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Dietary patterns are associated with cardiometabolic risk factors in a representative study population of German adults

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Abstract

Studies that investigated complex actual eating behaviours of the general population and their relation to cardiometabolic risk markers are sparse. We aimed to identify dietary patterns within a nationally representative sample of 4025 German adults by factor analysis based on validated dietary history interviews. Furthermore, we evaluated associations of the derived dietary patterns with abnormalities clustered within the metabolic syndrome and related metabolic markers by logistic regression models and ANCOVA. A high adherence to the 'processed foods' pattern reflected a high intake of refined grains, processed meat, red meat, high-sugar beverages, eggs, potatoes, beer, sweets and cakes, snacks and butter, whereas a high adherence to the 'health-conscious' pattern represented a high intake of vegetables, vegetable oils, legumes, fruits, fish and whole grains. For subjects in the highest compared with those in the lowest quintile of the processed foods pattern, the occurrence of abdominal obesity was 88 (95 % CI 31, 169) % higher, hypertension was 34 (95 % CI −4, 86) % higher, hypertriacylglycerolaemia was 59 (95 % CI 11, 128) % higher and the metabolic syndrome was 64 (95 % CI 10, 143) % higher when adjusted for age, sex, energy intake, socio-economic status, sport activity and smoking. Furthermore, subjects in the highest quintile had statistically significantly higher uric acid concentrations and lower folate concentrations (P for trend $<0{\cdot}05$). In contrast, subjects in the highest quintile of the health-conscious pattern had a 30 (95 % CI 10, 46) % lower occurrence of hypertension, higher folate concentrations and lower homocysteine and fibrinogen concentrations (P for trend $<0{\cdot}05$). These data strengthen the findings from non-representative studies and emphasise the importance of healthy overall food patterns for preventing metabolic disturbances.

Key words: Dietary patterns: Germany: Dietary surveys: Metabolic syndrome

Dietary pattern analysis has been recognised as an approach that considers the complexity of overall diet and facilitates nutritional recommendations[1,2]. Accordingly, organisations aiming for the prevention and treatment of cardiovascular and other chronic diseases increasingly focus on healthy overall dietary patterns instead of solely on single dietary components in their nutritional guidelines[3,4].

Dietary patterns, which are exploratively derived by factor analysis, reflect eating habits that are characteristic for the underlying study population[1]. So far, most studies that have identified such patterns and investigated their association with cardiometabolic factors have been based on selected subpopulations, particularly on subjects with a specific sex[5–11], age range[5,9,10,12–14], professional background[5–7,10] or living area[8–10,15–18], rather than on nationally representative samples. Thus, generalisability of results to the population level was limited. Furthermore, most studies on food patterns and metabolic risk factors involved study populations from the USA[6,7,17–21] or Asian countries[5,8–10,13,22], leaving largely unclear whether similar findings can be observed in populations from other parts of the world, especially from European countries.

Therefore, the aims of the present study were, first, to identify major food patterns existing in a nationally representative sample of German adults and, second, to evaluate their association with metabolic risk factors of CVD.

Methods

Study population

The German Health Interview and Examination Survey 1998, including 7124 German adults representative of the non-institutionalised 18- to 79-year-old German population, was

Abbreviation: DISHES 98, Dietary Interview Software for Health Examination Studies.

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conducted from October 1997 until March 1999[23]. For the selection of participants, a two-stage sampling procedure was applied. First, a representative sample of communities with regard to community size and federal state was drawn. Random samples of adult residents stratified by age (5-year intervals) and sex were then drawn from local population registries in proportion to the age and sex structure of the German adult population. The response rate was 61·4 %. A weighting factor that adjusts for deviations in demographic characteristics from the official German population assured the population representativeness of participants.

For the present analysis, we included the randomly selected subsample of 4030 subjects, who had also participated in a comprehensive dietary assessment of the German Nutrition Survey[23]. To correct for non-response and disproportionality compared with population structure (due to efforts to include a large proportion of women in childbearing age), a specific weighting factor was derived for the German Nutrition Survey sample. After excluding subjects with an implausible low total energy intake (< 800 kcal/d (< 3347 kJ/d) for men and < 500 kcal/d (< 2092) kJ/d) for women), the overall analytical sample comprised 4025 subjects (1761 men and 2264 women). To account for the issue of reverse causation, we excluded subjects with a history of myocardial infarction, stroke, diabetes or cancer in the analysis of cardiometabolic factors and the metabolic syndrome. To additionally minimise the effects of medication or supplement use, we further excluded subjects with antihypertensive medication in the analysis of blood pressure, with antihyperlipidaemic medication in the analysis of lipids, with antidiabetic medication in the analysis of glucose and HbA_{1c} and with regular folate or vitamin B-complex supplement use in the analysis of folate and homocysteine. We also excluded pregnant women from the analysis of BMI, waist circumference and the metabolic syndrome.

The survey was approved by the Federal Office for the Protection of Data, Germany. Each participant gave informed written consent before enrolment into the survey.

Assessment of dietary intake and dietary patterns

The dietary assessment within the German Nutrition Survey has been described in detail previously[24]. Briefly, trained nutritionists interviewed participants using the Dietary Interview Software for Health Examination Studies (DISHES 98; Robert-Koch Institute, Berlin, Germany), a computerised face-to-face dietary history instrument designed to assess the usual dietary intake of the preceding 4 weeks. Based on the assessment of the participant's usual meal patterns, frequency and amount of the food and drink items consumed during each meal were obtained. In addition, questions on dietary regimen, changes in dietary habits during the last 4 weeks, use of dietary supplements and, for women, questions on pregnancy and lactation were included in the interview. The DISHES 98 tool codes the specified food items and dietary supplements during the interview. For further standardisation, the software connects item codes directly to the German Food Code and Nutrient Data Base[25] version II.3 and a supplement composition table to calculate nutrient intakes. Estimation of portion sizes was facilitated by standardised tableware models and food templates. The relative validity of DISHES 98 was assessed in comparison with 3 d weighted dietary records and a 24 h dietary recall and revealed correlations for nutrient intakes in a reasonable range (0·34–0·69 for 3 d weighted dietary records and 0·27–0·65 for the 24 h recall)[24].

To identify dietary patterns, the 2678 different food items assessed by DISHES 98 were first aggregated into food groups. For that purpose, we used the 133 food categories combined previously in the present study population[26], added fruit juice, beer, wine, liquor, coffee and tea as separate categories for drinks, and aggregated all defined categories according to similarities in nutrient profiles into thirty-four food groups (compare with Table 1). Second, we applied factor analysis (principal component analysis) with the orthogonal rotation procedure varimax to the predefined food groups[27]. Each obtained dietary pattern (called factor) represents a linear combination of all food groups, which are weighted by their factor loadings. The first pattern

Table 1. Factor loadings for food groups of the two major dietary patterns in a representative sample of German adults*

Food group	Factor 1 'Processed foods pattern'	Factor 2 'Health-conscious pattern'
Refined grains	0·72	–
Processed meat	0·66	–
Red meat	0·57	0·34
High-sugar beverages	0·50	−0·16
Eggs	0·41	0·23
Potatoes	0·38	0·32
Beer	0·38	–
Sweets and cakes	0·37	–
Snacks	0·37	–
Butter	0·37	0·16
Organ meats	0·19	–
Margarine	0·19	–
Coffee	0·16	–
High-fat diary	–	–
Liquor	–	–
Mayonnaise	–	–
Fruit juice	–	–
Low-fat dairy	–	–
Tea	−0·24	0·18
Cruciferous vegetables	–	0·65
Fruity and root vegetables	−0·19	0·58
Other vegetables†	–	0·55
Leafy vegetables	–	0·55
Vegetable oils	0·16	0·52
Legumes	–	0·39
Fruits	−0·32	0·39
Fish	–	0·34
Whole grains	−0·30	0·31
Other animal fats‡	0·26	0·31
Poultry	–	0·26
Nuts and seeds	–	0·17
Olives and olive oil	0·16	0·17
Wine	–	0·16
Low-sugar beverages	–	–

* Factor loadings are identical to Pearson's correlation coefficients. Factor loadings with absolute values < 0·15 are not shown for simplicity (*n* 4025).
† Vegetables other than cruciferous, fruity and root or leafy vegetables.
‡ Animal fats other than butter.

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explains as much inter-individual variation of the food groups as possible, the next pattern explains as much of the remaining variation as possible and so on. Each subject receives a score for each dietary pattern, with a higher score indicating a higher adherence to the respective pattern. We determined the dietary patterns to retain based on the scree test, i.e. the graphical presentation of eigenvalues, with eigenvalues greater than 1 explaining a greater amount of variance than contributed by any food group[27]. The scree test allowed us to clearly identify two major patterns with the largest eigenvalues (3·15 and 2·65, followed by eigenvalues ≤1·80 for the subsequent patterns). Based on the food groups that were loading highest on each pattern, these patterns were labelled as the 'processed foods' and 'health-conscious' patterns.

Assessment of sociodemographic and lifestyle factors

Information on age, socio-economic characteristics, smoking and sport activity was obtained by a standardised, self-administered questionnaire, which was checked for plausibility and completeness of information by trained interviewers in the presence of the participants. Socio-economic status was defined by an index combining information on education, household income and professional group[28] and assigned to a low, middle or high category. Smoking status was defined as never smoking, former smoking, occasional smoking or daily smoking. Sport activity was assessed using five categories ranging from 'no sport' to 'regularly more than 4 h/week' and was classified into no sport, less than 2 h sport/week and 2 h or more sport/week. Furthermore, a standardised, computer-assisted personal interview was conducted by specifically trained physicians to obtain information on medical history, including physician-diagnosed chronic diseases and medications used within the past 12 months.

Ascertainment of cardiometabolic factors

Physical examinations, including anthropometric measurements, blood pressure measurements and blood sampling, were performed by trained health professionals. BMI was calculated as the ratio of body weight to squared height. Mean systolic and diastolic blood pressure was calculated from the second and the third measurement using a mercury sphygmomanometer (Erkameter 3000; Erka, Bad Jölz, Germany). Venous blood samples were drawn after a fasting period of at least 3 h using the Gel-Monovettensystem supplied by Becton-Dickinson (Franklin Lakes, NJ, USA) and immediately processed and separated into aliquots. Serum was frozen and stored at −40°C until laboratory analysis.

Total serum cholesterol was assayed using the enzymatic cholesterol oxidase–peroxidase-4-aminophenazone method (Merck, Darmstad, Germany). Serum HDL-cholesterol was determined with an immunoseparation-based homogeneous assay (WAKO, Chuo-ku, Osaka, Japan). Serum TAG were measured with the glycerophosphate oxidase–peroxidase-4-aminophenazone method (Merck). LDL-cholesterol was calculated from the measurements of total cholesterol, HDL-cholesterol and TAG by means of the Friedewald equation[29]. Serum lipoprotein (a) was measured on a Cobas Mira analyser using turbidimetry with multiple-point calibration (Roche, Mannheim, Germany). Serum glucose was determined using the glucose oxidase–peroxidase-4-aminophenazone method (Merck). HbA_{1c} was analysed in whole blood using HPLC on a Diamat HPLC analyser (Bio-Rad, Munich, Germany) with a test-kit of Recipe (Munich). Fibrinogen in EDTA plasma (stored 3 d below −20°C) was assayed using the immuno-nephelometric method on a BNA analyser (DADE-Behring, Schwalbach, Germany). Serum uric acid was measured by the uricase–peroxidase-4-aminophenazone method (Merck). Serum homocysteine was analysed with a commercially available HPLC kit (Immundiagnostik, Bensheim, Germany) using a Shimadzu chromatography system (Chiyoda-ku, Tokyo, Japan) with fluorescence detection. Serum folate was estimated using a microparticle enzyme immunoassay on an AxSym analyser (Abbott, Chicago, IL, USA).

Definition of the metabolic syndrome

The metabolic syndrome was defined based on the National Cholesterol Education Program's Adult Treatment Panel III criteria[30], i.e. by the presence of at least three of the following five abnormalities: abdominal obesity (waist circumference >102 cm in men and >88 cm in women), hypertension (blood pressure ≥130/≥85 mmHg), low HDL-cholesterol (<400 mg/l in men and <500 mg/l in women), hypertriacylglycerolaemia (fasting TAG ≥1500 mg/l) and abnormal glucose homeostasis (fasting glucose ≥1100 mg/l). According to a recent study, on estimating the metabolic syndrome prevalence in this study population[31], we additionally used TAG values ≥2000 mg/l and HbA_{1c} values >6·1 % for non-fasting individuals (fasting time <8 h) as well as medication for diabetes or hypertension to classify participants in terms of hypertriacylglycerolaemia, abnormal glucose homeostasis or hypertension, respectively.

Statistical analyses

Mean values with 95 % CI of cardiometabolic risk markers according to quintiles of dietary pattern scores were calculated using ANCOVA. Standardised regression coefficients for the association between cardiometabolic risk markers and the continuous dietary pattern scores were obtained from linear regression analysis. Prevalence OR (95 % CI) for each pattern quintile were estimated by logistic regression analysis, using the lowest quintile as the reference category. Means, regression coefficients and OR were adjusted for age (years), sex and total energy intake (continuous). In a second model, we further adjusted for socio-economic status (low, middle and high), sport activity (none, 0·1–1·9, ≥2·0 h/week) and smoking status (never, past, occasional and daily). Trend tests were conducted by including the median score of each pattern quintile as a continuous variable into the models. Furthermore, we conducted stratified analyses to investigate whether the observed associations between dietary patterns and metabolic abnormalities were modified by

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sex or changed dietary habits before the dietary assessment. Interaction tests were performed by including a product term with the respective stratification variable and the median score of the pattern quintile as a continuous variable into the model.

For all analyses, a specific weighting factor that corrects for deviations in demographic characteristics between the study population and the German population structure as of 31 December 1997 was used. For each subject, this weighting factor is proportional to the under- or over-representation of the subject's 5-year age interval, sex, community size and federal state. For example, if in a specific age, community size and state subgroup, men are under-represented by a factor of 2 compared with women, then men of this specific subgroup get a weighting factor twice as high compared with women of the same subgroup. However, the total weighted sample size is identical to the unweighted.

All statistical analyses were performed using the SAS statistical software package version 9.2 (SAS Institute, Cary, NC, USA). For all tests, $P<0{\cdot}05$ was considered significant.

Results

A high score for the processed foods pattern was characterised by a relatively high consumption of refined grains, processed meat, red meat, high-sugar beverages, eggs, potatoes, beer, sweets and cakes, snacks and butter (Table 1). In contrast, a high score for the health-conscious pattern represented a relatively high consumption of cruciferous vegetables, fruity vegetables, leafy vegetables, all other vegetables, vegetable oils, legumes, fruits, fish and whole grains. A high health-conscious pattern score also corresponded to a relatively high consumption of red meat and potatoes, but to a lesser degree than the processed foods pattern. When patterns were derived separately for men and women, they each showed a composition that was similar to that described for the overall population.

Participants with higher scores for the processed foods pattern were younger, more often men, with a lower percentage having high socio-economic status and more likely to smoke than those with lower scores for this pattern (Table 2). Furthermore, they were less likely to use vitamin or mineral supplements regularly and had a higher energy intake and a more unfavourable nutrient profile, particularly in terms of total and saturated fat, cholesterol, fibre, folate, vitamin C, vitamin E, β-carotene and calcium. Participants with higher scores for the health-conscious patterns were older, with a higher percentage having high socio-economic status, more active and less likely to smoke than those who scored low on this pattern. The relationships of the health-conscious pattern to vitamin and mineral supplements as well as to dietary intakes were generally in the opposite direction, but less pronounced, compared with the processed foods pattern.

In models adjusting for age, sex and energy intake, mean values of the cardiometabolic risk markers, including BMI, waist circumference, lipoprotein(a), TAG, the ratio of total: HDL-cholesterol, glucose, HbA_{1c} and uric acid, increased across rising quintiles of the processed foods pattern, whereas mean values of HDL-cholesterol (in women) and folate decreased (P for trend $<0{\cdot}05$; Table 3). For the health-conscious pattern, mean values of folate increased across rising quintiles, whereas mean values of the systolic blood pressure, HbA_{1c}, fibrinogen and homocysteine decreased. These results were supported by those from linear regression, when we analysed the association between the cardiometabolic risk markers and the continuous dietary pattern scores ($P<0{\cdot}05$; Table 4). After further accounting for socio-economic status, sport activity and smoking status, associations remained significant for anthropometric measures, TAG, glucose, uric acid and folate for the processed foods pattern and systolic blood pressure, HbA_{1c}, fibrinogen, homocysteine and folate for the health-conscious pattern.

When specifically focusing on the cardiometabolic abnormalities clustered within the metabolic syndrome, age-, sex- and energy intake-adjusted models revealed that associations between the patterns and each abnormality pointed into the expected direction (Table 5). While the direct associations with the processed foods pattern were all statistically significant, the inverse associations with the health-conscious pattern reached significance only for hypertension (P for trend $<0{\cdot}05$). Adjustment for socio-economic status and lifestyle factors attenuated the strength of associations, although their trend remained significant (P for trend $<0{\cdot}05$) for abdominal adiposity (OR 1·88, 95 % CI 1·31, 2·69 for the highest *v.* the lowest quintile), hypertension (OR 1·34, 95 % CI 0·96, 1·86), hypertriacylglycerolaemia (OR 1·59, 95 % CI 1·11, 2·28) and the metabolic syndrome overall (OR 1·64, 95 % CI 1·10, 2·43) with respect to the processed foods pattern as well as for hypertension (OR 0·70, 95 % CI 0·54, 0·90) in terms of the health-conscious pattern. Joint classification of the two patterns revealed the following, when participants in the lowest quintile of the processed foods pattern and the highest quintile of the health-conscious pattern (reference) were compared with those in the highest quintile of the processed foods pattern and the lowest quintile of the health-conscious pattern: OR 1·48 (95 % CI 0·79, 2·79) for abdominal obesity, OR 2·55 (95 % CI 1·49, 4·36) for hypertension, OR 0·92 (95 % CI 0·53, 1·59) for low HDL-cholesterol, OR 2·36 (95 % CI 1·33, 4·17) for hypertriacylglycerolaemia, OR 2·60 (95 % CI 1·03, 4·56) for abnormal glucose homeostasis and OR 2·26 (95 % CI 1·33, 4·16) for the metabolic syndrome (data not shown). Additional analyses for the metabolic syndrome showed no significant interaction between the patterns and sex or a changed diet in the 4 weeks before examination (P for interaction $>0{\cdot}05$).

Discussion

In the present representative study population of German adults, we identified two major dietary patterns, which we labelled as the processed foods pattern and health-conscious pattern. Greater adherence to the processed foods pattern – reflecting a high intake of refined grains, processed meat, red meat, high-sugar beverages, eggs, potatoes, beer, sweets and cakes, snacks and butter – was related to a higher prevalence of metabolic derangements, including abdominal

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Table 2. Sample characteristics by quintile of dietary patterns in a representative sample of German adults

(Mean values and standard deviations or percentages, *n* 4025)

	Quintiles of the processed foods pattern							Quintiles of the health-conscious pattern						
	1 (Lowest)		3		5 (Highest)			1 (Lowest)		3		5 (Highest)		
Characteristics	Mean	SD	Mean	SD	Mean	SD	*P* for trend	Mean	SD	Mean	SD	Mean	SD	*P* for trend
Age (years)	50·2	16·3	48·7	15·9	37·6	14·2		41·7	16·9	47·9	16·3	48·1	16·3	<0·0001
Sex (% male)	22·0		40·6		85·6		<0·0001	47·6		46·0		57·4		<0·0001
Socio-economic status (%)*														
Low	22·8		18·4		22·5			27·8		20·5		17·4		
Middle	50·8		55·7		60·7			56·1		55·2		55·7		
High	26·3		25·9		16·8		<0·0001	16·1		24·3		26·9		<0·0001
Current smoking (%)*	22·1		25·9		46·4		<0·0001	39·5		28·5		27·3		<0·0001
Sport activity ≥2 h/week (%)*	22·3		20·1		22·2		0·34	17·2		18·6		26·8		<0·0001
Vitamin or mineral supplements (%)†	26·1		23·3		15·6		<0·0001	17·9		23·3		24·0		0·02
Alcohol consumption (g/d)	6·1	10·2	9·3	11·6	19·0	22·0	<0·0001	9·1	14·0	10·0	13·4	13·3	18·5	<0·0001
Energy intake (MJ/d)	7·0	2·1	8·6	2·0	13·5	3·4	<0·0001	8·6	3·4	9·1	2·8	10·9	3·8	<0·0001
Dietary intake														
Total fat (% energy)	31·9	5·3	35·9	5·0	36·2	5·8	<0·0001	34·6	5·8	35·4	5·1	35·2	5·8	0·14
SFA (% energy)	13·6	2·9	15·7	2·8	15·5	3·1	<0·0001	15·2	3·2	15·4	2·8	14·6	3·1	<0·0001
Unsaturated fatty acids (% energy)	10·7	2·3	12·6	2·1	13·1	2·4	<0·0001	12·4	2·5	12·4	2·1	12·2	2·6	0·01
PUFA (% energy)	5·24	1·74	5·08	1·31	5·10	1·61	0·08	4·66	1·46	5·10	1·29	5·92	2·26	<0·0001
Cholesterol (mg/d)	225	85	326	93	518	177	<0·0001	290	130	346	132	410	195	<0·0001
Fibre (g/MJ)	3·96	0·94	2·89	0·62	2·17	0·53	<0·0001	2·43	0·74	2·93	0·76	3·46	1·11	<0·0001
Folate (μg/MJ)	42·5	22·4	35·2	59·2	24·2	8·3	<0·0001	30·3	58·2	32·2	15·5	37·7	23·5	<0·0001
Vitamin C (mg/MJ)	29·0	20·1	20·9	27·5	11·7	7·4	<0·0001	16·1	26·2	18·6	13·7	24·1	17·1	<0·0001
Vitamin E (mg/MJ)	3·05	6·68	2·87	9·84	1·26	1·85	<0·0001	2·09	7·29	2·17	6·71	2·70	6·19	0·02
β-Carotene (mg/MJ)	0·85	0·59	0·55	0·67	0·33	0·20	<0·0001	0·36	0·67	0·52	0·34	0·79	0·53	<0·0001
Vitamin D (μg/MJ)	0·39	0·33	0·39	0·35	0·28	0·17	<0·0001	0·28	0·28	0·38	0·30	0·42	0·37	<0·0001
K (g/MJ)	0·49	0·10	0·39	0·07	0·33	0·07	<0·0001	0·34	0·08	0·40	0·08	0·45	0·10	<0·0001
Mg (mg/MJ)	64·6	16·5	51·1	12·8	40·4	8·6	<0·0001	47·9	16·2	51·5	15·2	54·7	14·6	<0·0001
Ca (mg/MJ)	175	56	135	42	97	34	<0·0001	130	55	136	53	141	51	0·0004
Fe (mg/MJ)	2·02	1·02	1·66	0·43	1·44	0·27	<0·0001	1·50	0·46	1·71	0·99	1·85	0·48	<0·0001

* For sporting activity: missing values, *n* 20; for smoking: missing values, *n* 12; for socio-economic status: missing values, *n* 37.

† Supplement intake of vitamin B complex, vitamin C, vitamin E, folate, multivitamins or minerals ≥1 times/week.

Table 3. Cardiometabolic risk markers by quintile of dietary patterns in a representative sample of German adults*

(Mean values and 95 % confidence intervals)

	Quintiles of the processed foods pattern							Quintiles of the health-conscious pattern						
	1 (Lowest)		3		5 (Highest)			1 (Lowest)		3		5 (Highest)		
Characteristics	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI	*P* for trend	Mean	95 % CI	Mean	95 % CI	Mean	95 % CI	*P* for trend
BMI (kg/m^2)	25·7	25·4, 26·1	26·2	25·9, 26·5	26·9	26·5, 27·2	<0·0001	26·1	25·8, 26·4	26·2	25·9, 26·5	26·1	25·8, 26·4	0·26
Waist (cm)														
Men	92·9	91·1, 94·7	94·5	93·3, 95·8	96·0	95·2, 96·9	<0·0001	93·9	92·8, 95·0	95·2	94·1, 96·4	94·9	93·9, 95·9	0·05
Women	81·1	80·2, 82·1	82·9	81·9, 83·9	86·3	84·1, 88·5	<0·0001	82·6	81·5, 83·7	82·2	81·1, 83·3	81·9	80·7, 83·1	0·59
Systolic blood pressure (mmHg)	130	128, 131	130	129, 131	132	131, 134	0·06	133	131, 134	129	128, 131	129	128, 131	0·002
Diastolic blood pressure (mmHg)	81·7	80·7, 82·6	81·6	80·8, 82·4	82·0	81·0, 82·9	0·74	81·4	80·6, 82·2	81·8	81·0, 82·6	80·9	80·1, 81·8	0·27
Total cholesterol (mmol/l)	5·84	5·75, 5·93	5·95	5·87, 6·04	5·98	5·88, 6·08	0·22	5·91	5·83, 5·99	5·99	5·91, 6·07	5·95	5·87, 6·03	0·34
HDL-cholesterol (mmol/l)														
Men	1·31	1·24, 1·38	1·31	1·26, 1·36	1·29	1·26, 1·33	0·39	1·28	1·23, 1·32	1·29	1·25, 1·34	1·34	1·30, 1·38	0·16
Women	1·73	1·69, 1·77	1·68	1·64, 1·72	1·56	1·47, 1·65	0·01	1·66	1·62, 1·71	1·70	1·65, 1·74	1·72	1·67, 1·77	0·24
Total:HDL-cholesterol														
Men	4·64	4·33, 4·95	4·83	4·62, 5·05	5·00	4·85, 5·15	0·02	5·00	4·81, 5·20	4·90	4·71, 5·09	4·83	4·65, 5·00	0·74
Women	3·61	3·51, 3·72	3·73	3·62, 3·83	4·05	3·82, 4·28	0·002	3·76	3·65, 3·88	3·73	3·62, 3·84	3·67	3·54, 3·79	0·56
LDL-cholesterol (mmol/l)	3·64	3·56, 3·72	3·77	3·69, 3·84	3·73	3·64, 3·82	0·15	3·71	3·64, 3·78	3·81	3·73, 3·88	3·70	3·62, 3·77	0·15
Lipoprotein(a) (mg/l)†	283	253, 313	280	253, 308	342	311, 373	0·0007	303	277, 330	257	231, 284	294	267, 320	0·10
TAG (mmol/l)	1·49	1·40, 1·58	1·55	1·47, 1·64	1·81	1·72, 1·91	<0·0001	1·64	1·56, 1·73	1·58	1·50, 1·66	1·60	1·52, 1·69	0·17
Glucose (mmol/l)	5·18	5·11, 5·25	5·32	5·26, 5·39	5·32	5·25, 5·40	0·01	5·28	5·22, 5·35	5·30	5·23, 5·36	5·26	5·20, 5·33	0·12
HbA_{1c} (%)	5·35	5·30, 5·39	5·41	5·37, 5·45	5·43	5·39, 5·48	0·04	5·47	5·44, 5·51	5·39	5·35, 5·42	5·35	5·31, 5·39	<0·0001
Fibrinogen (g/l)†	2·87	2·82, 2·93	2·93	2·88, 2·98	2·93	2·87, 2·99	0·47	2·99	2·94, 3·04	2·92	2·87, 2·97	2·86	2·81, 2·91	0·003
Uric acid (μmol/l)	295	288, 303	298	291, 304	317	310, 325	0·0008	301	295, 308	303	296, 309	301	295, 308	0·65
Homocysteine (μmol/l)	9·8	9·5, 10·1	9·8	9·5, 10·1	10·5	10·1, 10·8	0·05	10·7	10·4, 11·0	10·0	9·7, 10·2	9·5	9·3, 9·8	<0·0001
Folate (μg/l)‡	8·41	8·05, 8·76	7·69	7·34, 8·04	6·66	6·05, 7·27	<0·0001	7·46	7·12, 7·81	8·14	7·76, 8·51	8·35	7·89, 8·80	0·003

* Adjusted for age (years), sex (where applicable) and total energy intake (continuous). Number of subjects (*n* 4025) for the specific characteristics can vary due to missing values and specific exclusion criteria (compare description of the study population).

† Conversion factor for lipoprotein (a): 1 mg/l = 0·00357 μmol/l and for fibrinogen: 1 g/l = 2·94 μmol/l.

‡ Folate was measured in women aged 18–40 years only.

Table 4. Standardised linear regression coefficients for the association between cardiometabolic risk markers and dietary patterns in a representative sample of German adults*

(*β*-Coefficients and *P* values)

	'Processed foods' pattern				'Health-conscious' pattern			
	Model 1†		Model 2‡		Model 1		Model 2	
Characteristics	*β*	*P*	*β*	*P*	*β*	*P*	*β*	*P*
BMI (kg/m^2)	0·10	<0·0001	0·075	0·0005	−0·0003	0·99	0·03	0·10
Waist circumference (cm)								
Men	0·11	<0·0001	0·087	0·002	0·023	0·33	0·053	0·03
Women	0·12	<0·0001	0·077	0·002	−0·018	0·39	0·009	0·67
Systolic blood pressure (mmHg)	0·041	0·04	0·034	0·12	−0·054	0·001	−0·042	0·01
Diastolic blood pressure (mmHg)	0·013	0·54	0·016	0·48	−0·006	0·73	−0·007	0·68
Total cholesterol	0·045	0·03	0·032	0·13	0·011	0·49	0·021	0·20
HDL-cholesterol								
Men	−0·042	0·17	0·006	0·85	0·066	0·02	0·037	0·18
Women	−0·093	0·0007	−0·046	0·10	0·051	0·03	0·014	0·56
Total:HDL-cholesterol								
Men	0·091	0·002	0·028	0·35	−0·037	0·17	0·006	0·83
Women	0·010	0·0002	0·050	0·06	−0·035	0·13	0·002	0·94
LDL-cholesterol	0·038	0·07	0·021	0·32	−0·003	0·85	0·011	0·49
Lipoprotein(a)	0·053	0·02	0·041	0·08	−0·015	0·41	−0·004	0·83
TAG	0·094	<0·0001	0·051	0·02	−0·026	0·13	−0·003	0·88
Glucose	0·062	0·004	0·049	0·03	−0·026	0·13	−0·014	0·42
HbA_{1c}	0·055	0·008	0·009	0·68	−0·077	<0·0001	−0·052	0·002
Fibrinogen	0·030	0·15	−0·012	0·56	−0·065	<0·0001	−0·034	0·04
Uric acid	0·065	0·0005	0·050	0·01	−0·009	0·54	0·003	0·84
Homocysteine	0·048	0·03	0·026	0·26	−0·093	<0·0001	−0·078	<0·0001
Folate§	−0·21	<0·0001	−0·19	<0·0001	0·13	0·0002	0·11	0·002

* Number of subjects for the specific characteristics (*n* 4025) can vary due to missing values and specific exclusion criteria (compare description of the study population).
† Regression coefficients are adjusted for age (years), sex and total energy intake (continuous).
‡ Regression coefficients are additionally adjusted for socio-economic status (low, middle and high), sport activity (none, 0·1–1·9, ≥2 h/week) and smoking status (never, past, occasional and daily).
§ Folate was measured in women aged 18–40 years only.

obesity, hypertension, hypertriacylglycerolaemia and the metabolic syndrome. In addition, greater adherence to this pattern was associated with more unfavourable concentrations of markers that are discussed to be related to the complex of the metabolic syndrome, particularly with higher concentrations of uric acid and lower concentrations of folate. In contrast, greater adherence to the health-conscious pattern – characterised by a high intake of vegetables, vegetable oils, legumes, fruits, fish and whole grains – was linked to a lower prevalence of hypertension as well as to higher concentrations of folate and lower concentrations of homocysteine and fibrinogen.

The identification of dietary patterns representative of the general population and their relation to metabolic risk markers has been rarely examined. Similar to the present study, two major dietary patterns, a 'Western' pattern (characterised by frequent intakes of processed meat, red meat, eggs and high-fat diary products) and an 'American-healthy' pattern (characterised by frequent intakes of vegetables, salad dressings and tea), were identified in a representative sample of the adult US population[21]. A high adherence to the Western pattern was adversely related to levels of folate and markers of glucose metabolism, but not to other risk factors such as systolic blood pressure or TAG. For the American-healthy pattern, no significant associations were observed.

Furthermore, previous studies have investigated the relationship between dietary patterns of various subpopulations and metabolic factors. Overall, it can be summarised from these studies that, despite the expected deviations in the dietary patterns' composition, which may be partly explained by specific characteristics of the study populations and culturally defined differences in eating habits, similarities with the present study are obvious. In most of these studies, two or three patterns were extracted. Consistently, one of the patterns was a rather unhealthy pattern, e.g. called 'Western', 'pasta and meat', 'fats and processed meats' or 'refined foods', with processed and red meats, refined grains, eggs and sweets as predominant food groups. Generally, a distinct, rather healthful pattern was also identified, e.g. referred to as 'prudent', 'vegetable', 'whole grains and fruits', or 'healthy balanced', with vegetables, fruits, whole grains and fish as determining food groups[5–8,12–20,32–35]. For the patterns characterised by animal and refined foods, adverse associations with parameters of abdominal obesity[5,9,16,18,20], blood pressure[5,10,18,33] and markers of lipid and glucose metabolism[5,7,10,13,15–17,20,33,34] could be observed, whereas associations of the patterns characterised by plant foods and fish often pointed into the opposite direction[5,7–10,12–17,20,33,34]. So far, few studies have investigated the association between patterns and the prevalence or incidence of the metabolic syndrome. These studies have found either a direct association for a 'Western' and 'sweets' pattern[5,16,18,19] or an inverse association for a 'healthy' pattern[5,16]. In addition, some studies have indicated

Table 5. Cardiometabolic abnormalities clustered within the metabolic syndrome by quintile of dietary patterns in a representative sample of German adults*

(Odds ratios and 95 % confidence intervals)

	Quintiles of the processed foods pattern					Quintiles of the health-conscious pattern						
	1 (Lowest)		3		5 (Highest)	1 (Lowest)		3		5 (Highest)		
Metabolic abnormality	OR	95 % CI	OR	95 % CI	*P* for trend	OR	95 % CI	OR	95 % CI	OR	95 % CI	*P* for trend
Abdominal obesity												
Model 1†	1·00	1·33	1·02, 1·72	2·46	1·74, 3·48	<0·0001	1·00	0·92	0·71, 1·20	0·93	0·71, 1·22	0·52
Model 2‡	1·00	1·21	0·92, 1·58	1·88	1·31, 2·69	<0·0001	1·00	1·01	0·77, 1·32	1·12	0·85, 1·48	0·46
Hypertension												
Model 1	1·00	1·18	0·91, 1·52	1·35	0·98, 1·86	0·03	1·00	0·83	0·65, 1·06	0·66	0·51, 0·85	0·002
Model 2	1·00	1·19	0·92, 1·54	1·34	0·96, 1·86	0·04	1·00	0·77	0·60, 0·99	0·70	0·54, 0·90	0·01
Low HDL-cholesterol												
Model 1	1·00	0·95	0·72, 1·25	1·37	0·99, 1·91	0·01	1·00	0·80	0·62, 1·03	0·82	0·63, 1·07	0·15
Model 2	1·00	0·86	0·65, 1·14	0·95	0·67, 1·35	0·90	1·00	0·92	0·70, 1·19	1·01	0·77, 1·32	0·94
Hypertriacylglycerolaemia												
Model 1	1·00	1·15	0·86, 1·53	2·06	1·46, 2·91	<0·0001	1·00	0·87	0·67, 1·14	0·91	0·69, 1·19	0·36
Model 2	1·00	1·09	0·81, 1·46	1·59	1·11, 2·28	0·0006	1·00	0·96	0·73, 1·26	1·05	0·79, 1·38	0·86
Abnormal glucose homeostasis												
Model 1	1·00	1·34	0·88, 2·03	2·30	1·34, 3·95	0·001	1·00	1·00	0·67, 1·49	0·70	0·46, 1·08	0·09
Model 2	1·00	1·17	0·76, 1·80	1·50	0·85, 2·67	0·11	1·00	1·02	0·68, 1·53	0·81	0·52, 1·25	0·26
Metabolic syndrome												
Model 1	1·00	1·23	0·91, 1·65	2·49	1·70, 3·64	<0·0001	1·00	0·96	0·72, 1·28	0·80	0·60, 1·07	0·06
Model 2	1·00	1·07	0·79, 1·45	1·64	1·10, 2·43	0·001	1·00	1·07	0·79, 1·44	0·98	0·72, 1·34	0·67

* Abdominal obesity: waist circumference >102 cm in men, >88 cm in women; hypertension: blood pressure ≥130/85 mmHg or use of antihypertensive medication; low HDL-cholesterol (<400 mg/l in men and <500 mg/l in women); hypertriacylglycerolaemia: TAG ≥1500 mg/l fasting or ≥2000 mg/l non-fasting; abnormal glucose homeostasis: glucose ≥1100 mg/l fasting or HbA_{1c} ≥6·1 or use of antidiabetic medication; metabolic syndrome: presence of at least three of the above components. Number of subjects within the specific models (*n* 4025) can vary due to missing values and specific exclusion criteria (compare description of the study population).

† Adjusted for age (years), sex and total energy intake (continuous).

‡ Additionally adjusted for socio-economic status (low, middle and high), sport activity (none, 0·1–1·9, ≥2 h/week) and smoking status (never, past, occasional and daily).

associations between the patterns and markers that are linked to the cardiometabolic complex such as markers of systemic inflammation[6,15,20,32,35] or folate metabolism[7,20,35]. In general, the results of the present and previous studies underline the suggested association between the present trend towards a Western-style diet high in refined and animal products at the expense of a healthier plant-based diet and the increasing trend of obesity and related metabolic diseases in developing countries[36].

The observation of divergent associations between the two identified dietary patterns and metabolic disturbances in the present study is supported by distinctive nutrient compositions of the patterns. For example, the intake of fibre and folate, which are known protective factors for CVD[37], was inversely associated with the processed foods pattern; in contrast, the intake of saturated fat and cholesterol, which are considered to increase cardiovascular risk[37], was directly related to this pattern. An opposite trend was evident for most of the nutrients for the health-conscious pattern, although associations were generally less pronounced. The latter observation might also have contributed to the overall weaker association of the health-conscious pattern with the cardiometabolic profile compared with the processed food pattern.

The carefully conducted representative design and the co-existence of detailed information on dietary habits and lifestyle factors as well as of standardised physical and biomarker measurements are among the strengths of the present study. However, dietary pattern identification by factor analysis is generally exposed to the limitation of subjectivity, particularly when grouping the food items, selecting the method of factor rotation or defining the number of patterns to be retained[38], which potentially has an impact on the patterns' composition and their relation to metabolic factors. To minimise subjectivity, we defined the food groups to approximate those used in previous studies and derived the patterns based on commonly applied procedures. Furthermore, factor analysis – by its nature being purely data-driven – provides no insight into the mechanisms responsible for the observed dietary pattern–risk factor associations. The identified dietary patterns may indicate a lifestyle in general[38]. In the present study, participants with different degrees of adherence to the patterns differed, e.g. according to their socio-economic status and smoking habit. Even though we adjusted for these and other potential confounder variables and also excluded subjects with a history of major diseases (that could have led to changed dietary habits) from the analysis of metabolic factors, the issues of residual confounding and reverse causation cannot be excluded due to the cross-sectional design of the present study.

In summary, in this general adult population, a higher adherence to a pattern predominantly characterised by processed foods was related to a higher prevalence of abdominal obesity, hypertension, hypertriacylglycerolaemia and the metabolic syndrome as well as to disadvantageous levels of uric acid and folate, whereas a higher adherence to a pattern largely characterised by vegetables, fruits and whole grains was related to a lower prevalence of hypertension and favourable levels of folate, homocysteine and fibrinogen. These results corroborate previous findings from non-representative studies and further emphasise the importance of healthy overall food patterns to protect from metabolic disturbances known to predispose to cardiovascular and other chronic diseases.

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