Empirically derived dietary patterns: interpretability and construct validity according to different factor rotation methods

Padrões alimentares empiricamente derivados: interpretabilidade e validade de construto segundo diferentes métodos de rotação fatorial

Patrones alimentarios empíricamente derivados: interpretabilidad y validez de constructo, según diferentes métodos de rotación en un análisis factorial

Michelle Alessandra de Castro [1]
Valéria Troncoso Baltar [2]
Soraya Sant'Ana de Castro Selem [1]
Dirce Maria Lobo Marchioni [1]
Regina Mara Fisberg [1]

[1] *Faculdade de Saúde Pública, Universidade de São Paulo, São Paulo, Brasil.*
[2] *Universidade Federal Fluminense, Niterói, Brasil.*

Correspondence
M. A. Castro
Faculdade de Saúde Pública, Universidade de São Paulo.
Av. Dr. Arnaldo 715, São Paulo, SP 01246-904, Brasil.
mi.ale.castro@gmail.com

Abstract

This study aimed to investigate the effects of factor rotation methods on interpretability and construct validity of dietary patterns derived in a representative sample of 1,102 Brazilian adults. Dietary patterns were derived from exploratory factor analysis. Orthogonal (varimax) and oblique rotations (promax, direct oblimin) were applied. Confirmatory factor analysis assessed construct validity of the dietary patterns derived according to two factor loading cut-offs (≥ |0.20| and ≥ |0.25|). Goodness-of-fit indexes assessed the model fit. Differences in composition and in interpretability of the first pattern were observed between varimax and promax/oblimin at cut-off ≥ |0.20|. At cut-off ≥ |0.25|, these differences were no longer observed. None of the patterns derived at cut-off ≥ |0.20| showed acceptable model fit. At cut-off ≥ |0.25|, the promax rotation produced the best model fit. The effects of factor rotation on dietary patterns differed according to the factor loading cut-off used in exploratory factor analysis.

Food Consumption; Food Habits; Public Health Nutrition; Statistical Factor Analysis

Resumo

*Objetivou-se investigar os efeitos dos métodos de rotação fatorial na interpretabilidade e validade de construto de padrões alimentares em uma amostra representativa de 1.102 adultos brasileiros. Os padrões foram derivados por análise fatorial exploratória. As rotações ortogonal (*varimax*) e oblíqua (*promax *e* oblimin *direta) foram utilizadas. Avaliou-se a validade de construto dos padrões segundo os pontos de corte de cargas fatoriais: (≥ |0,20| e ≥ |0,25|) por meio de análise fatorial confirmatória. Índices de qualidade de ajuste do modelo foram analisados. Observaram-se diferenças na composição e interpretabilidade do primeiro padrão obtido pelas rotações* varimax *e* promax/oblimin *no ponto de corte ≥ |0,20|. No ponto de corte ≥ |0,25|, não foram observadas diferenças. Nenhum dos padrões derivados no ponto de corte ≥ |0,20| apresentou qualidade de ajuste aceitável. No ponto de corte ≥ |0,25|, a rotação* promax *obteve o melhor ajuste. Os efeitos das rotações nos padrões alimentares diferiram segundo o ponto de corte de carga fatorial utilizado na análise fatorial exploratória.*

Consumo de Alimentos; Hábitos Alimentares; Nutrição em Saúde Pública; Análise Fatorial

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Introduction

Exploratory factor analysis (EFA) is a multivariate statistical method that has been used in nutritional epidemiology as a data-driven approach to derive dietary patterns. Dietary pattern analysis is of growing interest because it provides valuable and comprehensive information about the overall diet [1], accounting for the synergistic relation between a myriad of foods and nutrients consumed [2,3].

From a statistical perspective, EFA is concerned with modeling the covariance among observed variables in order to identify the latent constructs or factors underlying these variables [4]. In dietary pattern analysis, EFA combines, into a factor, food variables that are correlated to each other, but are independent of the other subset of variables [5]. The strength in which an observed variable correlates to a factor is measured by its factor loading [6].

In order to simplify the factor structure (i.e., matrix of factor loadings) and improve the interpretability of the factor, a rotation method is usually applied after the extraction of a subset of factors [5]. A simple factor structure is achieved when the variable loads highly on as few factors as possible and the loadings of the variables across the factors (cross-loadings) are approximately zero [7,8].

In dietary pattern analysis, the orthogonal varimax rotation has been the most commonly used rotation method [9,10]. Orthogonal rotation leads to uncorrelated factors that are considered simpler and easier to interpret [8,10], whereas non-orthogonal (oblique) rotation, such as promax and oblimin, allow producing correlated factors which are considered harder to interpret and, for this reason, have been used less in studies involving dietary pattern analysis [11,12,13,14,15,16,17].

Once estimated, the factor structure can be evaluated by confirmatory factor analysis (CFA). CFA is a powerful statistical method allowing for testing specific hypotheses about the factor structure by providing an indication of overall fit and precise criteria for assessing construct validity, i.e., the degree of correspondence between constructs and their measures [18,19,20]. This method evaluates whether a pre-specified factor structure provides a good fit to the data [7].

Considering that the effects of rotation methods on the factor structure, its interpretability and construct validity remain unclear in the field of nutritional epidemiology, the present study aimed to investigate the effects of both orthogonal and oblique rotation methods on composition, interpretability and construct validity of empirically derived dietary patterns. With this study it is expected to advance the current knowledge on procedures of factor analysis and to improve guidance for researchers interested in dietary pattern investigation.

Materials and methods

Study population

Data came from the *Health Survey of the City of São Paulo*, a cross-sectional population-based survey using a complex multistage sampling design to collect health and nutrition information as well as life conditions on a representative sample of residents of the city of São Paulo, Southeastern Brazil, between March 2008 and August 2011.

A two-stage cluster sampling of census tracts and households was performed. In the first stage, a total of 70 census tracts were randomly selected from the 267 urban census tracts in the city of São Paulo as the primary sampling units (PSU). In the second stage, 16,607 households were randomly selected within census tracts.

This sampling was drawn in order to interview infants (< 1 year-old); children (1-11 years); male adolescents (12-19 years); female adolescents (12-19 years); male adults (20-59 years); female adults (20-59 years); male elderly (60 years and over) and female elderly (60 years and over). For the present analysis, only individuals aged 20 years or more of both genders with complete food consumption data were selected (N = 1,102).

The main study was conducted according to the guidelines laid down in the *Declaration of Helsinki* and all procedures involving human subjects were approved by the Human Research Ethics Committee of the School of Public Health at the University of São Paulo. Written informed consent was obtained from all participants who agreed to participate.

Socioeconomic, anthropometric and lifestyle data collection

A structured questionnaire with information about socioeconomic (*per capita* family income; educational level), anthropometric (body weight and height), demographic (skin color, age) and lifestyle characteristics [smoking status; alcohol use; physical activity – *International Physical Activity Questionnaire* (IPAQ)] was applied at the individual's home by trained interviewers.

Dietary data collection

Dietary data were collected by both face-to-face and telephone interviews. In the face-to-face interview, the first 24-hour dietary recall (24HR) was collected according to procedures described in the USDA Five-Step Multiple Pass Method [21]. This method guides the individual through a 24 hour reference period of food intake (more commonly, the day before interview) and provides different opportunities for individuals to remember and describe all foods and beverages he or she has consumed [21]. During the telephone interview, the second 24HR was collected according to the interviewing system incorporated into the University of Minnesota's Nutrition Data System for Research (NDS-R). This interviewing system enhances data quality since it standardizes the probes about foods and portions consumed [22]. All individuals were advised to report food consumption in household measures as well as to mention the eating occasions, meal time, cooking methods, seasonings and brand names. Quality control of the 24HR was conducted during data collection in order to identify and correctly report on errors. Dietary data collection occurred in non-consecutive days throughout all seasons and days-of-the-week.

After dietary data collection, all household measures reported in each 24HR were converted into grams and milliliters according to Brazilian publications, which were also used to provide standard recipes of regional food preparations [23,24]. The NDS-R, version 2007, was also used to determine the nutrient content of each food and beverage consumed. This program was developed by the Nutrition Coordinating Center at the University of Minnesota, Minneapolis, USA, and has the USDA Food Composition Table as the primary database source.

Foods grouping

A total of 1,169 different foods were reported in both 24HR and were collapsed into 38 food groups for factor analysis. Foods consumed by at least 5% of the sample evaluated (948 foods) were combined according to the previously used criteria: similarity of the nutrient profile [25,26,27] (e.g., all types of coffees were combined into the "Coffee" group) and the particular dietary habits and culinary usage of the Southeastern Brazilian population [28] (e.g., "Beans" group includes brown and black beans because they are cooked pulses that are usually eaten with rice, whereas the "Other pulses" group includes soybeans, lentils, chickpeas and snow peas because these are usually consumed in different preparations, such as soups, creams and salads).

The correlation matrix of food groups was analyzed to identify how the food groups were correlated to each other. The correlation matrix revealed that four food groups (Cereals, Flours, Roots and Tubers, and Seafood) did not show a significant correlation (p-value > 0.05) with any other food group, and then were excluded from further analysis. A detailed description about the 34 food groups and its composition is provided in Table 1.

The food group intakes, in grams, were adjusted for the within-person variation through the web-based statistical modeling technique Multiple Source Method (MSM) before factor analysis. This is a statistical method developed within the European Food Consumption and Validation Project (EFCOVAL) which is suitable for estimating the usual nutrient and food intakes (including those episodically consumed) based on two or more short-term dietary methods such as 24HR [29].

Statistical analysis

Sociodemographic, anthropometric and lifestyle characteristics of participants were described by sex and compared through a Chi-squared test. All descriptive analyses were conducted using Stata version 12.0 (Stata Corp., College Station, USA), considering the sampling design effect (*svy* command for proportion analysis) and significance level of 5%.

Dietary patterns were derived from EFA using the robust maximum likelihood parameter estimation (MLR) available in Mplus software (version 6.12; Muthén & Muthén, Los Angeles, USA). MLR was chosen because it is an estimation procedure appropriate to non-normally distributed data allowing for complex sampling designs and is also available for use in CFA [30]. It leads to more appropriate estimates than the conventional maximum likelihood estimation when the assumption of multivariate normal distribution does not hold [31].

The Kaiser-Meyer-Olklin (KMO) test and Bartlett's sphericity test were used to measure the sample adequacy before deriving dietary patterns. KMO values above 0.50 and p-value < 0.05 for Bartlett's sphericity test were considered acceptable [32]. The communalities of the food groups were calculated, representing the variance of each observed variable explained by the factor solution. Also, the percentage of variance explained by the factors was estimated for each rotation method.

Table 1

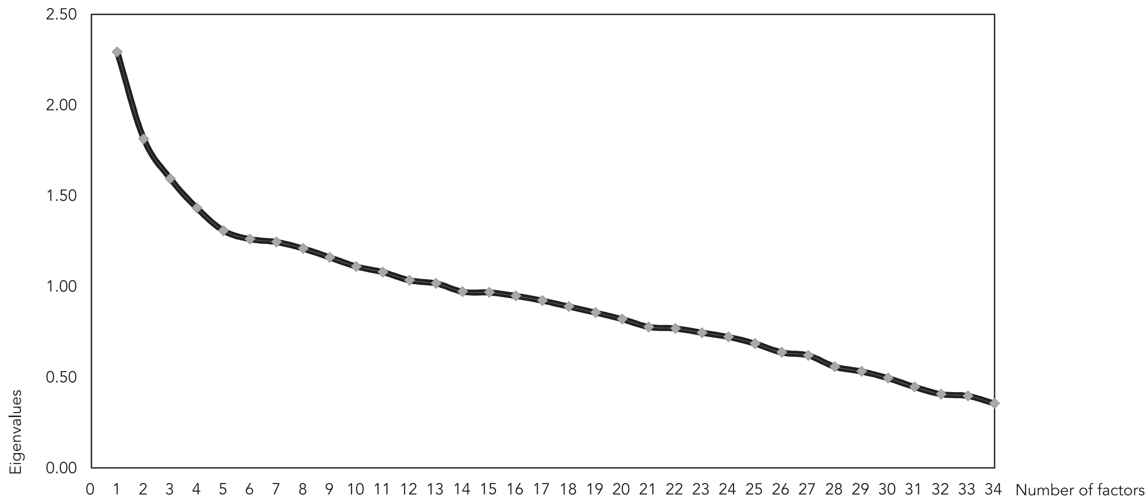
Description of the food groups used in the dietary pattern analysis. *Health Survey of the City of São Paulo*, Brazil, 2008-2011.

Food groups	**Food items**
Rice	Cooked white rice
Pasta	Cooked noodles, gnocchi, lasagna, cannelloni
Breads/Toasts/Crackers	French bread, Italian bread, loaf bread, buns, French toast, cookies, crackers
Whole breads	Whole wheat bread, Light whole bread
Fruits	Fresh fruits
Leafy vegetables	Lettuce, kale, escarole, spinach, cabbage, watercress, chard, arugula
Canned vegetables	Corn, peas, olives, hearts of palm, mushrooms, pickles
Non-leafy vegetables	Tomato, carrot, beet, chayote, cucumber, eggplant, okra, pumpkin, zucchini
Beef	Steak beef, ground beef, beef ribs (all cooking methods)
Pork	Pork chop, pork ribs, pork loin (all cooking methods)
Processed meat	Hamburger, sausages, frankfurters, nuggets, bacon, canned sardines, canned tuna
Poultry	Chicken, turkey (all cooking methods)
Chocolate powder	Cocoa powder, chocolate powder
Yellow cheese	Mozzarella cheese, parmesan cheese, cheddar cheese, provolone cheese
White cheese	White cheese, cottage cheese, ricotta cheese, cream cheese
Whole milk	Fluid whole milk (3% fat), whole milk powder
Low-fat and skim milk	Reduced fat milk (2% fat), skim milk, skim milk powder
Other dairy products	Yoghurt, fermented milk
Eggs	Fried eggs, scrambled eggs, omelet, boiled eggs, egg white, egg yolk
Other pulses	Cooked soybeans, lentils, chickpeas, white beans, Adzuki beans, snow peas
Beans	Cooked brown beans, black beans
Butter and margarine	Salted butter, unsalted butter, salted margarine, unsalted margarine, light margarine
Cakes and pastries	White cake, sweet pies, milk candy, chocolate pudding, peanut brittle, ice cream
Salty snacks	French fries
Sandwiches	Hot dog, hamburger sandwich, pizza, kebab, croquette, croissant, Italian focaccia
Coffee and tea	Coffee, instant coffee, herbal tea
Soda pop	Coke, diet coke, orange soda, lemon soda, *guaraná* soda
Fruit juices	Natural fruit juices, Industrialized fruit juices
Alcoholic beverages	Beer, wine, spirits, cognac, champagne
Cold cuts	Ham, mortadella, salami, roast beef
Salad dressing	Soybean oil, sunflower oil, olive oil, salt, vinegar
Sugar	White sugar
Fatty sauces and mayonnaise	White sauce, soy sauce, Worcestershire sauce, mustard sauce, ketchup, mayonnaise
Spices	Garlic, oregano, scallions, parsley, coriander, ground pepper

In order to identify the number of factors to retain, the Kaiser criterion (eigenvalue > 1.0) was used in the first step. This criterion is one of the most widely used in EFA with the rationale that the minimum variance explained by the factor should be equal to or greater than the variance of one single observed variable [33]. In this study, the Kaiser criterion would lead to the retaining of 14 factors which is an excessive number of factors for further analysis. Hence, a plot of the eigenvalues (the Cattell's scree test) was investigated in the second step and suggested two break points in the data that afforded two and four factor solutions (Figure 1). In the third step, the interpretability of two and four factor solutions was investigated. The two factor solution was more interpretable than the four factor solution and then was retained to investigate the effects of the factor rotations on the composition, interpretability and construct validity of each factor. For interpretation of the factor solution, food groups with a positive factor loading were considered as contributing directly to the factor, while food groups with negative loadings were considered

Figure 1

Scree plot of the eigenvalues of unrotated factors. *Health Survey of the City of São Paulo*, Brazil, 2008-2011.



to be inversely correlated with the factor. Considering the methodological purposes of this study, the factors were presented in alphanumeric labels rather than descriptive names, in order to facilitate reporting of results.

The factor rotation selected for this research was the same as those reported in previous studies on dietary pattern analysis that used factor analysis or principal component analysis: the orthogonal varimax [34,5,6,37,38,39,40], the oblique promax [11,12,13,14,15] and direct oblimin [16,17]. In brief, the varimax is a type of orthogonal rotation that attempts to maximize the variance of squared loadings on a factor, i.e., to reduce the cross-loadings of the variables, leading to uncorrelated simple factor structures [41]. The promax is an oblique rotation that is performed in two stages. In the first one, the target matrix of loadings is first defined through a varimax rotation. This matrix of loadings is raised to some power (kappa) – usually ranging from 2 to 4 – aiming to produce a simple factor structure. The second stage is obtained by computing a least square fit from the target matrix [42]. In this study, the Mplus default promax rotation power (kappa = 4) was used. Direct oblimin is another type of oblique rotation that aims to produce factors with perfect simple structure, i.e., factors with cross-loadings near zero or equal to zero. For this, a *delta* parameter ranging from 0 to 1 should be set. In this study, a *delta* equal to zero was chosen in an attempt to produce a simple factor structure [8,43].

After rotation, two factor loading cut-offs were applied to select the food items to CFA: ≥ |0.20| and ≥ |0.25|. These cut-offs were chosen because they represent two factor loading cut-offs applied in dietary pattern studies [34,35,36,37,38,39,40,44,45,46,47,48,49], that would lead, in this study, to a less restrictive number of food items than the most commonly applied cut-off (i.e., ≥ |0.30|). The CFA was executed in Mplus software 6.12 to assess the construct validity of each dietary pattern derived using the MLR estimation method.

The goodness-of-fit of the model was assessed by different indexes namely the adjusted Chi-squared test (χ^2/degrees of freedom) [30], the comparative fit index (CFI) [50], the Tucker-Lewis index (TLI) [51], the residual mean square error of approximation (RMSEA) [52] and its 90% confidence interval (90%CI), and the standardized root mean square residual (SRMR) [53,54]. They provide different information about model fit, such as absolute fit, fit adjusting for model parsimony and fit relative to a null model, allowing for a more conservative and reliable evaluation of the model [53]. Acceptable model fit was defined according to the following criteria: χ^2/degrees of freedom < 3.0 [30], CFI (> 0.90) [50], TLI (> 0.90) [51], RMSEA (≤ 0.06, 90%CI < 0.08) [52], and SRMR (≤ 0.08) [53,54]. A p-value < 0.05 was considered as significant in two-sided tests. Both EFA and CFA were performed following the complex survey design.

Results

Participant characteristics

Participants included 424 men and 678 women. Men and women had the same distribution of age, with about 46% of them aged 60 years and more (p-value = 0.669). Also, around 50% of men and 46% of women were normal weight (p-value = 0.433); 60% of men and 64% of women had low educational level (up to 8 years of study) (p-value = 0.069) and 83% of men and 84% of women had a maximum *per capita* income of R$ 1,000 per month (p-value = 0.599). A significantly higher proportion of women compared with men were of white skin color (63% *vs.* 57%, p-value = 0.040), non-smokers (85% *vs.* 76%, p-value < 0.001), non-alcohol drinkers (62% *vs.* 41%, p-value < 0.001) and with insufficient/sedentary physical activity level (55% *vs.* 40%, p-value < 0.001) (data not shown).

Dietary patterns composition and interpretability

Table 2 shows the communalities of the dietary variables as well as the factor-loading matrix of the dietary patterns derived from EFA according to different rotation methods. The KMO test and Bartlett's sphericity test confirmed the sample adequacy for factor analysis (KMO = 0.59 and p < 0.001, respectively). The percentage of variance explained by each factor was quite similar across rotation methods, ranging from 5.15 to 5.21 to the Factor 1 and from 4.43 to 4.52 to the Factor 2. Considering factor loadings ≥ |0.20|, the composition of the first dietary pattern (Factor 1) extracted by varimax rotation was slightly different from that extracted by both oblique rotations, Promax and Oblimin. The Factor 1 extracted by varimax rotation is composed of the traditional foods consumed by the Brazilian population namely rice, beans, sugar, white breads, butter and margarine, beef (positive loadings) and low-fat milk (negative loading). The Factor 1 patterns extracted by promax and oblimin rotation were identical to each other and included the aforementioned foods plus whole breads and white cheese, both with negative loadings. The second dietary pattern (Factor 2) was similar across factor rotations and was composed of salad dressing, leafy vegetables, non-leafy vegetables, spices, whole breads, white cheese, fruits and fruit juices. Among the food groups evaluated, salad dressing, rice, beans, leafy and non-leafy-vegetables were those with the highest percentage of variance explained by the factors, i.e., with the highest communalities.

Increasing the factor loading cut-off from ≥ |0.20| to ≥ |0.25|, the differences in Factor 1 across rotation methods were no longer observed. This factor was comprised of only four food items which characterize Brazilian staple foods, i.e., rice, beans, sugar and white breads. The Factor 2 extracted by varimax and promax rotations had a similar composition including foods consumed in a typical vegetable-based diet: salad dressing, leafy vegetables, non-leafy vegetables and spices. With respect to oblimin rotation, the Factor 2 comprised all the aforementioned vegetable foods plus whole breads.

Construct validity of dietary patterns

Table 3 presents the CFA results according to the factor loading cut-off ≥ |0.20| and different rotation methods. Regardless of rotation, the factor loadings were statistically significant for all dietary patterns (p-value < 0.05) and similar to the factor loadings obtained in EFA. Since promax and oblimin are oblique rotations and produced identical dietary patterns at cut-off ≥ |0.20|, the results of the CFA for these rotations were also identical. It should be pointed out that promax and oblimin produced dietary patterns with small but significant correlations (r = 0.17, p-value < 0.01) (data not shown). Irrespective of the factor rotation applied, none of the dietary patterns derived showed an acceptable model fit based on the fit indexes evaluated other than SRMR (whose values were < 0.08).

The factor loadings of all food items showed statistical significance at cut-off ≥ |0.25| for both orthogonal and oblique rotations (Table 4). The promax rotation, however, showed a better model fit than either varimax or oblimin. Although no differences were observed in the composition of the dietary patterns derived by varimax and promax rotations, the CFI, TLI, RMSEA and SRMR indicated a better fit for promax than for varimax. The oblimin rotation produced the worst result, with the CFI and TLI values being < 0.90. The interfactor correlation was small but significant with both promax (r = 0.19, p-value < 0.01) and oblimin rotations (r = 0.18, p-value < 0.01) (data not shown).

Discussion

This study was the first to provide evidence about the effects of different rotation methods in EFA

Table 2

Factor-loading matrix for dietary patterns derived according to different rotation methods. *Health Survey of the City of São Paulo*, Brazil, 2008-2011.

Food groups	Varimax rotation		Promax rotation		Oblimin rotation		Communality
	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2	
Rice	***0.72***	0.06	***0.72***	0.13	***0.71***	0.06	0.52
Beans	***0.67***	-0.03	***0.67***	0.03	***0.67***	-0.03	0.45
Sugar	***0.28***	-0.02	***0.28***	0.01	***0.29***	-0.02	0.08
Breads/Toasts/Crackers	**0.25**	-0.01	**0.25**	0.02	***0.25***	-0.01	0.06
Butter and margarine	**0.24**	0.06	**0.23**	0.09	**0.23**	0.06	0.06
Beef	**0.20**	0.10	0.19	0.12	0.18	0.10	0.05
Low-fat and skim milk	**-0.21**	0.15	**-0.22**	0.13	**-0.23**	0.15	0.07
Salad dressing	0.19	***0.73***	0.16	***0.75***	0.08	***0.74***	0.57
Leafy vegetables	0.10	***0.62***	0.07	***0.63***	0.00	***0.63***	0.39
Non-leafy vegetables *	0.00	***0.58***	-0.03	***0.58***	-0.09	***0.59***	0.34
Spices	0.05	***0.32***	0.03	***0.32***	0.00	***0.32***	0.10
Whole breads	-0.19	**0.24**	**-0.20**	**0.22**	**-0.23**	***0.25***	0.10
White cheese	-0.18	**0.24**	**-0.20**	**0.22**	**-0.22**	**0.24**	0.09
Fruits	-0.14	**0.23**	-0.16	**0.22**	-0.18	**0.23**	0.07
Fruit juices	-0.01	**0.22**	-0.02	**0.22**	-0.05	**0.23**	0.05
Eggs	0.17	0.11	0.16	0.13	0.15	0.11	0.04
Whole milk	0.15	0.00	0.15	0.02	0.15	0.00	0.02
Processed meat	0.14	0.09	0.14	0.10	0.13	0.09	0.03
Coffee and tea	0.14	-0.01	0.14	0.00	0.14	-0.01	0.02
Poultry	0.10	0.14	0.09	0.14	0.08	0.14	0.03
Soda pop	0.08	-0.02	0.08	-0.01	0.09	-0.02	0.01
Pork	0.05	0.00	0.05	0.01	0.05	0.00	0.00
Alcoholic beverages	0.02	0.05	0.02	0.05	0.01	0.05	0.00
Salty snacks	0.02	0.07	0.01	0.07	0.01	0.07	0.01
Chocolate powder	0.01	0.05	0.01	0.05	0.00	0.05	0.00
Cold cuts	0.01	0.07	0.01	0.07	0.00	0.07	0.01
Other dairy products	-0.01	0.15	-0.02	0.14	-0.04	0.15	0.02
Canned vegetables	-0.01	0.14	-0.02	0.14	-0.04	0.15	0.02
Yellow cheese	-0.03	0.09	-0.04	0.09	-0.05	0.09	0.01
Cakes/Confectionery products	-0.07	0.09	-0.07	0.09	-0.08	0.09	0.01
Pulses	-0.07	0.08	-0.07	0.07	-0.08	0.08	0.01
Sandwiches/Salty baked goods	-0.09	-0.04	-0.09	-0.05	-0.09	-0.04	0.01
Fatty Sauces/Creams/Mayonnaise	-0.11	0.06	-0.11	0.05	-0.12	0.06	0.02
Pasta	-0.12	0.01	-0.12	0.00	-0.12	0.01	0.01
Eigenvalues	1.76	1.51	1.75	1.51	1.77	1.54	-
Variance explained (%)	5.17	4.46	5.15	4.43	5.21	4.52	-

* Excluding roots and tubers.

Note: values in bold: factor loadings ≥ |0.20|; values in bold and italic: factor loadings ≥ |0.25|. KMO = 0.59; Bartlett's sphericity test ($p < 0.001$).

on composition, interpretability and construct validity of empirically derived dietary patterns and contributed to outline important issues as regards to this analysis. The only other study concerning factor rotation methods in nutritional epidemiology was published by Bountziouka & Panagiotakos [5] who evaluated these effects on short-term repeatability of four dietary patterns derived through principal component analysis (PCA). The authors observed that, irrespective of rotation type used, i.e., orthogonal (varimax; quartimax) or oblique (promax; direct oblimin), the short-term repeatability of the dietary patterns extracted was low.

The most noticeable findings of this study were the effects of rotation method on the com-

Table 3

Confirmatory factor analysis of dietary patterns derived according to factor loadings ≥ |0.20| * and rotation criteria. *Health Survey of the City of São Paulo,* Brazil, 2008-2011.

Varimax rotation		Promax rotation		Oblimin rotation	
Food groups	**Factor loading (SE)**	**Food groups**	**Factor loading (SE)**	**Food groups**	**Factor loading (SE)**
Factor 1		Factor 1		Factor 1	
Rice	0.79 (0.04) **	Rice	0.73 (0.04) **	Rice	0.73 (0.04) *
Beans	0.66 (0.04) **	Beans	0.68 (0.04) **	Beans	0.68 (0.04) *
Beef	0.23 (0.04) **	Sugar	0.26 (0.04) **	Sugar	0.26 (0.04) *
Sugar	0.23 (0.04) **	Breads/Toasts/Crackers	0.23 (0.05) **	Breads/Toasts/Crackers	0.23 (0.05) *
Butter and margarine	0.21 (0.05) **	Butter and margarine	0.22 (0.05) **	Butter and margarine	0.22 (0.05) *
Breads/Toasts/Crackers	0.19 (0.05) **	White cheese	-0.22 (0.04) **	White cheese	-0.22 (0.04) *
Low-fat and skim milk	-0.15 (0.04) **	Whole breads	-0.21 (0.04) **	Whole breads	-0.21 (0.04) *
		Low-fat and skim milk	-0.17 (0.03) **	Low-fat and skim milk	-0.17 (0.03) *
Factor 2		Factor 2		Factor 2	
Salad dressing	0.76 (0.03) **	Salad dressing	0.78 (0.03) **	Salad dressing	0.78 (0.03) *
Leafy vegetables	0.64 (0.03) **	Leafy vegetables	0.63 (0.03) **	Leafy vegetables	0.63 (0.03) *
Non-leafy vegetables	0.57 (0.03) **	Non-leafy vegetables	0.56 (0.03) **	Non-leafy vegetables	0.56 (0.03) *
Spices	0.33 (0.04) **	Spices	0.32 (0.04) **	Spices	0.32 (0.04) *
White cheese	0.20 (0.04) **	White cheese	0.23 (0.04) **	White cheese	0.23 (0.04) *
Fruit juices	0.20 (0.04) **	Whole Breads	0.22 (0.04) **	Whole breads	0.22 (0.04) *
Whole breads	0.19 (0.04) **	Fruit juices	0.20 (0.04) **	Fruit juices	0.20 (0.04) *
Fruits	0.19 (0.04) **	Fruits	0.18 (0.04) **	Fruits	0.18 (0.04) *
Goodness-of-fit indexes		Goodness-of-fit indexes		Goodness-of-fit indexes	
χ^2 (90 d.f.) *	634.14	χ^2 (74 d.f.) *	538.39	χ^2 (74 d.f.) **	538.39
χ^2/d.f.	7.05	χ^2/d.f.	7.28	χ^2/d.f.	7.28
RMSEA (90%CI)	0.07 (0.06; 0.08)	RMSEA (90%CI)	0.08 (0.07; 0.08)	RMSEA (90%CI)	0.08 (0.07; 0.08)
CFI	0.66	CFI	0.70	CFI	0.70
TLI	0.60	TLI	0.63	TLI	0.63
SRMR	0.07	SRMR	0.07	SRMR	0.07

CFI: comparative fit index; χ^2/d.f.: adjusted Chi-squared test; RMSEA, residual mean standard error of approximation; SE: square error; SRMR: standardized root mean square residual; TLI: Tucker-Lewis index.

* Factor loadings ≥ |0.20| from exploratory factor analysis;

** p-value < 0.01.

position and interpretability of dietary patterns that may be influenced by the factor loading cut-off selected during EFA. Considering the factor loading cut-off ≥ |0.20|, differences in composition and in interpretability of the first dietary pattern (Factor 1) but not of the second pattern (Factor 2) were observed between orthogonal and oblique rotations, i.e., between varimax and promax/oblimin rotations. These differences may be explained by the cross-loadings ≥ |0.20| of two food groups - white cheeses and whole breads – that occurred with oblique rotations. However, increasing the factor loading cut-off from ≥ |0.20| to ≥ |0.25| eliminated the cross-loadings and also the differences in the composition of the Factor 1 across rotation methods. Despite the differences produced on dietary patterns composition, the rotation methods produced similar results concerning the percentage of variance explained for Factors 1 and 2.

Differences in composition and interpretability of the dietary patterns across rotation methods may be less remarkable at higher factor loading cut-offs because this can contribute to reduce the occurrence of cross-loadings in the factor structure. It should be emphasized that

Table 4

Confirmatory factor analysis of dietary patterns derived according to factor loadings ≥ |0.25| * and rotation criteria. *Health Survey of the City of São Paulo*, Brazil, 2008-2011.

Varimax rotation		Promax rotation		Oblimin rotation	
Food groups	**Factor loading (SE)**	**Food Groups**	**Factor loading (SE)**	**Food groups**	**Factor loading (SE)**
Factor 1		Factor 1		Factor 1	
Rice	0.75 (0.05) **	Rice	0.79 (0.06) **	Rice	0.79 (0.06) *
Beans	0.71 (0.06) **	Beans	0.67 (0.06) **	Beans	0.67 (0.06) *
Sugar	0.22 (0.04) **	Sugar	0.21 (0.04) **	Sugar	0.21 (0.04) *
Breads/Toasts/Crackers	0.16 (0.04) **	Breads/Toasts/Crackers	0.16 (0.04) **	Breads/Toasts/Crackers	0.16 (0.04) *
Factor 2		Factor 2		Factor 2	
Salad dressing	0.82 (0.03) **	Salad dressing	0.84 (0.03) **	Salad dressing	0.82 (0.03) *
Leafy vegetables	0.61 (0.03) **	Leafy vegetables	0.61 (0.03) **	Leafy vegetables	0.61 (0.03) *
Non-leafy vegetables	0.54 (0.03) **	Non-leafy vegetables	0.53 (0.03) **	Non-leafy vegetables	0.54 (0.03) *
Spices	0.32 (0.04) **	Spices	0.32 (0.04) **	Spices	0.32 (0.04) *
				Whole breads	0.15 (0.04) *
Goodness-of-fit indexes		Goodness-of-fit indexes		Goodness-of-fit indexes	
χ^2 (20 d.f.) *	88.27	χ^2 (19 d.f.) **	69.68	χ^2 (26 d.f.) **	147.63
χ^2/d.f.	4.41	χ^2/d.f.	3.67	χ^2/d.f.	5.68
RMSEA (90%CI)	0.06 (0.04, 0.07)	RMSEA (90%CI)	0.05 (0.04, 0.06)	RMSEA (90%CI)	0.07 (0.06, 0.08)
CFI	0.92	CFI	0.94	CFI	0.87
TLI	0.89	TLI	0.91	TLI	0.82
SRMR	0.05	SRMR	0.04	SRMR	0.05

CFI: comparative fit index; χ^2/d.f.: adjusted Chi-squared test; RMSEA, residual mean square error of approximation; SE: standard error; SRMR: standardized root mean square residual; TLI: Tucker-Lewis index.

* Factor loadings ≥ |0.25| from exploratory factor analysis;

** p-value < 0.01.

although all rotations selected for this study aimed to reduce the cross-loadings toward zero [8,41,42,43], only the orthogonal varimax attained this purpose in both factor loading cut-offs. Therefore, researchers must also consider whether cross-loadings are interesting or not when selecting the rotation method and the factor loading cut-off for EFA in dietary pattern studies.

Another noticeble finding concerns the construct validity of the dietary patterns derived with different rotation methods and factor loading cut-offs. Regardless of rotation, the factors derived with the factor loading cut-off ≥ |0.20| did not show acceptable construct validity. Even if it was adequate to produce meaningful dietary patterns, this cut-off was quite low to select food items that could be valid to depict the dietary patterns of the population evaluated.

In fact, only the factors derived by promax rotation with a factor loading cut-off ≥ |0.25| in EFA showed an acceptable construct validity as indicated by all goodness-of-fit indexes except the adjusted Chi-squared test. Differently from the other indexes evaluated in this study, the adjusted Chi-squared test is directly influenced by the sample size and the number of variables observed. Hence, the larger the sample size and the number of variables, higher is the Chi-squared value. Also, the higher the number of free parameters of the model, lower is the number of degrees of freedom of the test [32]. Considering the limitations of the adjusted Chi-squared test, experts recommend evaluating model fit by different goodness-of-fit indexes including those analyzed in this study, because they reflect different aspects of the model adjustment [54].

It should also be mentioned that the orthogonal varimax rotation extracted factors with the same variables as the promax rotation, but without construct validity. It means that the assumption of independence of the factor structure was inappropriate for these data. Actually, the correlation between factors derived by oblique promax rotation was significant different to zero (r = 0.19). In this way, researchers must also be cognizant that the choice of an orthogonal rotation solely based on their independent assumption of the factors may fail to extract valid factors. Hence, it is important to verify whether this assumption is appropriate before deriving and interpreting the dietary patterns. If so, both orthogonal and oblique rotations will probably lead to similar factors at high factor loading cut-offs (e.g., ≥ |0.25|).

Moreover, it must be considered that the correlation between dietary patterns may produce factor scores that are also correlated, and thus, caution is needed when planning to use these scores as dependent variables in regression models. Since the independency assumption of the observations is required for traditional regression models, a methodological alternative is to apply the exploratory structural equation modeling (ESEM). This method has emerged as a suitable multivariate statistical modeling technique to examine associations between latent (e.g., dietary patterns) and observed variables, allowing for multiple dependent and independent variables in a single equation [30]. The ESEM relies on the covariance structure of the observed variables and can be interpreted as a combination of EFA, CFA and regression analysis, and is indicated when the researcher has a weak hypothesis about how multiple-observed variables load on the factors [30]. Another advantage of the ESEM to dietary pattern analysis includes the possibility of testing the significance of factor loadings in lieu of applying predetermined factor loading cut-offs, and this reduces the subjectivity during modeling. More details about this method can be found in Asparouhov & Muthén [55].

This study has some methodological features that should be addressed. First, the dietary patterns derived were based on data collected by a short-term dietary assessment method, i.e., by two non-consecutive 24HR. It is known that, although the short-term dietary assessment methods provide detailed data about types and amounts of foods consumed [56], they lead to a large within-person variation of dietary estimates. This variation could attenuate the correlation matrix of the foods and thus the factor loadings observed in each dietary pattern. To overcome this, the food groups were adjusted for the within-person variation through the MSM before proceeding to factor analysis as performed by Selem et al. [49]. It is worth mentioning that this adjustment may be considered a methodological advance in dietary pattern analysis and may have contributed to enhance the reliability of the results.

Second, the estimation method used in EFA to derive dietary patterns in this study differed from the frequently used method in other dietary pattern studies. The robust maximum likelihood parameter estimation (MLR) was chosen in EFA in lieu of the principal component factor method (PCF) because it was also available for use in CFA as an appropriate estimator to non-normally distributed data [31]. The use of MLR in both EFA and CFA aimed to avoid a misinterpretation of the results that might occur if different estimation procedures were applied for deriving dietary patterns and for assessing their construct validity.

Finally, this study could not evaluate the effects of rotation methods on composition, interpretability and construct validity of dietary patterns derived at the most applied factor loading cut-off, i.e., ≥ |0.30|, because it would lead to a very restrictive number of food items for factor's interpretability and CFA purposes. Nonetheless, the authors ensured methodological strictness by selecting two other cut-offs (≥ |0.20| and ≥ |0.25|) that are also commonly applied in dietary pattern studies [34,35,36,37,38,39,40,44,45,46,47,48,49].

In summary, the effects of rotation methods on composition, interpretability and construct validity of dietary patterns differed according to the factor loading cut-off used in EFA. Less remarkable differences in composition and interpretability of the dietary patterns according to rotation method may occur at higher cut-offs such as ≥ |0.25| compared with lower ones (≥ |0.20|). Irrespective of rotation method, dietary patterns derived at factor loading cut-off ≥ |0.20| did not show acceptable construct validity. At factor loading cut-offs ≥ |0.25|, however, the promax rotation showed a better model fit than either varimax or oblimin. Hence, the authors recommend performing at least one orthogonal and one oblique rotation in EFA, applying the factor loading cut-off and then comparing the factor solutions. Moreover, the CFA should be conducted to test the construct validity of the dietary patterns derived and to verify whether the factor loading cut-off chosen during the EFA is adequate or not to select the food items that truly depict dietary patterns of the population. Further studies are needed to investigate the effects of other rotation methods on the dietary patterns derived in different populations.

Resumen

*El estudio tuvo como objetivo investigar los efectos de los métodos de rotación en la interpretabilidad y validez de un constructo de patrones alimentarios, derivados de una muestra representativa de 1.102 adultos brasileños. Los patrones se derivaron de un análisis factorial exploratorio. Se aplicaron las rotaciones ortogonal (*varimax*) y oblicua (*promax, oblimin *directa). La validez de constructo de los patrones fue evaluada por un análisis factorial confirmatorio, según los puntos de corte de cargas factoriales: (≥ |0,20| y ≥ |0.25|). Se analizaron los índices de ajuste del modelo. Se observaron diferencias en la composición e interpretación del primer factor entre* varimax *y* promax/oblimin *en el punto de corte ≥ |0,20|. En el punto de corte ≥ |0,25|, ya no se observaron diferencias. Ninguno de los patrones derivados en el punto de corte ≥ |0,20| presentaron un ajuste del modelo aceptable. En el punto de corte ≥ |0,25|, la rotación* promax *produjo el mejor ajuste. Los efectos de las rotaciones factoriales en los patrones fueron variables, según el punto de corte de carga factorial utilizado en análisis factorial exploratorio.*

Consumo de Alimentos; Hábitos Alimenticios; Nutrición en Salud Pública; Análisis Factorial

Contributors

M. A. Castro proposed the analytical methodology for the study, carried out the statistical analysis and wrote the manuscript. V. T. Baltar provided expertise in statistical analysis and contributed in the manuscript write-up. S. S. C. Selem contributed towards the data anlaysis of food consumption and the manuscript write-up. D. M. L. Marchioni supervised the statistical analysis, provided expertise in the data analysis of food consumption and carried out a critical revision of the manuscript. R. M. Fisberg coordinated the data collection, collaborated with the write-up of the manuscript and was responsible for a critical revision of the text.

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