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Examining associations between dietary patterns and metabolic CVD risk factors: a novel use of structural equation modelling

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Abstract

The association between dietary patterns and metabolic cardiovascular risk factors has long been addressed but there is a lack of evidence towards the effects of the overall diet on the complex net of biological inter-relationships between risk factors. This study aimed to derive dietary patterns and examine their associations with metabolic cardiovascular risk factors following a theoretic model for the relationship between them. Participants included 417 adults of both sexes, enrolled to the cross-sectional population-based study performed in Brazil. Body weight, waist circumference, high-sensitivity C-reactive protein, blood pressure, total cholesterol:HDL-cholesterol ratio, TAG:HDL-cholesterol ratio, fasting plasma glucose and serum leptin were evaluated. Food consumption was assessed by two non-consecutive 24-h dietary recalls adjusted for the within-person variation of intake. A total of three dietary patterns were derived by exploratory structural equation modelling: 'Traditional', 'Prudent' and 'Modern'. The 'Traditional' pattern had a negative and direct effect on obesity indicators (serum LEP, body weight and waist circumference) and negative indirect effects on total cholesterol:HDL-cholesterol ratio, TAG:HDL-cholesterol ratio and fasting plasma glucose. The 'Prudent' pattern had a negative and direct effect on systolic blood pressure. No association was observed for the 'Modern' pattern and metabolic risk factors. In conclusion, the 'Traditional' and 'Prudent' dietary patterns were negatively associated with metabolic cardiovascular risk factors among Brazilian adults. Their apparent protective effects against obesity and high blood pressure may be important non-pharmacological strategies for the prevention and control of obesity-related metabolic disorders and CVD.

Key words: **Dietary patterns: Structural equation modelling: CVD: Risk factors: Cross-sectional analyses**

Dietary pattern analysis has been of growing interest in nutritional epidemiology as a multidimensional approach that allows the investigation of the overall effects of diet on human health, by taking into account the complex interactions among foods and nutrients consumed[1–3]. Two major approaches have long been applied to investigate dietary patterns. In the hypothesis-driven approach, scientific evidence or dietary recommendations are used to construct dietary indices or scores that evaluate the quality of the diet or the adherence to a particular pre-defined diet, as the Diet Quality Index, the Healthy Eating Index and the Mediterranean diet score[4]. In the data-driven approach, statistical methods such as exploratory factor analysis (EFA), principal component analysis and cluster analysis are used to empirically derive dietary patterns based on dietary data collected[4].

Over the past few decades, a number of evidences have been emerged towards the association between empirically derived dietary patterns and CVD risk[5,6] and cardiovascular mortality[7]. The 'Prudent pattern', characterised by fruits, vegetables, legumes, fish and whole grains has been associated with lower risk of CHD[5] and lower cardiovascular mortality among women[7], whereas the 'Western pattern', characterised by red and processed meats, refined grains, sugar, sweets and dairy products, has been associated with a greater risk of CHD and cardiovascular mortality[5,7].

The association of empirically derived dietary patterns with metabolic CVD risk factors has also been investigated[8–14], but no studies have proposed and tested a conceptual model, that is, a theoretic model that represents the hypothesised relationships between the variables under investigation, such as the biological inter-relationships of the CVD risk factors, and the effects of dietary patterns on these factors.

To investigate this association under a conceptual model, the structural equation model (SEM) is a suitable statistical method, allowing investigators to test the validity of the model based on a set of measured variables in an attempt to explain their observed variances and covariances[15]. Moreover, SEM allows for multiple

Abbreviations: 24-HDR, 24-h dietary recall; BP, blood pressure; BW, body weight; CFI, comparative fit index; DBP, diastolic blood pressure; ESEM, exploratory structural equation modelling; FPG, fasting plasma glucose; LEP, leptin; LRT, log-likelihood ratio test; pTEE, predicted energy intake; RMSEA, residual mean square error of approximation; SBP, systolic blood pressure; SEM, structural equation model; SRMR, standardised root mean square residual; TLI, Tucker–Lewis index; WC, waist circumference.

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linear equations, including direct and indirect effects, and latent variables, features not allowed by traditional regression methods.

Therefore, the aim of the present study was to derive dietary patterns and examine their associations with metabolic CVD risk factors under a conceptual model tested by SEM.

Methods

Study population

Data were obtained from the Health Survey of the City of São Paulo, a cross-sectional population-based survey, designed to collect health and nutrition information as well as life conditions on a probabilistic sample of residents of the city of São Paulo, Brazil, between September 2008 and August 2011.

A two-stage cluster sampling of census tracts and households was performed. In the first stage, seventy census tracts were randomly selected from the totality of urban census tracts in the city of São Paulo as the primary sampling units. In the second stage, households were randomly selected within census tracts, in order to allow data collection from about 600 adults (20–59 years) and 600 elderly (60 years and over) of both sexes.

A total of 1102 individuals aged 20 years and above were evaluated in the first stage of data collection, which occurred between 2008 and 2009. In this stage, a structured questionnaire enquiring about socio-economic (*per capita* family income; educational level), demographic (skin colour, age) and lifestyle characteristics (smoking status; alcohol use; physical activity), as well as food consumption (the first 24-h dietary recall (24-HDR)), was administered by qualified interviewers in individuals' homes. In the second stage of the study, which occurred between 2010 and 2011, a total of six telephone contacts and one home visit per individual were performed in order to find and invite the same individuals to participate. A total of 642 individuals agreed to participate, and 548 of them underwent a second dietary assessment, blood sample analysis and blood pressure (BP) assessment, as well as anthropometric measurements. In order to evaluate long-term changes in diet, that is, changes occurring between the first and the second dietary data collection, individuals were enquired by telephone about modifications in amounts and types of foods consumed after concluding the second dietary data collection. For the present study, only individuals with no missing data for each variable evaluated and with no changes in their diet were included (n 462).

This study was conducted according to the guidelines established in the Declaration of Helsinki. All procedures involving human subjects in this study were approved by the Research Ethics Committees at the School of Public Health, University of São Paulo (study protocol number 2001; authorisation 275/09). All participants provided their written informed consent before data collection in each stage of the study.

Dietary data collection

The first 24-HDR data were collected by face-to-face interviews according to procedures described in the United States Department of Agriculture (USDA) five-step multiple-pass method[16]. This method guides the individual through a 24-h reference period of food intake (more commonly, the day before interview) and provides different opportunities for he/she to remember and describe all foods and beverages consumed[16].

The second 24-HDR data were collected from the same individuals by telephone interviews 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 as it standardises the probes about foods and portions consumed[17]. All individuals were advised to report food consumption in household measures as well as to mention the eating occasions, meal time, cooking methods, seasonings used and brand names. Quality control of the 24-HDR was conducted during data collection in order to identify and correct reporting errors. Dietary data collection occurred on non-consecutive days throughout all seasons and days of the week.

After dietary data collection, all household measures reported in each 24-HDR were converted into grams and millilitres according to Brazilian publications, which were also consulted to obtain standard recipes of regional food preparations[18,19]. The NDS-R, version 2007, was used to determine the nutrient content of each food and beverage consumed. This programme was developed by the Nutrition Coordinating Center at the University of Minnesota, Minneapolis, MN, USA and has the USDA Food Composition Table as the primary database source.

Implausible energy intake

In order to avoid biased estimates for the relationship between dietary patterns and metabolic CVD risk factors, individuals who reported implausible energy intakes (i.e. under- and over-reporters) were removed from the analysis. The misreporting of energy intake was defined following procedures described in the study by McCrory *et al.*[20] and applied by Avelino *et al.*[21] in a sample of Brazilian adults. In brief, the agreement between the average reported energy intake (rEI) and the predicted total energy expenditure (pTEE) was evaluated for each individual. In this study, the pTEE was obtained by the equation proposed and validated by Vinken *et al.*[22]. This equation was developed based on data from free-living individuals aged 18–81 years who were evaluated by the double-labelled water (DLW) method.

To identify under- and over-reporters, a cut-off point of ±2 SD of the agreement between rEI and pTEE was applied based on principles proposed by Black[23]. This cut-off point takes into account the within-person CV of energy intake on the days of dietary assessment (in this case, 34·36 %), the CV of the technical measurement error of the DLW plus the biological variation in total energy expenditure (TEE) (8·2 %) and the CV of prediction error of the TEE by Vinken's equation (17·7 %)[20].

In the present study, the ±2 SD cut-off was equal to ±62 %. Therefore, individuals were considered under-reporters of energy intake if the agreement between rEI and pTEE was <38 % (n 26; 54·9 % BMI <30 kg/m^2; 68·6 % female), and individuals were considered over-reporters if the agreement between rEI and pTEE was >162 % (n 19; 66·7 % BMI <30 kg/m^2; 70·4 % female).

After removing under- and over-reporters (n 45), the final sample comprised 417 adults.

Foods grouping

In both 24-HDR, a total of 758 different foods were reported, of which 547 were consumed by at least 5 % of the sample, and then collapsed into thirty-four food groups as performed by Selem *et al.*[24] and by Castro *et al.*[25]. In the first step, the foods were combined according to the similarity of the nutrient profile[26–28] (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[29] (e.g. 'beans' group included brown and black beans because they are cooked legumes usually eaten with rice, whereas the 'legumes' group included soyabeans, lentils, chickpeas and snow peas because they are usually consumed in different preparations such as soups, creams and salads).

In the second step, food groups were analysed by the correlation matrix in order to verify how they were correlated to each other. Similar food groups with positive and significant correlations were aggregated into a single food group (e.g. leafy and non-leafy vegetables), and similar food groups with negative and significant correlations were maintained in different groups (e.g. whole milk and reduced-fat/skimmed milk). Finally, twenty-eight food groups were available for analysis (a detailed description of their composition is provided in Table 1).

Before dietary pattern analysis, the food group intakes (g) were adjusted for the within-person variation through the web-based statistical modelling technique Multiple Source Method (MSM). The MSM was developed within the European Food Consumption and Validation Project as a suitable technique for estimating the usual nutrient and food intakes (including those episodically consumed) based on two or more short-term dietary methods per individual such as 24-HDR[30].

Anthropometric measurements

Anthropometric measurements, BP and blood samples were obtained in participant homes by a trained nursing assistant following standardised protocols developed for the study. Body weight (BW, kg), height (cm) and waist circumference (WC) (cm) were measured for each individual according to the procedures recommended by the World Health Organisation[31,32]. BW, height and WC were measured in duplicate using a calibrated digital scale (Tanita®, HD-313; Tanita, accuracy: 100 g), a portable wall-mounted stadiometer (Seca®, model 208; Seca, accuracy: 1 mm) and a flexible anthropometric tape, respectively. The measurement of BW and height was performed with the individual standing firmly on a levelled surface, wearing light clothes and no shoes. WC was measured midway between the lowest rib and the iliac crest at the end of expiration[32]. The BW reading was recorded to the nearest 0·1 kg, whereas height and WC were recorded to the nearest 0·1 cm. The arithmetic means of BW, height and WC were calculated.

Blood pressure

BP was measured according to the 5th Brazilian Guidelines for Hypertension[33] using a validated oscillometer (Omron®, model HEM-712C; Omron Healthcare Inc.). Participants rested for 5 min while sitting before measurements, with the arm supported at heart level. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were initially measured in the right arm; 1 min after the first measurement, SBP and DBP were measured in the left arm. Two additional BP measurements were obtained in the arm with the largest values of SBP and DBP, with a 1 min interval between them. The arithmetic means of the last two measurements of SBP and DBP were calculated and considered for analysis.

Blood samples

Blood samples were collected by venepuncture in two 10-ml vacutainers after 12 h of overnight fasting. Blood samples were maintained in a polystyrene box with ice packs and transported within 2 h to the laboratory for immediate centrifugation at 3000 rpm for 15 min at room temperature. After centrifugation, serum samples were stored at −80°C until analysis. Serum total cholesterol (TC) and fractions (VLDL, LDL, HDL) as well as serum TAG were determined by enzymatic-colourimetric method. TC:HDL ratio and TAG:HDL ratio were also calculated. Serum high-sensitivity C-reactive protein (hs-CRP) was determined by an automated immunoturbidimetric assay system (IMMAGE Immunochemistry System; Beckman Coulter) with a minimum detectable dose of 0·06 mg/l. Serum leptin (LEP) concentrations were determined using a human RIA kit (HL-81K; Millipore) with a minimum detectable dose of 0·437 ng/ml. Fasting plasma glucose (FPG) was measured by enzymatic-colorimetric glucose oxidase procedure (GOD-Trinder; Labtest Diagsnóstica) with a minimum detectable dose of 20 mg/l.

Statistical analysis

Dietary patterns modelling. The exploratory structural equation modelling (ESEM) using the robust maximum likelihood (MLR) parameter estimation and the oblique Geomin rotation was applied to food group variables in order to empirically derive dietary patterns. ESEM is a multivariate statistical technique that can be interpreted as a combination of EFA and SEM. It relies on the covariance structure of the observed variables and is indicated when the researcher has a weak hypothesis about how multiple-observed variables load on the factors[34], a common situation in dietary pattern analyses. In addition, ESEM allows investigators to test the significance of factor loadings[15], which contributes to reduce the subjectivity during modelling and interpreting dietary patterns. More details about this method can be found in the study by Asparouhov & Muthén[15].

The MLR estimation method was chosen because it is an iterative estimation procedure that leads to more robust

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standard error estimates for continuous data following a non-normal multivariate distribution[34,35]. The oblique Geomin rotation was used to test the inter-factor correlations and to obtain a simple factor structure (i.e. a structure with variables loading high on as few factors as possible and with a minimal number of cross-loadings)[36].

Similar to confirmatory factor analysis, the ESEM requires the previous specification of the number of factors under investigation. For this, models with two, three and four factors were sequentially fitted and compared by the log-likelihood ratio test (LRT) and the χ^2 difference test, both adjusted by the Satorra–Bentler scaled correction. The number of factors in each model was based on the common number of previously reported dietary patterns derived through data-driven methods in national studies involving adults[13,14,24,26–29,37–43]. The Satorra–Bentler scaled correction was used in order to adjust the χ^2 and the log-likelihood estimates obtained by the MLR method[15,44]. The LRT and the χ^2 difference test provide a comparative evaluation of the goodness-of-fit of two models with different number of factors and/or free parameters, guiding researchers to choose the model with the smallest number of factors that fits well with the data[15]. Additional goodness-of-fit indices – namely, comparative fit index (CFI), Tucker–Lewis index (TLI), residual mean square error of approximation (RMSEA) and its 90 % CI and standardised root mean square residual (SRMR) – were also considered. They provide different information about model fit allowing for a more conservative and reliable evaluation of the model[34]. Acceptable model fit was defined according to the following criteria: CFI (>0·90)[45], TLI (>0·90)[46], RMSEA (≤0·06, 90 % CI <0·08)[47] and SRMR (≤0·08)[48].

The interpretability of the factors was also evaluated and considered during comparison of the models. Food groups with positive and significant factor loadings can be interpreted as contributing directly to the factor, whereas food groups with negative and significant factor loadings can be interpreted to be inversely correlated with the factor.

Modification index test was evaluated in order to identify significant correlations between measurement error terms (i.e. residuals) of food group variables that would improve model fit. Only plausible correlations were allowed (e.g. correlation between error terms of breads and of butter and margarine), considering that reporting errors for two or more foods may be correlated. All the analyses were executed in Mplus software (version 6.12; Muthén & Muthén). A P value <0·05 was considered to be significant in two-sided tests.

Conceptual model for the association between dietary patterns and metabolic CVD risk factors. The conceptual model for the association between dietary patterns and metabolic CVD risk factors was tested using the SEM analysis. Dietary patterns were expected to be directly associated with each metabolic CVD risk factor, namely, FPG, SBP, DBP, TAG:HDL, TC:HDL and hs-CRP, as well as with serum LEP, BW and WC.

Considering that serum LEP and WC represent obesity indicators that are positively correlated to BW, a latent variable named ‘obesity’ was constructed. A latent variable is a non-observed random variable, such as a factor, which comprises two or more correlated measured variables. The obesity latent variable allowed the estimation of the combined effects of serum LEP, BW and WC on each CVD risk factor.

The indirect effects of dietary patterns on metabolic CVD risk factors mediated by the obesity latent variable were estimated, under the hypothesis that dietary patterns can affect metabolic CVD risk factors also by leading to changes in total BW as well as in amounts and distribution of body fat.

Residual correlations between the outcome variables SBP and DBP and between TAG:HDL and TC:HDL were estimated based on a previous model for metabolic CVD risk factors[49]. In addition, residual correlations of FPG with TAG:HDL, TC:HDL and hs-CRP were expected, owing to evidences towards the association of glucose metabolic disturbances with atherogenic dyslipidaemia and inflammation[50].

The variables sex, age and race/ethnicity were controlled in all regression models. In addition, the variable energy was added to the obesity regression model. Antihypertensive, hypocholesterolaemic and antidiabetic medications were also controlled in regression models of BP, atherogenic dyslipidaemia and FPG, respectively.

The conceptual model was tested in Mplus software version 6.12 using the MLR estimation method and the oblique Geomin rotation. Delta method was used to estimate the standard errors for indirect effects. Standardised estimates of regression coefficients, correlation coefficients and indirect effects were reported. The acceptable goodness-of-fit of the model was also evaluated by the indices CFI (>0·90)[45], TLI (>0·90)[46], RMSEA (≤0·06, 90 % CI <0·08)[47] and SRMR (≤0·08)[48].

Results

Participant characteristics

Participants comprised 164 men (39 %) and 253 women (61 %), with an average age of 54 (SD 19) years. About 61 % of the participants were of white race. According to the National Cholesterol Education Program/Adult Treatment Panel III criterion[51], 55 % of the participants had abdominal obesity, 38 % high LDL-cholesterol, 37 % low HDL-cholesterol, 32 % hypertriacylglycerolaemia, 13 % elevated FPG and 44 % elevated BP. The overall prevalence of the metabolic syndrome was 26 % (data not shown). The usual energy intake of participants averaged 7255 (SD 1912) kJ (1734 (SD 457) kcal) with men exhibiting a higher average intake than women 8104 *v.* 6708 kJ (1937 *v.* 1602 kcal, respectively, P < 0·0001) (data not shown).

Dietary patterns modelling

The LRT and the χ^2 difference test adjusted by the Satorra–Bentler scaled correction were significant for comparison of models with two and three factors, suggesting a better fitting for the latter (LRT = 133·34 (df 26), P < 0·001; χ^2 = 123·01 (df 26), P < 0·001). Moreover, the goodness-of-fit indices of the model with two factors indicated an unacceptable fit (RMSEA: 0·037; 90 % CI 0·031, 0·044; CFI: 0·85; TLI: 0·80, SRMR: 0·05). In contrast, the model with three factors attained the criteria for an

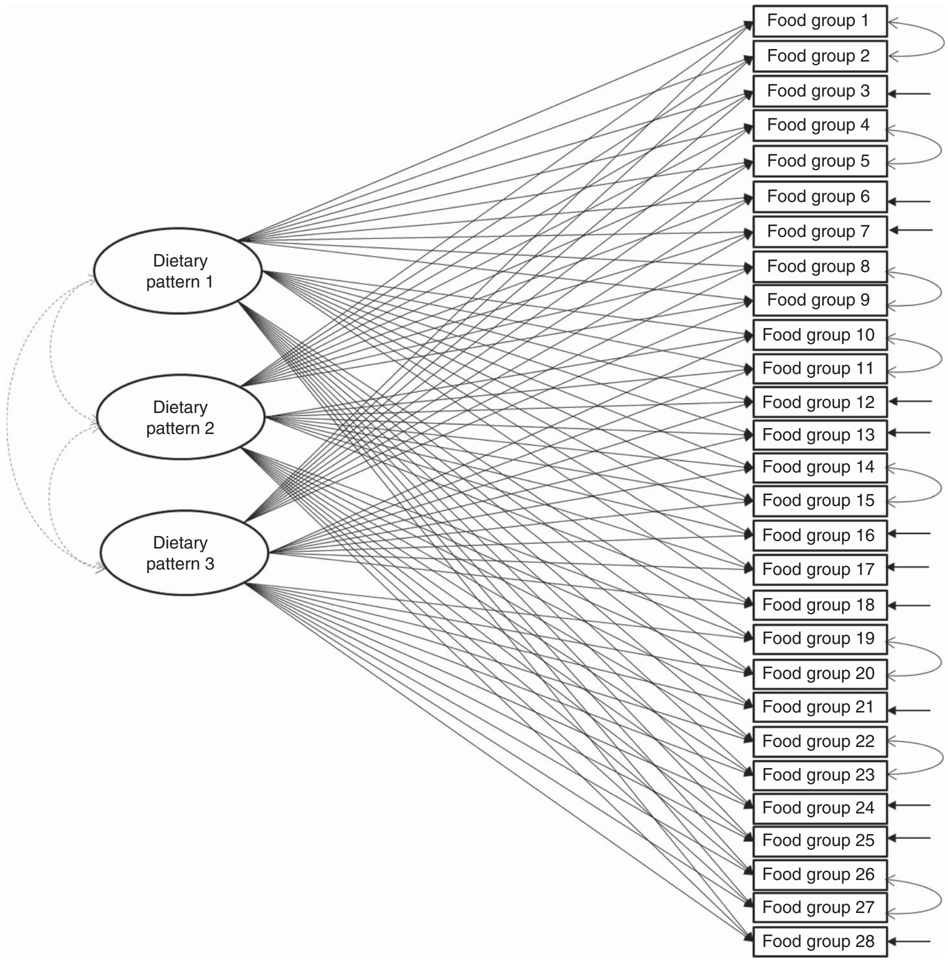

Fig. 1. Diagram of exploratory structural equation modelling with three factors (dietary patterns) and their indicator variables (food groups), Health Survey of São Paulo, Brazil, 2008–2011.

acceptable fit (RMSEA: 0·022; 90 % CI 0·010, 0·030; CFI: 0·95; TLI: 0·93, SRMR: 0·04).

Comparing models with three and four factors, a better fitting was observed for the model with four factors based on the LRT and the χ^2 difference test (LRT = 53·14 (df 25), $P < 0·001$; $\chi^2 = 59·17$ (df 25), $P < 0·001$). The goodness-of-fit indices confirmed a better fit for the model with four factors in comparison with the model with three factors (RMSEA: 0·011; 90 % CI 0·000, 0·023; CFI: 0·99; TLI: 0·98, SRMR: 0·03). However, only two food groups (red meats and alcoholic beverages) showed significant loadings on the fourth factor, which made the interpretation difficult. Therefore, the model with three factors, more parsimonious and interpretable, was selected for the subsequent analysis.

The ESEM diagram with three factors is displayed in Fig. 1. The ellipses represent the dietary patterns (i.e. the factors) and the rectangles denote the food groups (i.e. the measured variables). The two-sided arrows indicate the allowed correlation between dietary patterns (arrows between ellipses) and between the residual variances of the food group variables (arrows between rectangles). The one-sided arrows from the ellipses represent the factor loadings, whereas the one-sided arrows directed to food groups represent the residual variances of each variable.

Dietary patterns composition and associations with metabolic CVD risk factors

The factor-loading matrix of dietary patterns derived by ESEM analysis is presented in Table 1. The first dietary pattern labelled 'Traditional' had high positive loadings on rice and beans and low-to-moderate positive loadings on red meats, eggs, whole milk, butter and margarine, and sugar. Negative loadings were observed for legumes, low-fat and skimmed milk, cheese, whole breads, sweets, pasta, cold cuts, mayonnaise, sandwiches and alcoholic beverages. The second dietary pattern labelled 'Prudent' included vegetables, fruits, juices, fish and poultry, low-fat and skimmed milk, whole breads, olive oil and seasonings, all with positive loadings. Negative loadings were observed for sandwiches and alcoholic beverages. The third dietary pattern labelled 'Modern' included soda pop, red meats and alcoholic beverages with the highest positive loadings, followed by sandwiches, cold cuts, seasonings, mayonnaise and salty snacks. Negative loadings were

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Table 1. Factor-loading matrix for dietary patterns derived through exploratory structural equation modelling according to dietary data from two non-consecutive 24-h dietary recall, São Paulo, Brazil, 2008–2011
(Factor loadings with their standard errors)*

	Traditional			Prudent			Modern		
Food groups	Factor loading	SE	*P*	Factor loading	SE	*P*	Factor loading	SE	*P*
Rice (white rice)	0·74	0·04	<0·001	0·03	0·04	0·495	0·09	0·08	0·264
Beans (brown beans, black beans)	0·84	0·04	<0·001	−0·03	0·06	0·602	−0·02	0·04	0·585
Vegetables (leafy and non-leafy vegetables)	0·01	0·04	0·796	0·62	0·06	<0·001	0·01	0·06	0·838
Legumes (soyabeans, lentils, chickpeas)	−0·11	0·04	0·002	0·09	0·07	0·147	−0·08	0·05	0·115
Fruits (fresh fruits)	−0·05	0·06	0·407	0·31	0·10	0·003	−0·25	0·06	<0·001
Juices (natural fruit juices, industrialised fruit juices)	−0·11	0·06	0·088	0·15	0·07	0·040	0·13	0·07	0·061
Red meats (beef, pork, sausages)	0·20	0·07	0·004	0·04	0·09	0·670	0·34	0·09	<0·001
Fish and poultry	0·07	0·06	0·222	0·14	0·07	0·038	0·03	0·07	0·703
Eggs (chicken eggs, quail eggs)	0·17	0·06	0·006	0·05	0·08	0·507	0·09	0·06	0·133
Whole milk (3 % fat)	0·12	0·06	0·047	−0·11	0·09	0·228	−0·19	0·07	0·009
Low-fat and skimmed milk	−0·17	0·05	0·002	0·18	0·08	0·021	−0·09	0·06	0·172
Butter and margarine (salted and unsalted)	0·14	0·06	0·021	−0·02	0·07	0·733	0·05	0·07	0·475
Cheese (yellow cheese, white cheese)	−0·17	0·06	0·004	0·11	0·07	0·093	0·03	0·06	0·612
Coffee and tea (coffee, instant coffee, herbal teas)	0·12	0·07	0·068	0·08	0·11	0·459	−0·31	0·06	<0·001
Breads, toasts and crackers (French bread, Italian bread, buns)	0·08	0·06	0·196	−0·11	0·08	0·130	0·03	0·08	0·706
Whole breads, toasts and crackers (whole grains)	−0·13	0·05	0·004	0·18	0·07	0·009	0·01	0·05	0·856
Cookies (filled cookies; not filled cookies)	0·12	0·08	0·158	−0·27	0·06	<0·001	−0·09	0·08	0·242
Sweets (cakes, sweet pies, puddings, ice creams, candies)	−0·13	0·06	0·030	0·02	0·07	0·823	0·09	0·07	0·213
Sugar (white sugar)	0·19	0·06	0·001	−0·05	0·09	0·607	−0·21	0·06	0·001
Pasta (cooked noodles, gnocchi, lasagna, cannelloni)	−0·14	0·06	0·009	0·01	0·07	0·891	0·02	0·06	0·697
Olive oil (extra virgin olive oil, virgin olive oil)	0·09	0·05	0·108	0·55	0·07	<0·001	0·00	0·03	0·924
Seasonings (salt, garlic, scallions, parsley, oregano)	0·02	0·03	0·631	0·43	0·08	<0·001	0·17	0·07	0·021
Cold cuts (ham, mortadella, salami)	−0·12	0·05	0·011	−0·01	0·06	0·806	0·19	0·06	0·002
Mayonnaise	−0·12	0·04	0·002	0·07	0·06	0·255	0·11	0·05	0·020
Sandwiches and salty baked goods (hot dogs, hamburger sandwich, esfihas)	−0·17	0·06	0·004	−0·15	0·10	0·142	0·27	0·07	<0·001
Salty snacks (French fries, maize chips, potato chips)	0·00	0·07	0·976	−0·03	0·07	0·665	0·14	0·06	0·018
Soda pop (cola, fruit-flavoured soda)	0·01	0·01	0·954	−0·24	0·14	0·090	0·56	0·07	<0·001
Alcoholic beverages (beer, wine, cognac, spirits)	−0·16	0·06	0·010	0·06	0·12	0·590	0·33	0·10	<0·001

RMSEA, residual mean square error of approximation; CFI, comparative fit index; TLI, Tucker–Lewis index; SRMR, standardised root mean square residual.
*Inter-factor correlations: factor 1 (Traditional pattern) × factor 2 (Prudent pattern): *r* 0·04; *P* = 0·588. Factor 1 (Traditional pattern) × factor 3 (Modern pattern): *r* −0·14; *P* = 0·193. Factor 2 (Prudent pattern) × factor 3 (Modern pattern): *r* 0·30; *P* = 0·157. Goodness-of-fit indices: RMSEA: 0·031; 90 % CI 0·026, 0·035; CFI: 0·92; TLI: 0·90; SRMR: 0·043.

observed for fruits, whole milk, coffee and tea, and sugar. No correlations were found among the three dietary patterns derived.

Fig. 2 shows the SEM diagram with standardised estimates for the relationship between dietary patterns and metabolic CVD risk factors. The one-sided arrows from dietary patterns to the obesity latent variable and to metabolic CVD risk factors represent the standardised regression coefficients that can be interpreted as the change in standard deviation units in the outcome variable associated with a standard deviation change in the predictor variable[52]. The one-sided arrows from the obesity latent variable to metabolic CVD risk factors represent the regression coefficients, whereas the arrows from obesity to serum LEP, BW and WC indicate the standardised factor loadings of the measured variables. The two-sided arrows represent the correlation coefficients between dietary patterns. The residual correlation coefficients between outcome variables were omitted for simplicity.

The 'Traditional' dietary pattern had negative direct effects on the obesity latent variable, whereas the 'Prudent' pattern had negative direct effects on SBP. No association was observed between the 'Modern' pattern and obesity and neither between the pattern and metabolic CVD risk factors (Table 2). Moreover, the 'Traditional' pattern had small negative indirect effects on TAG:HDL, TC:HDL and FPG, through mediation effects of obesity (Table 3).

The obesity latent variable showed positive effects on all the CVD risk factors evaluated. Positive residual correlations were found between BP variables, TAG:HDL and TC:HDL, FPG and TAG:HDL as well as between FPG and TC:HDL (Table 2).

The model adjustments revealed positive associations of age with the 'Prudent' pattern ($\beta = 0{\cdot}29$ (SE 0·09); $P = 0{\cdot}001$), SBP ($\beta = 0{\cdot}55$ (SE 0·07); $P < 0{\cdot}001$) and DBP ($\beta = 0{\cdot}28$ (SE 0·08); $P = 0{\cdot}001$), and a negative association with the 'Modern' dietary pattern ($\beta = -0{\cdot}56$ (SE 0·14); $P < 0{\cdot}001$). Female sex was negatively associated with the 'Modern' dietary pattern ($\beta = -0{\cdot}34$ (SE 0·07); $P < 0{\cdot}001$), obesity ($\beta = -0{\cdot}22$ (SE 0·08); $P = 0{\cdot}004$), TAG:HDL-cholesterol ($\beta = -0{\cdot}18$ (SE 0·07); $P = 0{\cdot}008$) and TC:HDL ($\beta = -0{\cdot}19$ (SE 0·08); $P = 0{\cdot}012$), and was positively associated with the 'Traditional' pattern ($\beta = 0{\cdot}38$ (SE 0·05); $P < 0{\cdot}001$). Antihypertensive, hypocholesterolaemic and antidiabetic medications were positively associated with BP variables (SBP: $\beta = 0{\cdot}19$ (SE 0·05); $P < 0{\cdot}001$; DBP: $\beta = 0{\cdot}13$ (SE 0·05); $P = 0{\cdot}011$), TC:HDL ($\beta = 0{\cdot}11$ (SE 0·04); $P = 0{\cdot}007$) and FPG ($\beta = 0{\cdot}41$ (SE 0·07); $P < 0{\cdot}001$), respectively. No associations of race/ethnicity were observed. Energy intake was positively

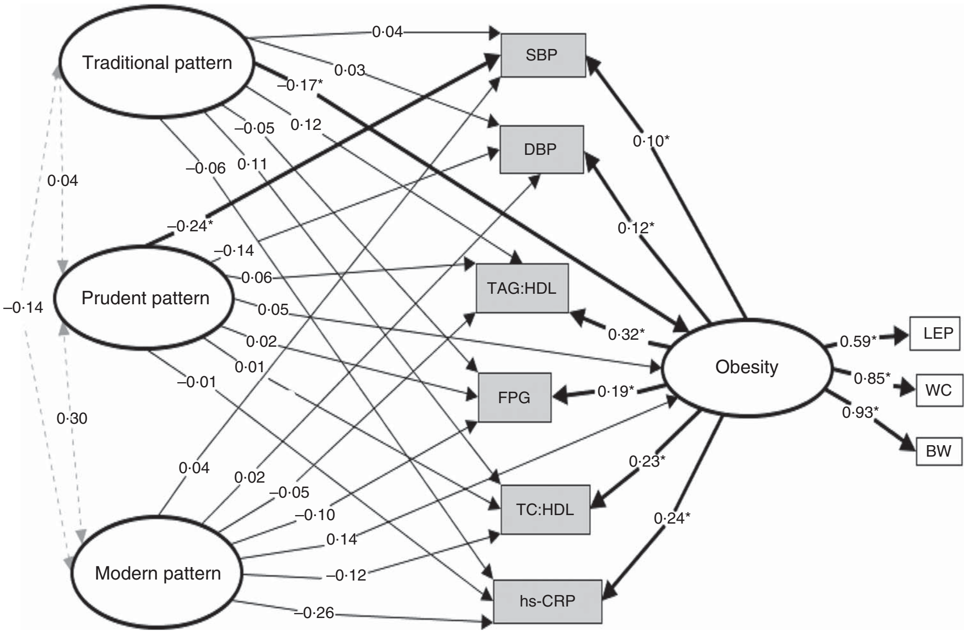

Fig. 2. Structural equation model diagram with standardised estimates for the relationship between dietary patterns and metabolic CVD risk factors, Health Survey of São Paulo, Brazil, 2008–2011. * Standardised coefficients significant at the critical value of 0·05. SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; hs-CRP, high-sensitivity C-reactive protein; LEP, leptin; WC, waist circumference; BW, body weight.

associated with the 'Modern' dietary pattern ($\beta = 0{\cdot}34$ (SE 0·13); $P = 0{\cdot}009$) but not with the obesity latent variable (data not shown).

Discussion

This is an original study that proposed the application of the ESEM to empirically derive dietary patterns and used the SEM to examine their associations with metabolic CVD risk factors following a conceptual model for adults. In addition, to our knowledge, this is the first study to report an inverse association between the 'Traditional' dietary pattern and a combination of obesity markers, namely, BW, WC and serum LEP.

In the present study, the 'Traditional' pattern, characterised by high loadings on typical Brazilian staple foods such as rice and beans and by low-to-moderate loadings on red meats, eggs, whole milk, butter and margarine, and sugar, showed a direct negative effect on the obesity latent variable. This finding suggests a protective role of the 'Traditional' pattern against weight gain, increased fat mass and abdominal fat accumulation, which is in agreement with a previous report of 13–14 % lower risk of overweight and obesity in Brazilian subjects following a 'Traditional' diet[37].

Among the food groups pertaining to the Brazilian 'Traditional' pattern, beans may be the major responsible food group for the protective effects observed. Beans are a subgroup of legumes with low glycaemic index that are important sources of phytochemicals and nutrients, such as insoluble and soluble dietary fibre, K and vegetable proteins[53]. In Brazil, this food group is the most consumed vegetable protein-rich food and the main dietary source of fibre among adults[54], with its average usual consumption in the population evaluated to be about 87 g (equivalent to one serving) (data not shown).

Evidences towards the association between beans consumption and lower BW and WC were previously described. In a cross-sectional study with more than 8000 adult participants in the National Health and Nutrition Examination Survey (1999–2002), Papanikolaou & Fulgoni[55] reported lower BW, smaller WC and reduced risk of overall and abdominal obesity among beans consumers compared with non-consumers. The authors argued that the favourable weight associations observed among beans consumers may be related to the fibre content of this food, owing to the effects of fibres on increased satiety, and consequently on reduced energy intake[56].

Moreover, an independent negative association of legumes and total fibre intake with circulating LEP was reported in two population-based studies with Japanese adults[57,58]. Although the biological mechanisms underlying this association require further investigation, it can be interpreted that the 'Traditional' pattern may contribute to prevention of excessive BW and abdominal obesity by reducing LEP, a key adipocyte-derived hormone that plays an important role in regulating appetite and BW[49].

In contrast with previous studies that have not detected associations of 'Traditional' dietary pattern with metabolic CVD risk factors[13] or detected positive effects of this pattern on one or more CVD risk factors[27,38,59], the present study identified small negative effects of the 'Traditional' dietary pattern on TAG:HDL, TC:HDL and FPG, through mediation of obesity markers. These results indicate the suitability of the Brazilian 'Traditional' dietary pattern as an adjuvant for BW control and prevention of atherogenic dyslipidaemia and hyperglycaemia.

The second dietary pattern labelled 'Prudent' was quite similar to the Dietary Approach to Stop Hypertension (DASH)

Table 2. Parameter estimates and model fitness of the SEM analysis of dietary patterns and metabolic CVD risk factors, São Paulo, Brazil, 2008–2011

	Standardised estimates	SE	*P*
Direct effects of dietary patterns			
Traditional pattern → obesity	−0·17	0·07	0·014
Traditional pattern → SBP	0·04	0·05	0·463
Traditional pattern → DBP	0·03	0·06	0·580
Traditional pattern → hs-CRP	−0·06	0·05	0·198
Traditional pattern → FPG	−0·05	0·04	0·175
Traditional pattern → TAG:HDL	0·12	0·07	0·083
Traditional pattern → TC:HDL	0·11	0·08	0·204
Prudent pattern → obesity	0·05	0·09	0·607
Prudent pattern → SBP	−0·24	0·06	<0·001
Prudent pattern → DBP	−0·14	0·07	0·055
Prudent pattern → hs-CRP	−0·01	0·07	0·884
Prudent pattern → FPG	0·02	0·07	0·771
Prudent pattern → TAG:HDL	0·06	0·08	0·397
Prudent pattern → TC:HDL	0·01	0·07	0·983
Modern pattern → obesity	0·14	0·13	0·301
Modern pattern → SBP	0·04	0·08	0·625
Modern pattern → DBP	0·02	0·10	0·825
Modern pattern → hs-CRP	−0·26	0·16	0·107
Modern pattern → FPG	−0·10	0·09	0·248
Modern pattern → TAG:HDL	−0·05	0·11	0·696
Modern pattern → TC:HDL	−0·12	0·13	0·376
Direct effects of obesity			
Obesity → SBP	0·10	0·04	0·013
Obesity → DBP	0·12	0·04	0·006
Obesity → hs-CRP	0·24	0·04	<0·001
Obesity → FPG	0·19	0·05	<0·001
Obesity → TAG:HDL	0·32	0·05	<0·001
Obesity → TC:HDL	0·23	0·04	<0·001
Factor loadings of obesity			
Obesity → LEP	0·59	0·03	<0·001
Obesity → BW	0·93	0·02	<0·001
Obesity → WC	0·85	0·03	<0·001
Correlation coefficients			
Traditional and Prudent	0·04	0·07	0·588
Traditional and Modern	−0·14	0·10	0·193
Prudent and Modern	0·30	0·21	0·157
Residual correlation coefficients			
SBP and DBP	0·66	0·06	<0·001
FPG and hs-CRP	0·16	0·09	0·075
TAG:HDL-cholesterol and TC:HDL	0·65	0·05	<0·001
FPG and TAG:HDL	0·19	0·05	<0·001
FPG and TC:HDL	0·11	0·05	0·034
Model fitness			
AIC	40 823·96		
Adjusted BIC	41 032·03		
χ^2 (df)	954·09 (683)		<0·001
χ^2/df	1·39		
RMSEA	0·031		
90 % CI	0·026, 0·035		
CFI	0·921		
TLI	0·902		
SRMR	0·043		

SBP, systolic blood pressure; DBP, diastolic blood pressure; hs-CRP, high-sensitivity C-reactive protein; FPG, fasting plasma glucose; LEP, leptin; BW, body weight; WC, waist circumference; TC, total cholesterol; AIC, Akaike criterion; BIC, sample size-adjusted Bayesian criterion; χ^2/df, adjusted χ^2 test; RMSEA, residual mean square error of approximation; CFI, comparative fit index; TLI, Tucker–Lewis index; SRMR, standardised root mean square residual.

diet[60] and resembled other dietary patterns labelled ‘Healthy’[9,13,42], ‘Healthy conscious’[12,61], ‘Health aware’[11] and, more recently, ‘Fruits, vegetables, nuts and legumes’[62], by including fruits, vegetables, juices, fish and poultry, low-fat and skimmed milk, whole breads, olive oil, and seasonings. The ‘Prudent’ dietary pattern was negatively associated with SBP, but not with DBP, suggesting its effectiveness in lowering BP of individuals with isolated systolic hypertension (ISH), an important risk factor for coronary events[63]. ISH is more frequent among middle-aged and elderly people owing to the rise in SBP accompanied by the fall in DBP with age[64], and was the most frequent subtype of uncontrolled hypertension among US middle-aged adults[65]. Other beneficial effects ascribed to the ‘Prudent’ dietary pattern include reduction in risk of stroke (−32 %)[66], CHD (up to −30 %)[5,8,66] and cardiovascular mortality (−28 %)[7]. The synergistic effect of

Table 3. Total and indirect effects of dietary patterns on metabolic CVD risk factors, Health Survey of São Paulo, Brazil, 2008–2011 (Standardised coefficients with their standard errors)

	Total effects*			Indirect effects†		
Standardised effects	Standardised coefficient	SE	*P*	Standardised coefficient	SE	*P*
Dietary patterns → SBP						
Traditional pattern → SBP	0·02	0·05	0·668	−0·02	0·01	0·088
Prudent pattern → SBP	−0·24	0·06	<0·001	0·01	0·01	0·621
Modern pattern → SBP	0·05	0·08	0·512	0·01	0·01	0·319
Dietary patterns → DBP						
Traditional pattern → DBP	0·01	0·06	0·836	−0·02	0·01	0·075
Prudent pattern → DBP	−0·14	0·07	0·064	0·01	0·01	0·616
Modern pattern → DBP	0·04	0·10	0·692	0·02	0·02	0·322
Dietary patterns → TAG:HDL						
Traditional pattern → TAG:HDL	0·07	0·08	0·358	−0·05	0·02	0·019
Prudent pattern → TAG:HDL	0·08	0·08	0·303	0·01	0·03	0·607
Modern pattern → TAG:HDL	0·00	0·12	0·998	0·04	0·04	0·307
Dietary patterns → TC:HDL						
Traditional pattern → TC:HDL	0·07	0·09	0·433	−0·04	0·02	0·017
Prudent pattern → TC:HDL	0·01	0·07	0·897	0·01	0·02	0·607
Modern pattern → TCL:HDL	−0·09	0·13	0·515	0·03	0·03	0·329
Dietary patterns → FPG						
Traditional pattern → FPG	−0·08	0·04	0·043	−0·03	0·02	0·039
Prudent pattern → FPG	0·03	0·07	0·675	0·01	0·02	0·613
Modern pattern → FPG	−0·08	0·08	0·364	0·03	0·03	0·316
Dietary patterns → hs-CRP						
Traditional pattern → hs-CRP	−0·10	0·05	0·059	−0·04	0·02	0·050
Prudent pattern → hs-CRP	0·00	0·06	0·987	0·01	0·02	0·606
Modern pattern → hs-CRP	−0·23	0·16	0·142	0·03	0·03	0·331

SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; FPG, fasting plasma glucose; hs-CRP, high-sensitivity C-reactive protein.
* Total effects are the sum of direct and indirect effects of dietary patterns on metabolic CVD risk factors.
† Indirect effects of the dietary patterns on metabolic CVD risk factors mediated by obesity latent variable.

multiple nutrients and phytochemicals found in fruits and vegetables (e.g. K, carotenoids, vitamin C and flavonoids)[67], in whole grains (e.g. total fibre, resistant starch, oligosaccharides, B-vitamins, antioxidants)[68], in low-fat dairy products (e.g. Ca, vitamin D and conjugated linolenic acid)[69,70] and in olive oil (e.g. oleic acid and phenolic compounds)[71,72] may explain the cardioprotective role of the 'Prudent' pattern.

An unexpected finding was the lack of association between the 'Modern' dietary pattern and metabolic CVD risk factors. This pattern, composed primarily by soda pop, alcoholic beverages, red meats, cold cuts, mayonnaise, sandwiches, seasonings and salty snacks, resembles the 'Western' and the 'Processed Foods' dietary patterns identified in national[14,27,28,37] and international studies[5,6,8,66,73] as playing harmful effects on cardiovascular health. Elevated insulin concentration[8], increased abdominal obesity[14,27,28], elevated BP, LDL and TC[14], and hypertriacylglycerolaemia[12] are the most frequently metabolic disturbances related to the 'Western' dietary pattern. Moreover, a 28 % higher risk of mortality from CVD was identified in women at the upper quintile of adherence to the 'Western' pattern in comparison with those at the lowest quintile[7]. Considering that the 'Modern' dietary pattern was markedly related to lower age, it is possible that our study did not have enough statistical power to detect this association in a subgroup at lower risk of CVD disease.

The present study has some methodological features that must be outlined. Applying the ESEM analysis to empirically derive dietary patterns allowed testing the significance of the factor loadings in lieu of applying pre-determined cut-off points to the factor-loading matrix, as performed in EFA and principal component analysis. Taking the present data, a great number of significant food groups would not be considered if a factor loading cut-off ≥|0·25| or ≥|0·30| was applied, for example. Therefore, the ESEM analysis has the advantage to ensure methodological strictness to dietary pattern investigation by reducing the subjectivity during modelling.

In addition, the SEM allowed the estimation of indirect effects of the dietary patterns on metabolic CVD risk factors, which contributed to expand the body of evidences towards the association of the dietary patterns with metabolic CVD risk modulation. It should be mentioned, however, that, although the conceptual model of this study showed an acceptable fit, it does not rule out other models with equal goodness-of-fit that underline a different pathway for the relationship between dietary patterns and metabolic CVD risk factors.

Limitations of this study include the cross-sectional design that does not allow inferring the causal relationships between dietary patterns and metabolic CVD risk factors owing to the chance of reverse causality. Moreover, other variables not evaluated in this study may exert some effects on both dietary patterns and metabolic CVD risk factors (e.g. socio-economic status, educational level, physical activity, smoking habits, genetic variations). Therefore, further studies in longitudinal settings that control for other variables should be performed to confirm the present findings.

Furthermore, the dietary patterns derived were based on data collected by two non-consecutive 24-HDR, which are prone to measurement error, memory bias and to a large within-person variation of the dietary estimates[74]. To overcome these aspects and to enhance data reliability, procedures were applied to structure data collection following the multiple-pass method, to control for the quality of the 24-HDR during data collection, to remove under- and over-reporters of energy intake and to adjust for the within-person variation of the food group intakes.

In conclusion, the 'Traditional' and 'Prudent' dietary patterns, derived by ESEM, were negatively associated with metabolic CVD risk factors among Brazilian adults. Their apparent protective effects against obesity and high BP may be important non-pharmacological strategies for the prevention and control of obesity-related metabolic disorders and CVD.

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All the authors participated sufficiently during manuscript preparation to take public responsibility for the article content. M. A. C. designed the study's analytic strategy, performed all statistical analyses and drafted the manuscript. V. T. B. provided statistical expertise and collaborated with manuscript preparation. R. M. F. coordinated data collection. D. M. M. and R. M. F. supervised statistical analysis and manuscript preparation and performed critical revision of the manuscript.

The authors declare that there are no conflicts of interest.

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