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Assessing nutritional quality as a 'vital sign' of cardiometabolic health

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Abstract

High overall nutritional quality (NQ) is an important component of ideal cardiovascular health, a concept introduced in 2010 by the American Heart Association. However, data on the independent contribution of overall NQ to the variation in the cardiometabolic risk (CMR) profile are limited. This observational study aimed to investigate the association between overall NQ and the CMR profile in 4785 participants (65·4 % of men, age 43·3 (SD 10·8) years) who underwent a cardiometabolic health evaluation, including lifestyle habits, anthropometric measurements, blood pressure, lipid profile and HbA1c concentrations. In addition, a submaximal exercise test was conducted to assess cardiorespiratory fitness (CRF). Using a standardised NQ questionnaire (twenty-five items food-based questionnaire), participants were classified into three subgroups: (1) low, (2) moderate or (3) high NQ and variance and multiple linear regression analyses were performed. Results showed that less than 15 % of participants presented a high NQ. A high NQ was associated with a healthier lifestyle habits and a more favourable CMR profile (lower values of waist circumference and cholesterol:HDL-cholesterol ratio, lower concentrations of non-HDL-cholesterol, TAG and HbA1c). Some of these associations were independent of age, physical activity level (PAL) and CRF. A better NQ was also associated with a lower proportion of participants presenting the hypertriacylglycerolaemic waist phenotype independently of both PAL and CRF. The present study suggests that overall NQ can be assessed with a short food-based questionnaire and should be considered in clinical practice as a new 'vital sign' associated with other health behaviours and cardiometabolic health.

Key words: Nutritional quality: Physical activity: Cardiorespiratory fitness: Ideal cardiovascular health: Cardiometabolic risk: Hypertriacylglycerolaemic waist: Workplace health programmes

Despite major improvements in its clinical management over the last decades, the prevalence of CVD and associated risk factors remains high, representing a major societal economic burden[1]. To address this issue, the concept of primordial prevention has been put forward, focusing on maintaining an optimal health rather than trying to prevent CVD in individuals with risk factors[2,3]. In its strategic goals for 2020, the American Heart Association (AHA) introduced the concept of ideal cardiovascular (CV) health based on three biological risk factors (blood pressure (BP), lipids and glucose) and four health behaviours or markers (BMI, non-smoking, physical activity level (PAL) and nutritional quality (NQ))[3]. Epidemiological studies have confirmed that each of these seven metrics are independently associated with CVD[4,5]. For instance, at any level of biological risk factors, health behaviours remain strongly related with the incidence of CVD and mortality risk[5,6]. The proportions of Americans (20–49 years) reaching the ideal targets for each health behaviour metrics are 32·6 % for BMI, 73·1 % for non-smoking, 42·0 % for PAL and only 0·2 % for NQ[1]. Therefore, improvements in eating habits are obviously needed to improve CV health at the population level.

To promote healthier eating habits, both the AHA and the 2015 Dietary Guidelines Advisory Committee have highlighted the relevance of targeting overall NQ[7,8]. In this regard, although there is no consensual definition on how to assess overall NQ, many studies that have used various approaches and tools to assess food-based NQ have shown that some of these food-based dietary patterns are clearly associated with an overall better cardiometabolic risk (CMR) profile consistent with current nutritional guidelines or evidence-based recommendations[1,9–18]. Over the past decades, several methods have been developed to assess overall NQ. Approaches that target food

Abbreviations: AHA, American Heart Association; BP, blood pressure; CMR, cardiometabolic risk; CRF, cardiorespiratory fitness; CV, cardiovascular; DST, Dietary Screening Tool; hyperTG, hypertriacylglycerolaemic; NQ, nutritional quality; PAL, physical activity level; VAT, visceral adipose tissue; WC, waist circumference.

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items rather than isolated nutrients or distribution of macronutrients have been reported to be quite useful in the evaluation and the management of eating habits related to cardiometabolic health[12]. CMR encompasses traditional CVD risk factors such as age, sex, LDL- and HDL-cholesterol, BP and genetics in addition to the dysmetabolic state of abdominal obesity and is used to assess the global risk of developing cardiometabolic disorders such as CVD and type 2 diabetes[19].

The objective of the present study was to evaluate the ability of overall NQ assessed with a short food-based questionnaire to predict markers of the CMR profile in a workplace health programme targeting lifestyle habits (the Grand Défi Entreprise project).

Methods

Participants

The Grand Défi Entreprise is a workplace health and wellness programme with onsite comprehensive cardiometabolic and cardiorespiratory health evaluations of workers, including a 3-month lifestyle intervention programme. Participants were recruited on a voluntary basis through the workplace health programme from March 2011 to November 2017 among twenty-eight corporations of the Province of Québec with no inclusion or exclusion criteria. The present paper reports analyses conducted on the baseline CMR data obtained on a total sample of 4785 workers (3128 men and 1657 women) from a cohort of 4831. Only forty-six participants were excluded from the analyses since they did not complete the Dietary Screening Tool (DST) for the evaluation of the NQ. More details on this programme have been previously published[20]. Briefly, participants completed standardised questionnaires on medical history and health behaviours such as NQ, PAL and smoking. Collected data included anthropometric measurements, body composition, waist circumference (WC), BP, lipid profile, HbA1c and cardiorespiratory fitness (CRF). The present study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by the local Institutional Review Board (2011–1858, 20636). Written informed consent was obtained from all participants.

Overall nutritional quality

Among the different tools proposed in the literature to evaluate NQ, we have selected the DST[21], as it allows to evaluate the NQ of the participants and to provide nutritional recommendations on the worksite. This NQ questionnaire was developed in a North American adult population. The DST is, to our knowledge, the only tool that does not require the use of an intermediate method such as a 24 h recall, a food diary or a quantitative and exhaustive food frequency questionnaire. In contrast to other frequently used NQ indices[18,22], the DST does not measure adherence to nutrition guidelines or predefined dietary patterns. The DST is rather based on the consumption frequency of several food items (poultry, fruits, processed meats, etc.) and food groups (cereal products, dairy products, etc.) as well as the evaluation of certain habits such as the addition of sugar, the consumption of alcohol or the use of nutritional supplements. Participants answered the twenty-five items of the DST in approximately 10 min. A score is assigned to each question according to the subject's response using a predefined scoring system. Frequent consumption of high NQ foods or food groups (whole fruits, vegetables, unfried fish, whole grains and milk) is given more points as well as low-frequency intakes of low NQ food or food groups (processed meat, snacks, sugary foods and added fats). The total NQ score ranged from 0 to 100 and participants were classified according to three predefined NQ subgroups: (1) low (score < 60), (2) moderate (score 60–75) or (3) high (score > 75)[21].

Physical activity level

PAL was assessed with a self-administered, short and validated questionnaire which focused on the volume of aerobic physical activities (cycling, running, swimming, etc.) performed during leisure time and by season[23]. A mean PAL in min per week was calculated and then used to classify participants in four PAL subgroups: (1) sedentary (<30 min/week), (2) moderately inactive (30–149 min/week), (3) moderately active (150–299 min/week) or (4) active (≥300 min/week).

Anthropometric measurements and body composition

Height and weight were measured and BMI was calculated[24]. WC was obtained following standardised procedures[25]. Percentage of body fat was estimated by bioelectrical impedance with a Tanita TBF-300A body composition analyser (Tanita Corporation).

Cardiometabolic risk profile

Resting BP was measured on both arms of participants after they had been seated for at least 5 min with an automated Suntech 247 sphygmomanometer (Suntech Medical). Blood samples in the non-fasting state were collected on the forearm vein and analysed with an Abaxis Piccolo Xpress Chemistry Analyzer to obtain different cholesterol fractions and TAG (Thermo Fisher). From 2011 to 2015, HbA1c concentrations were assessed by a turbidimetric inhibition immunoassay with a Cobas Integra 400/800 system (Roche)[26]. Since 2016, HbA1c concentrations are measured by monoclonal antibody agglutination reaction with an immunoassay DCA Vantage analyser (Siemens Healthcare).

Cardiorespiratory fitness

According to a previously described protocol, a submaximal treadmill exercise test was performed to assess CRF[20]. Using both ACSM's metabolic equations and the least square method, VO_{2max} was estimated by extrapolating oxygen consumption to age-estimated maximal heart rate[27,28]. Depending on their age, sex and estimated VO_{2max}, participants were classified in four CRF subgroups: (1) very poor/poor, (2) fair, (3) good or (4) excellent/superior[27].

Hypertriacylglycerolaemic waist phenotype

The hypertriacylglycerolaemic (hyperTG) waist phenotype is a simple clinical marker useful for identifying viscerally obese

individuals who are also likely to present metabolic abnormalities[29,30]. Criteria are WC ≥ 90·0 cm and TAG ≥ 2·0 mmol/l for men or WC ≥ 85·0 cm and TAG ≥ 1·5 mmol/l for women[29,30].

Cardiovascular risk

Predicted 10-year CV risk of the participants and their vascular age were determined using standardised methods[31,32].

Ideal cardiovascular health

The proportion of participants within each category (ideal, intermediate and poor) of the seven metrics defining the ideal CV health was determined mainly according to the AHA definition[3]. Criteria used were (1) smoking: never smoke or quit smoking for at least 12 months (ideal) and current smoking (poor), (2) BMI: < 25 kg/m^2 (ideal) and ≥ 30 kg/m^2 (poor), (3) PAL: ≥ 150 min/week (ideal) and none (poor), (4) total cholesterol: < 5·2 mmol/l (ideal) and ≥ 6·2 mmol/l (poor) and (5) BP: systolic BP < 120 mmHg and diastolic BP < 80 mmHg (ideal) and systolic BP ≥ 140 mmHg or diastolic BP ≥ 90 mmHg (poor). Unlike the AHA definition, the healthy diet score was replaced by the NQ: > 75 (ideal) and < 60 (poor)[21] and fasting plasma glucose was replaced by HbA1c concentrations: < 5·7 % (ideal) and ≥ 6·5 % (poor)[33]. Metrics between ideal and poor levels were considered in the intermediate category. Participants taking medications for dyslipidaemia, hypertension or diabetes were classified in the intermediate category if treated to goal. Otherwise, they were classified in the intermediate or poor category depending on the level reached under treatment.

Statistical analyses

No sample size calculation was performed since data presented are from an exploratory analysis of an observational study of 4785 workers that provided us with an opportunity to examine the potential relationships between lifestyle variables and biological risk variables. Furthermore, a few studies have examined the relationship between NQ indices and CMR factors in different sample sizes ranging from 488 to 1493 participants[34–36].

As a significant sex interaction term was found for many cardiometabolic variables, analyses have been performed by sex separately, with the exception of analyses leading to findings presented in Fig. 3 where men and women were pooled but using sex-dependent criteria to define CRF and hyperTG waist. Differences in the CMR profile across NQ subgroups were analysed using one-way ANOVA and adjusted for age on separate residual variances in each group, as effect that specifies heterogeneity in the covariance structure was significant (heteroscedasticity) compared with the same variance between groups. The Satterthwaite's degree of freedom statement was added for variables analysed using unequal variance structures. *Posteriori* comparisons were performed using the Tukey–Kramer adjustment for multiple comparisons. Categorical variables were compared by χ^2 tests.

To investigate the relationships between the CMR profile variables and a set of explanatory variables (NQ, PAL and VO_{2max}), multiple linear regression models were performed. All statistical regression models were first adjusted for age (Table 2), and then for additional potential confounding factors such as smoking status, alcohol intake, educational level and use of lipid-lowering, hypotensive and hypoglycaemic drugs (Table 3). The univariate normality assumption was verified with the Shapiro–Wilk tests on the error distribution from the statistical models. The Brown and Forsythe's variation of Levene's test statistic was used to verify the homogeneity of variances. For variables which normality and variance assumptions were not fulfilled, the logarithm transformation was used. The results were considered significant with P values ≤ 0·05. All data were analysed using Statistical Analysis Software Studio 3.4 (SAS Institute Inc.).

Results

Mean age of the 4785 participants was 43·3 (SD 10·8) years; 94·2 % of them were Caucasians and 50·7 % blue-collar workers. The mean NQ score was 62 (SD 13) and the proportion of participants with a high NQ was 14·2 %. Mean BMI was 27·1 (SD 4·9) kg/m^2; 40 % were overweight and 24 % met the criterion for obesity. Moreover, 59·2 % of all participants showed an elevated WC and 81·9 % of overweight/obese participants were abdominally obese. Use of lipid-lowering and antihypertensive drugs was reported by 11·4 and 11·0 % of the participants, respectively. Among all participants, 2·3 % had a history of CHD or stroke.

Fig. 1 presents the proportion of participants in the poor, intermediate and ideal categories of metrics of ideal CV health according to the AHA definition[3]. Proportions of men and women classified in the ideal category were 81·5 and 83·4 % for non-smoking; 26·9 and 53·5 % had a BMI < 25 kg/m^2; 63·0 and 60·3 % reached PAL recommendations; 10·4 and 21·5 % presented a high NQ; 56·5 and 70·7 % had total cholesterol concentrations < 5·17 mmol/l; 14·1 and 39·1 % had a systolic BP < 120 and a diastolic BP < 80 mmHg; and 65·3 and 82·1 % had HbA1c concentrations < 5·7 %, respectively.

Characteristics of participants according to NQ subgroups adjusted for age are shown in Table 1. In both men and women, proportion of smokers as well as BMI and percentage of body fat values progressively decreased from low to high subgroups of NQ, while PAL and estimated VO_{2max} increased. Furthermore, both 10-year CV risk and vascular age were lower in the moderate and high NQ subgroups compared with the low NQ subgroups in both sexes. Fig. 2 presents various CMR variables across NQ subgroups adjusted for age. In both men and women, non-HDL-cholesterol concentrations were lower in the moderate and high NQ subgroups compared with the low NQ subgroup (P < 0·05). Moreover, men and women with a high NQ had lower cholesterol:HDL-cholesterol ratio compared with participants with a low NQ (P < 0·001). In comparison with men with low NQ, the mean WC of men with moderate or high NQ was 2·5 and 5·9 cm smaller, respectively. A similar trend was observed in women, WC being 3·4 and 7·1 cm smaller in the moderate and the high NQ subgroups, respectively, compared with the low NQ subgroup (P < 0·001). Among men with a moderate or a high NQ, TAG concentrations were lower by 7·9 and 17·7 %, respectively, in comparison with men with a low NQ

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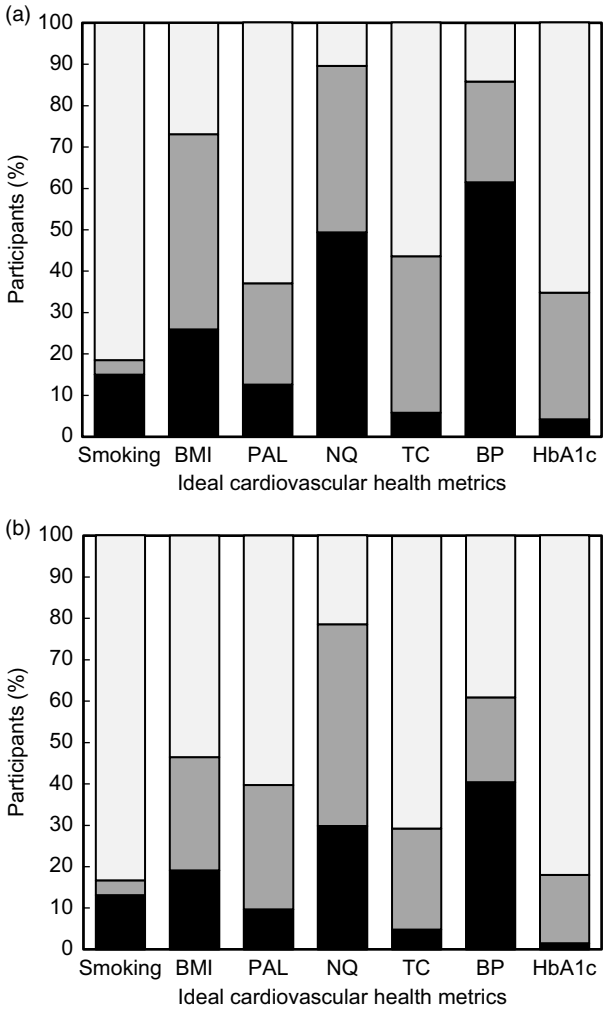

Fig. 1. Proportion of participants in the poor (■), intermediate (▒) or ideal (□) category of metrics of ideal cardiovascular health in (a) men and (b) women. The analysis included 3128 men and 1657 women. The proportion of participants within each category was determined mainly according to the definition of the American Heart Association (AHA)[3]. Criteria used were (1) smoking: never smoke or quit smoking for at least 12 months (ideal) and current smoking (poor), (2) BMI: < 25 kg/m^2 (ideal) and ≥ 30 kg/m^2 (poor), (3) physical activity level (PAL): ≥ 150 min/week (ideal) and none (poor), (4) total cholesterol (TC): < 5·2 mmol/l (ideal) and ≥ 6·2 mmol/l (poor) and (5) blood pressure (BP): systolic BP < 120 mmHg and diastolic BP < 80 mmHg (ideal) and systolic BP ≥ 140 mmHg or diastolic BP ≥ 90 mmHg (poor). Unlike the AHA definition, the healthy diet score was replaced by nutritional quality (NQ): > 75 (ideal) and < 60 (poor)[21] and fasting plasma glucose was replaced by HbA1c concentrations: < 5·7 % (ideal) and ≥ 6·5 % (poor)[33]. Metrics between ideal and poor levels were considered in the intermediate category. Participants taking medications for dyslipidaemia, hypertension or diabetes were classified in the intermediate category if treated to goal. Otherwise, they were classified in the intermediate or poor category depending on the level reached under treatment.

(P < 0·01). TAG concentrations were also 5·1 and 10·9 % lower among women in the moderate and the high NQ subgroups, respectively, compared with women with a low NQ (P < 0·01). Accordingly, there was an inverse association between the percentage of men and women with the hyperTG waist phenotype and NQ (P < 0·001). In both men and women, HbA1c concentrations were lower in the moderate and the high NQ subgroups in comparison with workers with a low NQ (P < 0·05). Resting systolic BP was 2 mmHg lower in men and in women with a high NQ compared with those with a low NQ (P < 0·05). Resting diastolic BP showed an inverse association with NQ in men only (P < 0·01).

Fig. 3 shows that the percentage of participants with the hyperTG waist phenotype was progressively lower as a function of higher PAL as well as higher NQ. It was shown by χ^2 tests that there was (1) 2·5 times more hyperTG waist carriers in the sedentary/low NQ subgroup than in the active/high NQ subgroup (P < 0·001) and (2) 3·2 times more hyperTG waist carriers in the very poor/poor CRF/low NQ subgroup than in the excellent/superior CRF/high NQ subgroup (P < 0·001). Furthermore, within the moderately inactive, moderately active and the active subgroups of PAL, the percentage of men and women with the hyperTG waist phenotype decreased as a function of increased NQ. Moreover, when PAL subgroups were substituted by CRF categories, both CRF and NQ were inversely associated with the percentage of individuals with the hyperTG waist phenotype.

Multiple linear regression analyses were conducted by sex to examine the independent contributions of NQ, PAL and estimated VO_{2max} to the variance of CMR variables after statistical

Table 1. Characteristics of participants according to nutritional quality†
(Numbers; percentages; mean values and standard deviations)

	Nutritional quality					
	Low		Moderate		High	
	Mean	SD	Mean	SD	Mean	SD
Men (*n*)	1546		1256		326	
Tertiary education‡ (%)	42·7		54·8		66·6	
High household income§ (%)	69·5		74·7		79·4	
Current smokers (%)	19·4		11·5		7·7	
Type 2 diabetes (%)	4·8		4·0		1·8	
Nutritional quality	49[a]	8	67***[b]	4	80***[c]	4
Age (years)	44·4	10·8	44·0	10·7	44·2	10·4
BMI‖ (kg/m^2)	28·3[a]	4·8	27·5***[b]	4·1	26·5***[b]	3·6
Body fat (%)	25·3[a]	7·1	23·8***[b]	6·4	22·1***[c]	5·9
Total cholesterol‖ (mmol/l)	4·76[a]	0·94	4·68[a,b]	0·88	4·58**[b]	0·83
LDL-cholesterol (mmol/l)	2·51	0·80	2·50	0·74	2·46	0·70
HDL-cholesterol (mmol/l)	1·25	0·30	1·27	0·30	1·28	0·31
Estimated VO_{2max} (ml/kg per min)	40·5[a]	9·7	42·5***[b]	9·5	44·7***[c]	10·1
Physical activity level (min/week)	226[a]	289	290***[b]	266	413***[c]	346
Framingham Risk Score (%)	6·4[a]	5·0	5·9*[b]	4·7	5·0**[c]	3·7
Vascular age (years)	51·8[a]	13·7	50·0***[b]	13·1	47·1***[c]	11·7
Women (*n*)	493		808		356	
Menopausal (%)	15·4		15·8		18·0	
Tertiary education‡ (%)	57·8		73·1		80·3	
High household income§ (%)	53·3		60·3		62·1	
Current smokers (%)	19·9		11·2		7·9	
Type 2 diabetes (%)	1·8		1·5		0·8	
Nutritional quality	51[a]	7	67***[b]	5	81***[c]	4
Age (years)	41·0[a]	10·9	41·6[a,b]	10·6	42·8*[b]	11·0
BMI‖ (kg/m^2)	26·9[a]	5·8	25·7***[b]	5·3	24·2***[c]	4·4
Body fat (%)	34·5[a]	8·3	32·6***[b]	8·1	30·4***[c]	8·0
Total cholesterol‖ (mmol/l)	4·76[a]	0·88	4·65*[b]	0·83	4·68[a,b]	0·86
LDL-cholesterol (mmol/l)	2·53[a]	0·70	2·43*[b]	0·66	2·43**[b]	0·72
HDL-cholesterol (mmol/l)	1·58	0·35	1·58	0·35	1·62	0·34
Estimated VO_{2max} (ml/kg per min)	32·8[a]	8·5	34·1**[b]	8·7	35·4**[c]	8·6
Physical activity level (min/week)	156[a]	144	223***[b]	190	301***[c]	231
Framingham Risk Score (%)	3·4[a]	3·5	3·1*[b]	3·3	3·1***[b]	2·9
Vascular age (years)	45·6[a]	15·8	43·2***[b]	14·5	43·4***[b]	15·2

[a,b,c] Mean values with unlike superscript letters were significantly different.
* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.
† Analyses are age-adjusted one-way ANOVA with Tukey–Kramer's *post hoc* corrections for multiple comparisons and were performed separately in men and in women.
‡ Tertiary education was defined as post-secondary education.
§ A high household income was defined as an income greater than CAN$ 60 000.
‖ Analyses were performed on log-transformed data.

adjustment for age (Table 2). In both men and women, estimated VO_{2max} was the main independent variable explaining the largest proportion of the variance of BMI, WC, non-HDL-cholesterol, cholesterol:HDL-cholesterol, TAG and systolic and diastolic BP. In this multiple regression model, in men NQ remained independently associated with all the CMR variables with the exception of systolic BP, whereas in women NQ was only independently associated with BMI, WC, HbA1c and systolic BP. The second multiple regression model, including WC, showed that this crude index of visceral adipose tissue (VAT) contributed the most to the variance of CMR variables in both men and women after adjustment for age (Table 3). However, NQ remained significantly related to non-HDL-cholesterol, TAG and diastolic BP in men and only to HbA1c concentrations in women. Additional adjustments for potential confounding factors such as smoking status, alcohol intake, educational level and use of lipid-lowering hypotensive or hypoglycaemic drugs yielded similar results in men, with the exception of HbA1c that did not reach statistical significance (data not shown). In women, data remained unchanged after adjustment for these potential confounders.

Discussion

Among participants (*n* 4785; 65·4 % of men) recruited through a workplace health programme, a higher NQ was associated with a more favourable CMR profile and with a lower estimated 10-year CV risk in both men and women. Participants with a high NQ were also more physically active and less likely to be smokers, a finding consistent with the literature[37,38]. Hence, these findings suggest that overall NQ could be a simple marker of a global healthier lifestyle and of a more favourable CMR profile. However, overall NQ was the health behaviour with the lowest proportion of participants in the ideal category, a finding also

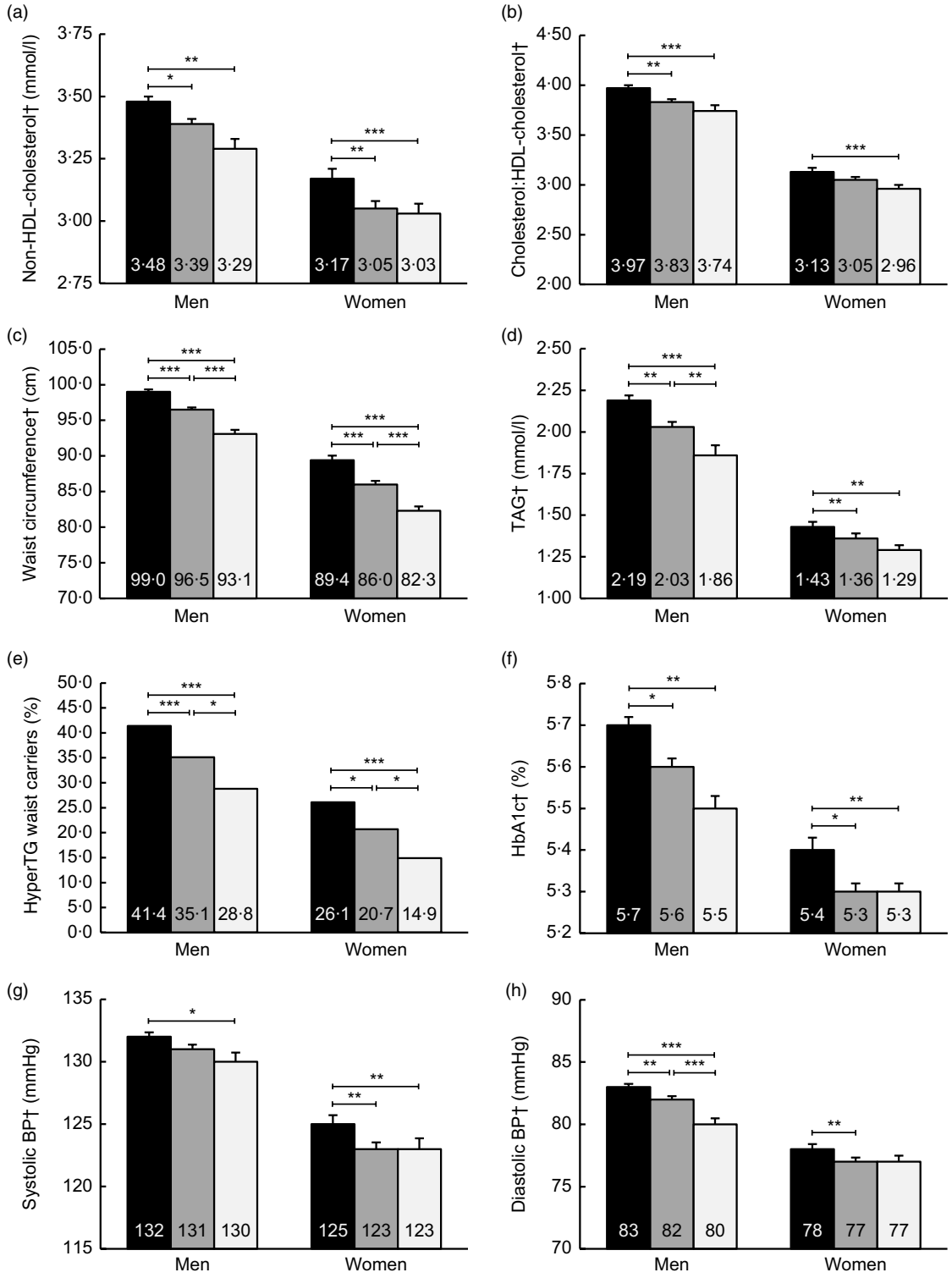

Fig. 2. Cardiometabolic risk profile across nutritional quality (NQ) subgroups: low NQ (■; <60), moderate NQ (□; 60–75) and high NQ (□; >75). (a) Non-HDL-cholesterol (men, *n* 3035; women, *n* 1621); (b) cholesterol:HDL-cholesterol (men, *n* 3034; women, *n* 1621); (c) waist circumference (men, *n* 3126; women, *n* 1649); (d) TAG (men, *n* 3083; women, *n* 1645); (e) hypertriacylglycerolaemic (hyperTG) waist carriers (men, *n* 2776; women, *n* 1357); (f) HbA1c (men, *n* 3083; women, *n* 1645); (g) systolic blood pressure (BP) (men, *n* 3127; women, *n* 1657); (h) diastolic BP (men, *n* 3127; women, *n* 1657). Values are means with their standard errors, except for panel (e) where values are expressed in percentages. Analyses are age-adjusted one-way ANOVA and were performed separately in men and in women. *Posteriori* comparisons were performed using the Tukey–Kramer adjustment for multiple comparisons. Categorical variables were compared by χ^2 tests. * $P < 0{\cdot}05$, ** $P < 0{\cdot}01$, *** $P < 0{\cdot}001$. † Analyses were performed on log-transformed data. Criteria for hyperTG waist are waist circumference ≥ 90·0 cm and TAG ≥ 2·0 mmol/l in men and waist circumference ≥ 85·0 cm and TAG ≥ 1·5 mmol/l for women[29,30].

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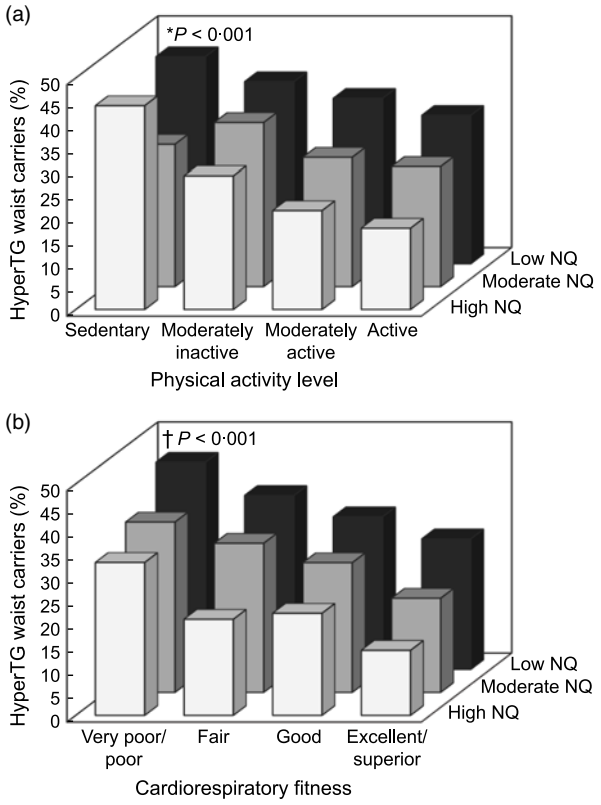

Fig. 3. Proportion of carriers of the hypertriacylglycerolaemic (hyperTG) waist phenotype according to nutritional quality (NQ) and (a) physical activity level or (b) cardiorespiratory fitness. NQ subgroups: low (<60), moderate (60–75) and high (>75). Physical activity level subgroups: sedentary (<30 min/week), moderately inactive (30–149 min/week), moderately active (150–299 min/week) and active (≥ 300 min/week). Cardiorespiratory fitness subgroups are defined as proposed by American College of Sports and Medicine guidelines[27]. Criteria for hyperTG waist are waist circumference ≥ 90·0 cm and TAG ≥ 2·0 mmol/l in men and waist circumference ≥ 85·0 cm and TAG ≥ 1·5 mmol/l in women[29,30]. * Statistical difference between the sedentary/low NQ subgroup and the active/high NQ subgroup. † Statistical difference between the very poor/poor cardiorespiratory fitness/low NQ subgroup and the excellent/superior cardiorespiratory fitness/high NQ subgroup.

reported in other population studies[1]. Therefore, assessment of lifestyle habits such as overall NQ appears relevant to target health behaviours contributing to a more deteriorated CMR profile.

The cross-sectional design of the present study has limitations. Although the workplace health programme was offered to all employees within each participating company, we cannot translate our results to the general population. Social desirability and response set biases are expected and both NQ and PAL were likely overestimated[39]. Consequently, the proportion of participants with non-ideal NQ and PAL may be greater than reported. Despite these limitations, NQ was strongly associated with variation in CMR profile as well as with the percentage of participants with the hyperTG waist phenotype (a simple marker of visceral obesity)[29,30] independently of PAL and CRF.

Men and women with a high NQ showed a more favourable CMR profile and a decreased percentage of participants with visceral obesity or type 2 diabetes in comparison with participants with a low NQ. These findings are consistent with many studies where adherence to healthy dietary patterns such as the Mediterranean diet or the Dietary Approaches to Stop Hypertension (DASH) type eating plan has been inversely associated with the CMR profile and with a reduced risk for type 2 diabetes[16,40–43]. These studies assessed adherence to *a priori* defined dietary patterns known to be beneficial regarding CVD prevention, whereas the DST used in the present study targets various food items associated with overall NQ regardless of a specific dietary pattern. From a practical standpoint, a high NQ score implied, for instance, regular consumption of whole grains (both breads and cereals) ≥ 3 times a week, eating cakes and pies less than once a week, avoiding deli meats, having one fruit a day, eating unfried fish once a week and eating two daily servings of vegetables. Thereby, it is suggested that a diet of high overall NQ is achievable through various healthy dietary patterns by following very simple food-based nutritional advice consistent with current guidelines.

As in other studies, NQ, PAL and CRF were closely interrelated and seemed to show synergistic association with CMR profile[37,44,45]. To our knowledge, the present study is the first to report the association between health behaviours and the hyperTG waist phenotype, a simple clinical marker of visceral obesity related to metabolic abnormalities[29,30]. NQ was inversely associated with the hyperTG waist phenotype independently of either PAL or CRF. These results reinforce the importance of the contribution of NQ to the most detrimental form of overweight/obesity, visceral obesity and emphasise the significance of targeting NQ even within active or fit individuals. A large longitudinal study has previously reported no association between NQ and CMR profile after adjustment for CRF[45]. In the present study, multiple regression analyses showed that association of NQ with most of the CMR variables examined remained significant after control for age, PAL and estimated VO_{2max} as an indicator of CRF. Thus, the contribution of NQ to the CMR profile is partly independent from its contribution to traditional CV risk factors such as lipid profile, diastolic BP and HbA1c concentrations. Consequently, these results suggest that NQ may provide protection against CVD through mechanisms beyond traditional CV risk factors[14,46,47]. A plausible hypothesis would be that VAT modulates the association of NQ with CMR variables[48,49]. In this regard, our second model (Table 3) aimed at testing this hypothesis and revealed that WC was the main independent factor associated with most CMR profile variables in both men and women. Nevertheless, NQ remained significantly related to the lipid profile and diastolic BP in men as well as to HbA1c in women. It is therefore likely that physiological mechanisms related to visceral adiposity contribute to these associations as men are known to store more VAT than women[50]. Therefore, PAL, CRF and probably VAT modulated the association of NQ with CMR variables, but the present cross-sectional study cannot address this question. Nevertheless, the contribution of health behaviours to the CMR profile are probably synergistic and closely interrelated, the real issue being whether they can be assessed in clinical practice. For this purpose, NQ assessment appears as a promising indicator of lifestyle habits.

Table 2. Association of nutritional quality (NQ), physical activity level (PAL) and VO_{2max} with cardiometabolic risk profile variables* (R^2; β; standard errors; *t* values; *P* values and standardised β)

	R^2	β	SEM	*t*	*P*	Standardised β
Men						
BMI†	0·1319					
NQ		–0·00078439	0·00020959	–3·74	<0·001	–0·06620
PAL		–0·00001622	0·00000896	–1·81	0·0703	–0·03222
VO_{2max}		–0·00494	0·00029251	–16·90	<0·001	–0·32722
Waist circumference†	0·1912					
NQ		–0·00087319	0·00016349	–5·34	<0·001	–0·09118
PAL		–0·00003206	0·00000698	–4·59	<0·001	–0·07882
VO_{2max}		–0·00388	0·00022818	–16·99	<0·001	–0·31771
Non-HDL-cholesterol†	0·0231					
NQ		–0·00115	0·00038447	–2·99	0·0028	–0·05690
PAL		–0·00001198	0·00001630	–0·74	0·4624	–0·01405
VO_{2max}		–0·00237	0·00053488	–4·42	<0·001	–0·09211
Cholesterol:HDL-cholesterol†	0·0303					
NQ		–0·00118	0·00039245	–3·02	0·0026	–0·05713
PAL		–0·00003641	0·00001664	–2·19	0·0287	–0·04168
VO_{2max}		–0·00375	0·00054581	–6·87	<0·001	–0·14255
TAG†	0·0454					
NQ		–0·00355	0·00079879	–4·44	<0·0001	–0·08288
VO_{2max}		–0·00673	0·00111	–6·05	<0·001	–0·12363
HbA1c	0·1084					
NQ		–0·00040088	0·00014638	–2·74	0·0062	–0·05239
PAL		0·00000246	0·00000663	0·37	0·7103	0·00716
VO_{2max}		–0·00059970	0·00019851	–3·02	0·0025	–0·06271
Systolic blood pressure†	0·0543					
NQ		–0·00026487	0·00014354	–1·85	0·0651	–0·03406
PAL		0·00001456	0·00000613	2·37	0·0177	0·04406
VO_{2max}		–0·00109	0·00020026	–5·44	<0·001	–0·10986
Diastolic blood pressure†	0·0849					
NQ		–0·00071710	0·00016121	–4·45	<0·001	–0·08076
PAL		0·00001063	0·00000689	1·54	0·1230	0·02817
VO_{2max}		–0·00215	0·00022490	–9·56	<0·001	–0·19010
Women						
BMI†	0·1650					
NQ		–0·00197	0·00037658	–5·24	<0·001	–0·13051
PAL		–0·00001133	0·00002244	–0·50	0·6138	–0·01259
VO_{2max}		–0·00707	0·00053543	–13·20	<0·001	–0·34715
Waist circumference†	0·1909					
NQ		–0·00182	0·00029559	–6·15	<0·001	–0·15095
PAL		–0·00001500	0·00001760	–0·85	0·3941	–0·02094
VO_{2max}		–0·00519	0·00042029	–12·35	<0·001	–0·31995
Non-HDL-cholesterol†	0·1361					
NQ		–0·00105	0·00055453	–1·90	0·0578	–0·04852
PAL		–0·00000964	0·00003294	–0·29	0·7699	–0·00748
VO_{2max}		–0·00429	0·00078628	–5·45	<0·001	–0·14708
Cholesterol:HDL-cholesterol†	0·0852					
NQ		–0·00069370	0·00052311	–1·33	0·1850	–0·03487
PAL		–0·00007560	0·00003107	–2·43	0·0151	–0·06405
VO_{2max}		–0·00494	0·00074174	–6·66	<0·001	–0·18494
TAG†	0·0695					
NQ		–0·00196	0·00105	–1·87	0·0614	–0·04938
PAL		–0·00011371	0·00006231	–1·82	0·0682	–0·04818
VO_{2max}		–0·00826	0·00149	–5·55	<0·001	–0·15426
HbA1c	0·1510					
NQ		–0·00082322	0·00017633	–4·67	<0·001	–0·12970
PAL		0·00001512	0·00001074	1·41	0·1595	0·03920
VO_{2max}		0·00016664	0·00025488	0·65	0·5134	0·01906
Systolic blood pressure†	0·1292					
NQ		–0·00055885	0·00024897	–2·24	0·0249	–0·05711
PAL		0·00001264	0·00001484	0·85	0·3945	0·02170
VO_{2max}		–0·00251	0·00035399	–7·09	<0·001	–0·19033
Diastolic blood pressure†	0·0749					
NQ		–0·00046321	0·00026128	–1·77	0·0765	–0·04649
PAL		0·00001589	0·00001557	1·02	0·3075	0·02680
VO_{2max}		–0·00304	0·00037150	–8·17	<0·001	–0·22621

* Analyses are multiple linear regression and age-adjusted and were performed separately in men and in women.
† Analyses were performed on log-transformed data.

Table 3. Association of nutritional quality (NQ), physical activity level (PAL), VO_{2max} and waist circumference (WC) with cardiometabolic risk profile variables* (R^2; β; standard errors; *t* values; *P* values and standardised β)

	R^2	β	SEM	*t*	*P*	Standardised β
Men						
Non-HDL-cholesterol†	0·0449					
NQ		–0·00085645	0·00038237	–2·24	0·0252	–0·04233
PAL		–0·00000185	0·00001618	–0·11	0·9091	–0·00217
VO_{2max}		–0·00105	0·00055494	–1·90	0·0578	–0·04099
WC		0·00352	0·00043962	8·00	<0·001	0·16212
Cholesterol:HDL-cholesterol†	0·1217					
NQ		–0·00053128	0·00037568	–1·41	0·1574	–0·02563
PAL		–0·00001444	0·00001589	–0·91	0·3636	–0·01653
VO_{2max}		–0·00091518	0·00054508	–1·68	0·0933	–0·03478
WC		0·00745	0·00043183	17·26	<0·001	0·33540
TAG†	0·1125					
NQ		–0·00233	0·00077472	–3·01	0·0026	–0·05457
PAL		–0·00000960	0·00003284	–0·29	0·7702	–0·00531
VO_{2max}		–0·00161	0·00113	–1·43	0·1530	–0·02958
WC		0·01319	0·00088886	14·84	<0·001	0·28846
HbA1c	0·1240					
NQ		–0·00027700	0·00014574	–1·90	0·0575	–0·03628
PAL		0·00000645	0·00000658	0·98	0·3273	0·01878
VO_{2max}		–0·00016311	0·00020534	–0·79	0·4271	–0·01709
WC		0·00113	0·00016480	6·86	<0·001	0·13907
Systolic blood pressure†	0·0844					
NQ		–0·00012373	0·00014209	–0·87	0·3840	–0·01590
PAL		0·00001955	0·00000606	3·23	0·0013	0·05916
VO_{2max}		–0·00046662	0·00020704	–2·25	0·0243	–0·04707
WC		0·00160	0·00016311	9·81	<0·001	0·19241
Diastolic blood pressure†	0·1245					
NQ		–0·00053273	0·00015865	–3·36	<0·001	–0·05997
PAL		0·00001717	0·00000676	2·54	0·0112	0·04552
VO_{2max}		–0·00134	0·00023116	–5·81	<0·001	–0·11867
WC		0·00210	0·00018212	11·51	<0·001	0·22075
Women						
Non-HDL-cholesterol†	0·1746					
NQ		–0·00033768	0·00054955	–0·61	0·5390	–0·01556
PAL		–0·00000334	0·00003223	–0·10	0·9175	–0·00259
VO_{2max}		–0·00227	0·00080769	–2·81	0·0050	–0·07792
WC		0·00445	0·00053780	8·27	<0·001	0·21781
Cholesterol:HDL-cholesterol†	0·1995					
NQ		0·00040660	0·00049612	0·82	0·4126	0·02043
PAL		–0·00006514	0·00002909	–2·24	0·0253	–0·05519
VO_{2max}		–0·00173	0·00072916	–2·37	0·0179	–0·06467
WC		0·00701	0·00048551	14·44	<0·001	0·37437
TAG†	0·1729					
NQ		0·00016026	0·00100	0·16	0·8727	0·00404
PAL		–0·00009322	0·00005880	–1·59	0·1130	–0·03950
VO_{2max}		–0·00216	0·00147	–1·47	0·1430	–0·04035
WC		0·01336	0·00098361	13·59	<0·001	0·35573
HbA1c	0·1925					
NQ		–0·00060770	0·00017460	–3·48	<0·001	–0·09570
PAL		0·00001672	0·00001049	1·59	0·1112	0·04333
VO_{2max}		0·00081474	0·00026200	3·11	0·0019	0·09314
WC		0·00137	0·00017513	7·84	<0·001	0·22380
Systolic blood pressure†	0·1722					
NQ		–0·00022406	0·00024619	–0·91	0·3629	–0·02289
PAL		0·00001571	0·00001448	1·09	0·2781	0·02697
VO_{2max}		–0·00154	0·00036279	–4·23	<0·001	–0·11643
WC		0·00212	0·00024182	8·78	<0·001	0·22938
Diastolic blood pressure†	0·1092					
NQ		–0·00016387	0·00025995	–0·63	0·5285	–0·01644
PAL		0·00001881	0·00001529	1·23	0·2188	0·03172
VO_{2max}		–0·00214	0·00038307	–5·59	<0·001	–0·15954
WC		0·00193	0·00025534	7·57	<0·001	0·20524

* Analyses are multiple linear regression and age-adjusted and were performed separately in men and in women.
† Analyses were performed on log-transformed data.

Conclusions

The independent contribution of NQ to the CMR profile and its inverse association with the hyperTG waist phenotype, regardless of PAL or CRF, suggests that targeting physical activity or fitness alone is not enough to optimise the CV health of men and women. Although causal relationships cannot be inferred from these cross-sectional analyses, results of the present study suggest that targeting overall NQ assessed with a short food-based questionnaire is feasible in clinical practice and should be considered as a new 'vital sign' associated with other health behaviours and cardiometabolic health.

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The authors' contributions were: P. P., J. P. D. and N. A. designed the research (project conception, development of overall research plan and study oversight) and conducted the research (hands-on conduct of the experiments and data collection); J. P. D. and N. A. provided the database; D. B. P., J. P. D. and N. A. analysed data and performed statistical analyses; D. B. P. drafted the manuscript; and P. P., J. P. D. and N. A. reviewed and edited it. All authors read and approved the final manuscript.

The authors declare that there are no conflicts of interest.

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