3.4 Strategies for identifying relevant food patterns

The substantial, temporal and spatial characterization of food intake can be carried through in manifold ways and will never be exhausted. Research can pick out individual aspects which, as a rule, will have to be restricted to the essential indices. One will have to decide whether all dimensions are of importance or whether, dependent on the research problem, only certain indices should be enlisted for the purpose of characterization. As a rule, many indices of food intake behavior will remain, in spite of previous reduction, and will enter into the study model. The strategy to be followed most frequently will be to determine which food items are of importance for the study, for example on the basis of their nutrient content. As far as the research problem makes no other demands, food items will have to be combined into groups. In the same way, it will be possible to identify those food items which form the basis of nutrition in the respective study population (core diet). From this statement, it becomes clear that by data reduction from the manifold offer of food items only relatively few foods remain for the study model.

Apart from the qualitative validation of the food intake behavior there is the quantitative aspect. It can be determined for every individual participant which quantity he or she consumed at what time and what place. In so doing it is often sufficient to revert to portion sizes which are usually used in the household, since these are only of relative importance compared to the potential variability in frequency.

It is evident that these structures of the quantities in meals, in addition to the qualitative information, grant further insight into the food intake behavior of the individual.

An important aspect when covering human nutrition is the question of how the study expense can be reduced, and the use of "abridged methods" is indicated. The concept of concentrating on the basic foodstuffs which constitute the essential part of the nutrition of the group under investigation, has already been introduced. This means that a rough assignment of individual persons is made with regard to the food items which, for instance, play an important role in the provision with nutrients. By standardized presentation, i.e., which is merely related to those foods, when investigating the nutrition, the expense of the investigation is considerably reduced and only information on the relevant aspects of food intake behavior will become available. The concept to concentrate on certain aspects of food intake behavior according to a fixed schema of evaluation can be generalized and considered as a basic concept to cover nutritional action. According to the research problem supplied by the schema of evaluation, certain aspects of food intake can be picked out and covered by relatively simple methods. Examples for such simple short cut dietary intake measurement methods are developed in the cancer epidemiology (21, 46, 94, 102, 107) (e.g., vitamin A/carotene scores (43, 90)), but are also found in investigations into coronary heart diseases (e.g., cholesterol score) (51), and in public health nutrition (e.g., to identify risk high-eating patterns) (29, 60, 80, 83, 89, 91). However, one should be conscious of the fact that the actual object of the study remains food intake in the multidimensional network and that only on the basis of prior knowledge have corresponding evaluation standards or criteria been set up.

Another strategy, presupposing an intensive coverage of the nutritional behavior, is the judgment of food intake after the investigation. A possible standard of evaluation, certainly of interest in many problems, is the intake of nutrients in connection with the foodstuffs. For the choice of coefficients of evaluation, food tables are available indicating the average content of a nutrient or substance for a certain foodstuff. Less attention has so far been paid to the standards of evaluation for other fields of nutritional behavior which can be of importance for nutritional research and can constitute essential structural features for nutrition. Only a few aspects can be indicated by way of example, such as evaluation according to gustatory, olfactory, visual, or haptic impressions (34, 36, 77, 88). By corresponding tables of coefficients, information on food consumption could be translated and treated statistically in the same way as with nutrients.

4 Discussion

From the various aspects presented earlier only the forming of food pattern will be discussed here because it was our feeling that this area needs most urgent clarification among nutrition epidemiologists.

The forming of food patterns and their introduction into etiological models should not be discussed without including recent developments in epidemiological etiological research which can be characterized by focusing on interrelations among independent variables and measurement errors of the dependent and independent variables. Intercorrelations and measurement errors are connected inso far as both have consequences for statistical modelling.

The correlation of a variable with the investigated risk factor is one of the requirements for being a confounder variable which, if not controlled, leads to a biased risk estimate. Many working groups were able to show that misclassification of the confounding variables in the range which can be observed in nutritional studies prevents or reduces the control of such confounding effects (44, 99, 103). But most nutritional factors are interrelated and are therefore potential confounders. These findings led us to conclude that in some instances only crude risk estimates had been obtained in epidemiological studies based on food records or retrospective dietary questionnaires.

This finding clearly shows the limitation of epidemiological nutritional studies, but also underscores the exploratory character of such approaches. In a specific stage of knowledge the exploratory search for relationships, which should be investigated further with study designs more able to add evidence for a causal relation, is an acceptable and valuable procedure (42). It should be mentioned that epidemiology have study designs available by which single nutritional factors can be tested very strongly regarding causal influences such as intervention studies (15).

It is obvious that strategies to cope with the limitations of some epidemiological study designs are needed because of the great value of such studies exploring etiological mechanisms in the field of nutrition and health. One interesting approach to cope with the limitations is to introduce the measurement errors into the statistical model (104). Also, the

usefulness of latent structure equation models has to be investigated for its use for epidemiological studies such as LISREL or LISCOMP which have a measurement error model as integral part of the total statistical model (57, 71).

A further strategy – and proposed here – is to investigate the internal structure of the nutritional variables which enables the researchers to properly interpret the findings in light of findings from other areas or biological plausibility. One way to explore the internal structure inherent to nutritional variables is by means of forming patterns as integrated indices. Based on various statistical algorithms which should be used to deal with the wealth of data and throughout which the structure can be revealed without subjective inferences patterns can be defined as a constellation of variables (over persons, "factor analysis"), as a similarity between persons (over variables, "cluster analysis"), or as indices derived through preformed patterns of criteria. All concepts had been used previously and there is no preference for one method over the other. Only simple factor analysis should be cautiously applied because measurement errors affect the variance structure and can lead to inappropriate factor solutions. With LISREL, a more powerful statistical factor analysis system is available in which misclassification of variables is taken into account (conformatoric factor analysis) (65).

We think that intuitively, the existence of food patterns is widely accepted by scientists despite there being no scientific philosophy of identifying and using them. It is the hypothesis that food patterns may differentiate the population in groups of different lifestyles much more precisely (considering misclassification) than single food items. The identification and assignment of subjects to patterns which usually comprise many single variables may not be as vulnerable to measurement errors and misclassification because of the broader base of judgments and will show stronger effects on health than by using single variables – but further research may show if this holds true in reality.

Acknowledgement

We thank Mrs. Blumenthal for helping in preparing the manuscript and Mrs. Edinger for the typing.

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Received December 15, 1988

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