

Interactive effects of exercise, alcohol, and vegetarian diet on coronary artery disease risk factors in 9242 runners: The National Runners' Health Study¹⁻³

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ABSTRACT In a national survey, 199 male and 152 female vegetarian runners and 7054 male and 1837 female omnivorous runners provided data on weekly intakes of alcohol, red meat, fish, and fruit, and weekly distance run. This information was compared with physician-supplied medical data to test whether 1) running benefits vegetarians, 2) alcohol and running distance contribute independently to concentrations of high-density-lipoprotein (HDL) cholesterol, and 3) running mitigates the hypertensive effects of alcohol. Greater reported weekly distance run by vegetarians was associated with greater HDL-cholesterol concentrations [slopes \pm SEs for men and women, respectively: 0.003 ± 0.001 and 0.005 ± 0.002 (mmol/L)/km] and lower waist (-0.06 ± 0.02 and -0.08 ± 0.02 cm/km), hip (-0.05 ± 0.03 and -0.07 ± 0.02 cm/km), and chest (-0.05 ± 0.02 cm/km for both) circumferences. In men and women, alcohol and running distance contributed independently to higher HDL-cholesterol concentrations. Men who ran > 72 km and drank > 177 mL (6 oz) alcohol/wk were five times more likely to have clinically defined high HDL cholesterol (≥ 1.55 mmol/L, or ≥ 60 mg/dL) than were nondrinkers running < 24 km/wk. Regardless of running level, men's blood pressure increased in association with alcohol intake. These data suggest that 1) running distance in vegetarians and vegans has the same relation to HDL cholesterol (increasing) and adiposity (decreasing) as reported previously for omnivores, 2) alcohol and running distance contribute independently to higher HDL cholesterol, and 3) running does not abate the hypertensive effects of alcohol in men. Also, vigorous exercise provides important health benefits beyond those obtained by diet. *Am J Clin Nutr* 1997;66:1197-206.

KEY WORDS Vegetarianism, veganism, alcohol, diet, running, physical activity, high-density lipoproteins, low-density lipoproteins, blood pressure, adiposity, coronary artery disease, humans

INTRODUCTION

The 1995 *Dietary Guidelines* for Americans recommend limited intakes of animal products and acknowledge some health benefits of vegetarianism and moderate alcohol intake (1). Physical activity is recommended, particularly with the goal of maintaining a stable weight. Yet little information exists on how diet and physical activity interact. Does exercise prevent the decrease in plasma high-density lipoprotein (HDL) caused by high-carbohydrate, low-fat diets? Do vegetarians

benefit from vigorous physical activity? Are the health benefits of alcohol and physical activity additive? Does exercise mitigate the consequences of poor dietary choices? Some may reason that the adoption of either a healthy diet or a physically active lifestyle alone is sufficient.

Both diet and exercise affect adiposity, blood pressure, and lipoprotein concentrations. Plasma HDL-cholesterol concentrations are increased by running (2-10) and alcohol intake (11, 12) but decreased by vegetarianism (13-15). Both runners and vegetarians have low plasma concentrations of low-density-lipoprotein (LDL) cholesterol (9, 10, 13-16). Blood pressure is lowered by running (17) and eating a vegetarian diet (18, 19) and raised by drinking alcohol (12). The prevalence of adiposity and central obesity are reduced in runners (2-5, 9, 10, 16) and vegetarians (15, 18, 20). Strict vegetarians (vegans) have lower LDL-cholesterol and HDL-cholesterol concentrations than lactovegetarians (21).

Some observations suggest that diet could mitigate the effects of exercise on lipoproteins. The Tarahumara Indians of Mexico for example, who consume diets very low in fat (12%) and high in carbohydrates (75%), have low average HDL-cholesterol concentrations (0.70 mmol/L, or 27 mg/dL) despite their high physical activity (22). In another example, sedentary men who entered a 1-y exercise training program may have had their lipoprotein responses to weight loss attenuated by a low-fat, high-carbohydrate diet (4). They needed to lose nearly twice as much weight to produce approximately the same increases in HDL₂ as seen in men following unrestricted diets (5). Thompson et al (23) speculated that running may blunt the HDL-cholesterol and triacylglycerol responses to a high-fat diet. The differences in lipoproteins that they observed between runners fed high-fat and high-carbohydrate diets were considerably smaller than those reported for sedentary subjects (24).

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The benefits of running on coronary artery disease (CAD) risk factors are well known for omnivores but poorly understood for vegetarians (2–10). Although vegetarians are a minority among Americans, they represent a significant proportion of the world's people. Evidence of the health benefits of vigorous activity in vegetarians and vegans provides a foundation for promoting physical activity more globally. Even among omnivores, the interactive effects of diet and exercise on CAD risk factors have not been examined previously in a large vigorously active sample. A large cross-sectional study of 8891 omnivores and 351 vegetarians, although lacking the ability to prove causal relations, provides a sensitive and statistically powerful test of these interactions. We reported elsewhere on the dose-response relation between running distance and CAD risk factors in the omnivorous runners of this sample (2, 3). The current study compares vegetarian status and self-reported intakes of alcohol, red meat, fish, and fruit with physician-supplied medical data to 1) assess the benefits of running in vegetarians, 2) assess the relative contributions of alcohol and running distance on HDL cholesterol, and 3) test for interactions between diet and exercise and their effects on CAD risk factors.

METHODS

A two-page questionnaire, distributed nationally at races and to subscribers of the nation's largest running magazine (*Runners' World*, Emmaus, PA), solicited information on demographics (age, race, and education), running history [age at which subjects started running ≥ 19 km/wk (12 miles/wk), average weekly distance and number of marathons run over the preceding 5 y, and best marathon and 10-km running times], weight history (greatest and current weight, weight when started running, least weight as a runner, and body circumferences of the chest, waist, and hips), diet (vegetarianism and current weekly intakes of alcohol, red meat, fish, and fruit), current and past cigarette use, prior history of heart attacks and cancer, and medications taken for blood pressure, thyroid, high cholesterol, or diabetes. The questionnaire also requested permission to obtain participants' heights; weights; HDL, LDL, and total cholesterol and triacylglycerol concentrations; blood pressures; and resting heart rates from the runners' physicians.

The amount of alcohol consumed per week was calculated on the basis of 14.2 mL/12-oz bottle of beer, 14.2 mL/4-oz glass of wine, and 17.7 mL per drink of hard liquor (25). Intakes of fruit, fish, and red meat (beef, lamb, and pork) were reported as servings per week. Alcohol, red meat, fruit, and fish consumption were validated by correlating reported usual weekly intakes from the questionnaires with recorded actual intakes from 4-d food records in a subsample of 110 men. The correlations were within the range typically achieved with food-frequency questionnaires (26, 27). The two methods agreed most strongly for alcohol intake ($r = 0.65$) and moderately for red meat ($r = 0.46$) and fruit ($r = 0.38$). A weak correlation for fish consumption presumably relates in part to infrequent intake ($r = 0.19$).

The average number of kilometers run per week was computed by averaging the reported yearly distances over the preceding 5 y. The test-retest correlations for self-reported distance run per week ($r = 0.89$, unpublished data from 110

runners who completed duplicate questionnaires several months apart) compared favorably with those reported for the Minnesota leisure-time physical activity questionnaire (28) and others (29, 30). Body mass index (BMI) was calculated as the weight in kilograms divided by height squared in meters. Two approaches were used to validate questions on anthropometric measurements from 110 men: 1) test-retest correlations from duplicate questionnaires and 2) correlations of clinical measurements of height, weight, and circumference measurements with their self-reported values. Self-reported height and weight showed strong agreement with the duplicate questionnaires ($r = 0.98$ and $r = 0.97$, respectively) and with the clinic measurements of these variables ($r = 0.96$ for both). There were reasonable but somewhat weaker test-retest correlations for self-reported waist circumference ($r = 0.84$), hip circumference ($r = 0.79$), and chest circumference ($r = 0.93$). Self-reported body circumferences also correlated reasonably with the clinic's circumference measurements of the waist ($r = 0.68$), hip ($r = 0.63$), and chest ($r = 0.77$). The somewhat weaker reproducibility of the waist, hip, and chest measurements indicated that the probability of a statistical type II error (false-negative result) would be greater for these variables than for height and weight, but it should not have affected the probability of the type I statistical error (false-positive result) (31).

We estimated that 15–19% of the subjects who received our questionnaire responded (uncertainty due to unknown numbers of race participants who received the questionnaire, and undeliverable addresses). Physician-supplied HDL concentrations were obtained for 26% of the respondents. The remainder either did not give permission to release medical data (27%), had no HDL-cholesterol concentrations in their medical record (22%), or had nonresponsive physicians (25%). HDL-cholesterol values were obtained from 7054 omnivorous and 820 professed vegetarian, white male runners and from 1837 omnivorous and 357 vegetarian white female runners who were without prior history of heart disease or cancer and who were not taking medications that might affect lipoprotein concentrations. Lactovegetarians and vegans were identified by self report. We excluded 360 professed male vegetarians who reported occasional weekly red meat intake and 261 who reported occasional fish intake, leaving 199 vegetarians (167 lactovegetarians and 32 vegans). We excluded 68 professed female vegetarians who occasionally ate meat and 137 who occasionally ate fish, leaving 152 vegetarians (122 lactovegetarians and 30 vegans). There were too few male and female vegans to be analyzed separately, thus the data for both sexes were combined and adjusted for sex. Multiple-regression analyses were used to test for linear relations between distance run and risk factor status. Trends for nominal variables were tested by logistic regression (32).

RESULTS

Vegetarianism

Vegetarians ran significantly further, consumed less alcohol and more fruit, had lower BMIs, and smaller hips than omnivorous runners (Table 1). In addition, male vegetarian runners had smaller waists and chests; lower plasma concentrations of

TABLE 1
Characteristics of vegetarian and omnivorous runners¹

	Male runners		Female runners	
	Vegetarians (n = 199)	Omnivores (n = 7054)	Vegetarians (n = 152)	Omnivores (n = 1837)
Age (y)	45.18 ± 9.36	45.90 ± 9.64	38.83 ± 9.13 ²	40.42 ± 9.53
Distance run (km)	45.60 ± 25.81 ³	38.05 ± 20.15	40.62 ± 21.34 ⁴	35.94 ± 18.25
Time run (y)	11.69 ± 6.91	12.28 ± 7.91	8.86 ± 5.16	9.02 ± 5.68
Resting pulse rate (beats/min)	62.04 ± 11.20	62.27 ± 10.51	62.15 ± 9.08 ⁴	65.28 ± 10.18
Alcohol intake (mL)	39.08 ± 69.22 ³	85.63 ± 115.31	26.27 ± 47.01 ³	52.78 ± 82.26
Dietary intake (servings/wk)				
Beef, lamb, or pork	—	2.81 ± 2.43	—	1.99 ± 1.96
Fish	—	1.66 ± 1.48	—	1.45 ± 1.33
Fruit	16.93 ± 12.25 ³	11.23 ± 8.57	14.89 ± 9.20 ³	11.50 ± 7.40
Body mass index (kg/m ²)	22.91 ± 2.43 ³	23.78 ± 2.47	20.80 ± 2.03 ²	21.28 ± 2.46
Body circumference (cm)				
Waist	83.22 ± 6.41 ³	84.95 ± 6.03	67.89 ± 6.05	68.56 ± 6.97
Hip	92.85 ± 6.53 ⁵	95.23 ± 7.09	90.72 ± 5.83 ²	91.82 ± 6.50
Chest	100.37 ± 7.24 ²	101.58 ± 6.95	87.98 ± 4.48	87.95 ± 5.38
Systolic BP (mm Hg)	122.09 ± 15.04	121.66 ± 13.37	111.85 ± 15.07	112.96 ± 13.26
Diastolic BP (mm Hg)	76.58 ± 10.54	77.06 ± 8.74	72.60 ± 10.60	71.62 ± 9.16
Total cholesterol (mmol/L)	4.91 ± 1.00 ⁴	5.08 ± 0.89	4.71 ± 0.76	4.84 ± 0.87
HDL cholesterol (mmol/L)	1.26 ± 0.32 ⁴	1.34 ± 0.35	1.61 ± 0.42	1.64 ± 0.41
LDL cholesterol (mmol/L)	3.08 ± 0.91 ²	3.22 ± 0.81	2.67 ± 0.66	2.79 ± 0.76
Triacylglycerols (mmol/L)	1.26 ± 0.71 ²	1.16 ± 0.72	0.93 ± 0.50	0.92 ± 0.63
Total:HDL cholesterol	4.13 ± 1.32	4.03 ± 1.23	3.07 ± 0.77	3.08 ± 0.86

¹ \bar{x} ± SD. BP, blood pressure.²⁻⁵ Significantly different from omnivores: ² $P < 0.05$, ³ $P < 0.0001$, ⁴ $P < 0.01$, ⁵ $P < 0.001$.

total cholesterol, HDL cholesterol, and LDL cholesterol; and higher triacylglycerol concentrations than omnivorous male runners. There were no significant differences in the number of years run, resting pulse rate, blood pressure, or ratio of total cholesterol to HDL cholesterol between vegetarians and omnivores.

The regression slopes between weekly running distance and CAD risk factors in vegetarians are given in **Table 2**. The omnivores' slopes were reported previously (2, 3) and are presented for comparison. Greater distance run by male and female vegetarians was associated with greater concentrations

of HDL cholesterol and lower circumferences of the waist, hip, and chest. Greater distance run was also associated with lower ratios of total to HDL cholesterol in male vegetarians, and with lower BMI in female vegetarians. The regression slope relating weekly distance run to HDL cholesterol, LDL cholesterol, total cholesterol:HDL cholesterol, triacylglycerols, systolic blood pressure, and circumferences of the waist, hip, and chest in vegetarians were not significantly different from those of omnivorous runners. Per kilometer run per week, the associated reduction in BMI was 0.021 ± 0.007 smaller in male vegetarians ($P = 0.002$) and diastolic blood pressure was 0.08 ± 0.04

TABLE 2Relations between reported distance run per week and adiposity, blood pressure, and plasma lipoprotein concentrations in vegetarian and omnivorous runners¹

	Male runners		Female runners	
	Vegetarians (n = 194)	Omnivores (n = 7054)	Vegetarians (n = 152)	Omnivores (n = 1837)
HDL cholesterol (mmol/L)	0.003 ± 0.001 ²	0.004 ± 0.000 ³	0.005 ± 0.002 ²	0.003 ± 0.001 ³
LDL cholesterol (mmol/L)	0.001 ± 0.003	-0.002 ± 0.000 ³	0.003 ± 0.003	-0.001 ± 0.001
Total:HDL cholesterol	-0.008 ± 0.004 ⁴	-0.012 ± 0.001 ³	-0.004 ± 0.003	-0.005 ± 0.001 ³
Triacylglycerols (mmol/L)	-0.003 ± 0.002	-0.005 ± 0.000 ³	-0.003 ± 0.002	-0.001 ± 0.001
Systolic BP (mm Hg)	-0.079 ± 0.047	-0.040 ± 0.009 ³	-0.115 ± 0.063	-0.057 ± 0.019 ²
Diastolic BP (mm Hg)	-0.006 ± 0.033	-0.028 ± 0.006 ³	-0.053 ± 0.045	-0.028 ± 0.013 ⁴
Body mass index (kg/m ²)	-0.012 ± 0.007	-0.033 ± 0.001 ³	-0.026 ± 0.008 ⁵	-0.036 ± 0.003 ³
Body circumference (cm)				
Waist	-0.059 ± 0.018 ⁵	-0.083 ± 0.004 ³	-0.075 ± 0.023 ⁵	-0.091 ± 0.009 ³
Hip	-0.051 ± 0.025 ⁴	-0.076 ± 0.006 ³	-0.066 ± 0.022 ²	-0.097 ± 0.009 ³
Chest	-0.049 ± 0.023 ⁴	-0.059 ± 0.004 ³	-0.048 ± 0.017 ²	-0.052 ± 0.007 ³

¹ Regression slope ± SE. BP, blood pressure.²⁻⁵ Slope significantly different from zero: ² $P < 0.01$, ³ $P < 0.0001$, ⁴ $P < 0.05$, ⁵ $P < 0.001$.

mm Hg greater in female vegetarians ($P = 0.05$) than in omnivores of the same sex. However, there were no significant differences between the regression slopes of vegetarians and omnivores for BMI in females ($P = 0.29$) or diastolic blood pressure in males ($P = 0.44$).

Vegans

Data for the 32 male and 30 female vegan runners were combined and multiple-regression analysis used to adjust for mean differences between sexes. The same regression slope was fitted to both male and female runners once it was established that sex did not affect the slopes for any of the variables analyzed. Greater weekly running distance was associated with greater HDL-cholesterol concentrations [by 0.006 ± 0.002 (mmol/L)/km] and lower systolic blood pressure (by 0.18 ± 0.08 mm Hg/km) and waist circumference (by 0.11 ± 0.03 cm/km) (Figure 1). The regression slopes for the remaining variables were not significant.

Alcohol

Mean plasma HDL-cholesterol concentrations by weekly running distance and alcohol intake in runners (omnivores plus vegetarians, the results being essentially identical for omnivores analyzed separately) are given in Table 3. Also shown are the regression slopes for the increase in HDL cholesterol per kilometer run stratified by alcohol intake, and the increase in HDL cholesterol per milliliter alcohol consumed per week stratified by running distance. For nearly every level of men's alcohol intake, each 24-km increment in weekly running distance was associated with significantly higher HDL cholesterol. Moreover, the regression slopes between running distance and HDL cholesterol were strongly significant regardless of alcohol consumption. Alcohol intake was associated with higher HDL cholesterol regardless of running level. The significant regression slopes between alcohol intake and HDL at all levels of weekly running distance in women runners are also shown in Table 3.

Multiple-regression analysis of all 7254 men (not shown) showed that HDL cholesterol increased (slope \pm SE) 0.0008 ± 0.0001 mmol/L per milliliter alcohol consumed per week (0.024 ± 0.001 mmol/L per ounce consumed) and 0.0034 ± 0.0002 (mmol/L)/km run, but that there was no interaction between the effects of alcohol and weekly running distance on HDL ($P = 0.43$ for interaction). Similarly, in the 2149 women runners, HDL cholesterol increased 0.0009 ± 0.0001 mmol/L per milliliter alcohol consumed per week (0.027 ± 0.003 mmol/L per ounce consumed) and increased 0.0034 ± 0.0005 (mmol/L)/km run, with no interaction between alcohol and weekly distance run ($P = 0.68$).

Plasma HDL cholesterol ≥ 1.55 mmol/L (≥ 60 mg/dL) has been recognized by the National Cholesterol Education Program as being protective against CAD, sufficiently protective to eliminate the detrimental effects of one risk factor [eg, diabetes, hypertension, cigarette smoking, family history of premature CAD, or being a male aged ≥ 45 y (33)]. A three-dimensional bar chart of the percentage of men with clinically defined high HDL cholesterol is shown in Figure 2. The percentage increases linearly with incremental increases in running distance among nondrinkers, in men

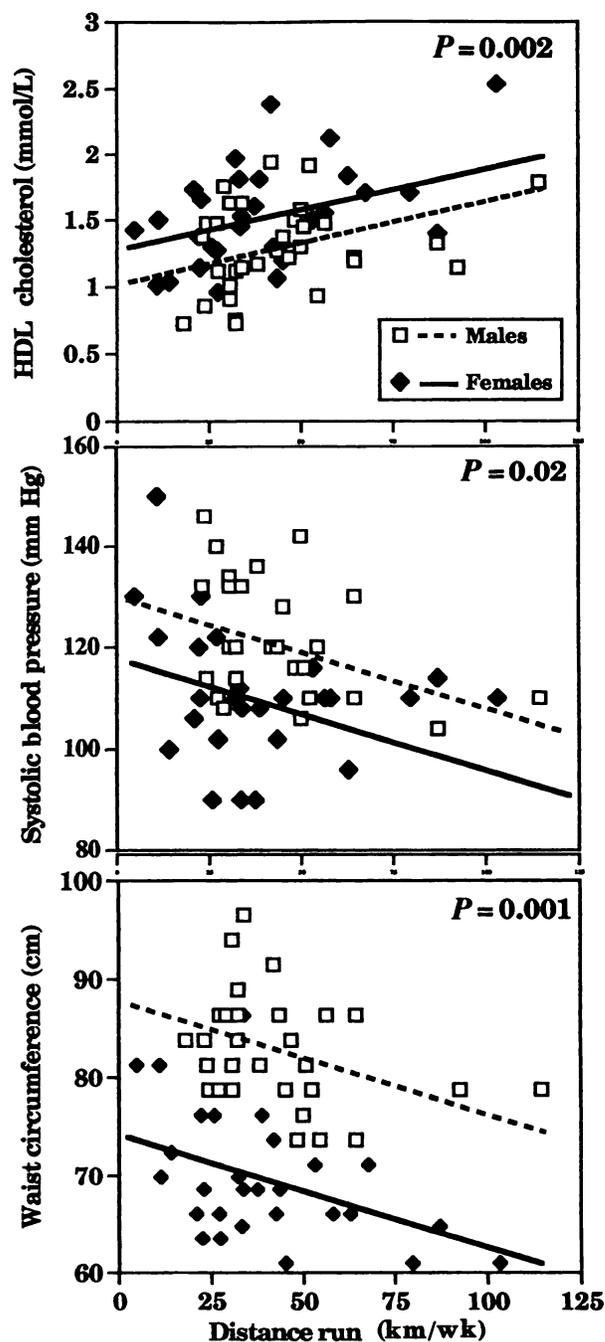


FIGURE 1. Relations between weekly running distance and HDL cholesterol, systolic blood pressure, and waist circumference in 32 male and 30 female vegan runners. The lines correspond to the regression slope from a multiple-linear-regression model that fits the same slope but has separate intercepts for male and female vegans. The slopes were not significantly different between the sexes.

consuming < 59 mL (2 oz), 60–118 mL (2–4 oz), 119–177 mL (4–6 oz), and > 177 mL (6 oz) alcohol/wk. The percentage with high HDL cholesterol increased linearly with increases in alcohol intake regardless of the distance run. Men who ran > 72 km and drank > 177 mL alcohol/wk were five times more likely to have high HDL than nondrinkers running < 24 km/wk. The percentage of women

TABLE 3
Increase in HDL cholesterol, by alcohol intake and reported weekly distance run (0 to ≥ 72 km)¹

Alcohol intake (mL/wk)	HDL cholesterol				Regression slope for increase in HDL cholesterol (mmol/L)/km
	0–24 km (0–15 miles)/wk	24–48 km (15–30 miles)/wk	48–72 km (30–45 miles)/wk	≥ 72 km (≥ 45 miles)/wk	
<i>mmol/L</i>					
Male runners					
0 (<i>n</i> = 2196)	1.16 \pm 0.01	1.23 \pm 0.01 ²	1.32 \pm 0.01 ^{2,3}	1.40 \pm 0.03 ^{2,4}	0.003 \pm 0.000 (<i>P</i> < 0.0001)
1–59 (<i>n</i> = 1984)	1.22 \pm 0.01	1.29 \pm 0.01 ²	1.37 \pm 0.02 ^{2,3}	1.46 \pm 0.03 ^{2,4}	0.003 \pm 0.000 (<i>P</i> < 0.0001)
60–118 (<i>n</i> = 1239)	1.28 \pm 0.02	1.33 \pm 0.01 ²	1.42 \pm 0.02 ^{2,3}	1.52 \pm 0.04 ^{2,4}	0.003 \pm 0.000 (<i>P</i> < 0.0001)
119–177 (<i>n</i> = 694)	1.36 \pm 0.03	1.39 \pm 0.02	1.50 \pm 0.03 ^{2,3}	1.65 \pm 0.07 ^{2,4}	0.004 \pm 0.001 (<i>P</i> < 0.0001)
≥ 178 (<i>n</i> = 1139)	1.40 \pm 0.02	1.51 \pm 0.02 ²	1.62 \pm 0.03 ^{2,3}	1.67 \pm 0.04 ^{2,3}	0.004 \pm 0.001 (<i>P</i> < 0.0001)
Regression slope for increase in HDL cholesterol (mmol/L) ⁵	0.0008 \pm 0.0001	0.0008 \pm 0.0000	0.0010 \pm 0.0001	0.0008 \pm 0.0001	
<i>P</i>	< 0.0001	< 0.0001	< 0.0001	< 0.0001	
Female runners					
0 (<i>n</i> = 754)	1.48 \pm 0.02	1.59 \pm 0.02 ²	1.62 \pm 0.03 ²	1.69 \pm 0.06 ²	0.003 \pm 0.001 (<i>P</i> < 0.0001)
1–89 (<i>n</i> = 848)	1.54 \pm 0.02	1.65 \pm 0.02 ²	1.74 \pm 0.03 ^{2,3}	1.75 \pm 0.109 ²	0.003 \pm 0.001 (<i>P</i> < 0.0001)
90–177 (<i>n</i> = 263)	1.61 \pm 0.05	1.74 \pm 0.04	1.85 \pm 0.05 ²	1.81 \pm 0.16	0.003 \pm 0.001 (<i>P</i> = 0.04)
≥ 178 (<i>n</i> = 124)	1.89 \pm 0.08	1.82 \pm 0.05	1.94 \pm 0.09	2.48 \pm 0.25 ^{2,4}	0.006 \pm 0.002 (<i>P</i> = 0.0076)
Regression slope for increase in HDL cholesterol (mmol/L) ⁵	0.0013 \pm 0.0002	0.0009 \pm 0.0002	0.0005 \pm 0.0002	0.0020 \pm 0.0006	
<i>P</i>	< 0.0001	< 0.0001	< 0.01	< 0.002	

¹ Linear trends based on regression analysis within each category of running distance or alcohol consumption.

² $\bar{x} \pm$ SE.

³ Significantly different from 0–24 km/wk, *P* \leq 0.05 (*t* test).

⁴ Significantly different from 24–48 km/wk, *P* \leq 0.05 (*t* test).

⁵ Significantly different from 48–72 km/wk, *P* \leq 0.05 (*t* test).

⁶ mmol/L per mL alcohol consumed/wk. *n* in brackets.

runners with high HDL cholesterol increased linearly with increases in alcohol intake regardless of running distance and increased linearly with weekly running distance in three of the four alcohol-consumption groups (Figure 3).

The regression slopes for blood pressure versus reported alcohol intake are shown in Table 4. The men's systolic and diastolic pressures were significantly greater with alcohol intake in all categories of running distance. The women's blood pressures were only weakly associated with alcohol intake.

Red meat and fruit consumption

The associations between adiposity and reported weekly servings of red meat and fruit are shown in Table 4. In both men and women, diets containing higher amounts of red meat were associated with higher BMIs and broader waistlines. The associations were generally significant within all distance categories. Fruit consumption was associated with low BMIs and slimmer waists in men but not in women. In men, the associations of BMI with fruit and meat diminished with greater weekly running distance. The lower BMI values associated with low red meat consumption and high fruit intake were also noted when the analyses were restricted to the 7054 male omnivores (Figure 4).

DISCUSSION

Consistent with sedentary populations (13–15, 18–21), we found that male vegetarian runners had lower BMIs; narrower

waists, hips, and chests; lower plasma concentrations of total-, HDL-, and LDL cholesterol; and higher triacylglycerol concentrations than omnivorous runners (Table 1). Female vegetarians were leaner than omnivorous female runners (Table 1). Even though less weight usually implies high HDL-cholesterol concentrations (34), male vegetarians had both lower HDL-cholesterol concentrations and lower BMIs than omnivores (Table 1). These discrepancies may have been due to the lower total fat, saturated fat, and cholesterol and higher carbohydrate, fiber, and polyunsaturated fat consumption of the vegetarians (20, 35), or to relative intakes of animal and plant protein (36, 37).

Diet and alcohol could affect lipoproteins through their effects on lipoprotein lipase activity. The lower HDL-cholesterol concentrations, higher triacylglycerol concentrations, and presumed higher carbohydrate intakes in vegetarian runners than in omnivorous runners are consistent with the increase in triacylglycerols and reduction in HDL cholesterol that Thompson et al (23) observed when they replaced fat with carbohydrates in the diets of omnivorous runners. High lipase activity of adipose (38) and skeletal muscles (39) is thought to cause, at least in part, the high HDL-cholesterol concentrations of runners. Kiens et al (40) showed that muscle lipoprotein lipase activity was nearly doubled in runners who increased their dietary fat from 43% to 54%. Roberts et al (41) showed that high-carbohydrate diets decrease the lipoprotein lipase activity of both skeletal muscle and adipose tissue of runners, and

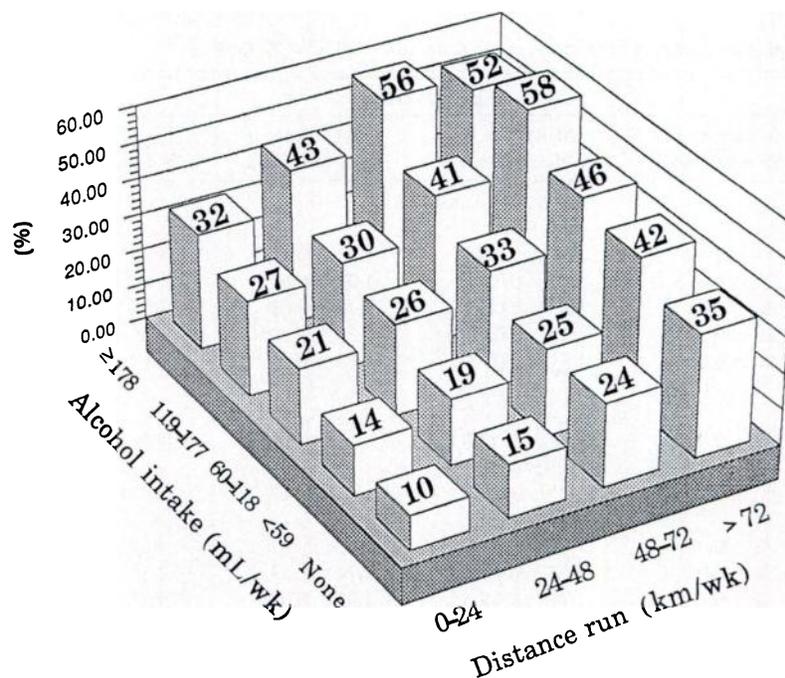


FIGURE 2. Bivariate bar chart of the percentage of 7252 omnivorous and vegetarian male runners with clinically high HDL cholesterol (≥ 1.55 mmol/L) versus reported alcohol intake and distance run per week. The percentage of men with high HDL was significantly greater with greater alcohol intake within all running distance strata ($P < 0.001$), and significantly greater with greater running distance within all alcohol strata ($P < 0.001$).

Lithell et al (42) showed a 45% reduction in skeletal muscle lipase activity of sedentary individuals when carbohydrates were increased from 31% to 48%.

The present report showed that vegetarians and vegans who ran the farthest had higher HDL-cholesterol concentrations and lower waist circumferences than those running

shorter distances (Table 2, Figure 1). The systolic blood pressures of vegans were also lower with greater running distance (Figure 1). These analyses extend the apparent health benefits of vigorous exercise, well documented in omnivores (2, 3), to vegetarians. Others have shown that acute changes in lipoproteins during an ultralong-distance

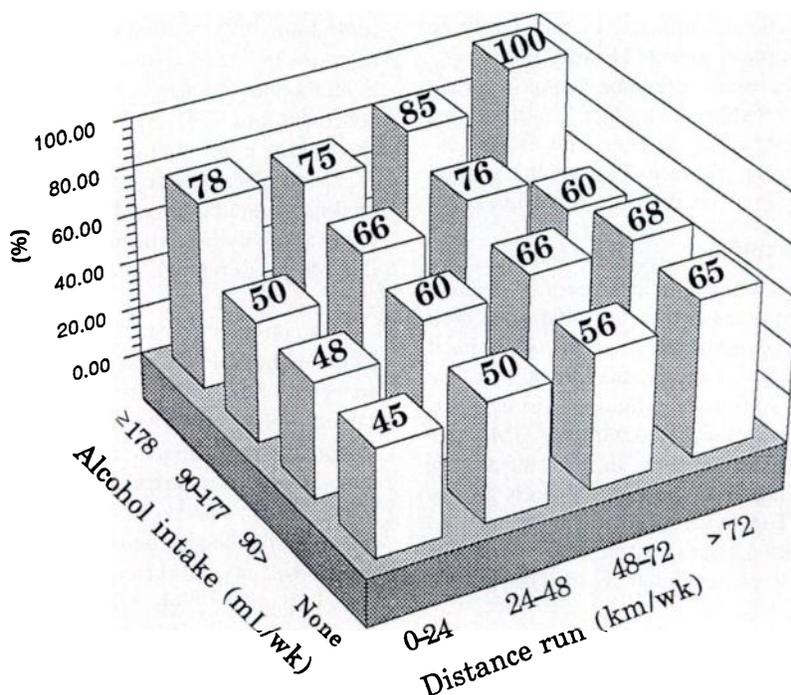


FIGURE 3. Bivariate bar chart of the percentage of 2149 omnivorous and vegetarian female runners with clinically high HDL cholesterol (≥ 1.55 mmol/L) versus reported alcohol intake and distance run per week. Note that the percentage axis is not the same as for male runners.

TABLE 4

Regression slopes (\pm SE) of blood pressure versus alcohol intake and adiposity versus red meat and fruit intake (omnivores and vegetarians combined)

	Male runners		Female runners	
	Regression slope \pm SE	P	Regression slope \pm SE	P
Systolic blood pressure (mm Hg) versus alcohol (mL/wk)				
All runners	0.0085 \pm 0.0015	< 0.0001	0.0075 \pm 0.0041	0.06
0–24 km/wk	0.0098 \pm 0.0031	0.002	–0.0074 \pm 0.0097	0.46
24–48 km/wk	0.0066 \pm 0.0021	0.002	0.0104 \pm 0.0061	0.09
48–72 km/wk	0.0097 \pm 0.0033	0.003	0.0137 \pm 0.0069	0.05
> 72 km/wk	0.0179 \pm 0.0048	0.0003	0.0025 \pm 0.0236	0.92
Diastolic blood pressure (mm Hg) versus alcohol (mL/wk)				
All runners	0.0056 \pm 0.0010	< 0.0001	0.0056 \pm 0.0028	0.05
0–24 km/wk	0.0041 \pm 0.0020	0.04	–0.0041 \pm 0.0065	0.52
24–48 km/wk	0.0048 \pm 0.0014	0.0007	0.0111 \pm 0.0043	0.009
48–72 km/wk	0.0069 \pm 0.0021	0.001	0.0065 \pm 0.0049	0.19
> 72 km/wk	0.0109 \pm 0.0033	0.0008	–0.0063 \pm 0.0170	0.71
Body mass index (kg/m²) per weekly servings of red meat				
All runners	0.128 \pm 0.012	< 0.0001	0.169 \pm 0.028	< 0.0001
0–24 km/wk	0.124 \pm 0.027	< 0.0001	0.153 \pm 0.065	0.02
24–48 km/wk	0.104 \pm 0.016	< 0.0001	0.136 \pm 0.036	0.0002
48–72 km/wk	0.082 \pm 0.024	0.0008	0.077 \pm 0.050	0.12
> 72 km/wk	0.060 \pm 0.040	0.13	0.225 \pm 0.087	0.01
Body mass index (kg/m²) per weekly servings of fruit				
All runners	–0.025 \pm 0.003	< 0.0001	–0.005 \pm 0.007	0.53
0–24 km/wk	–0.032 \pm 0.009	< 0.0003	–0.004 \pm 0.018	0.81
24–48 km/wk	–0.020 \pm 0.005	0.0001	0.001 \pm 0.010	0.94
48–72 km/wk	–0.013 \pm 0.006	0.03	0.011 \pm 0.011	0.33
> 72 km/wk	–0.003 \pm 0.007	0.66	–0.021 \pm 0.024	0.37
Waist circumference (cm) per weekly servings of red meat				
All runners	0.268 \pm 0.030	< 0.0001	0.515 \pm 0.082	< 0.0001
0–24 km/wk	0.102 \pm 0.066	0.17	0.453 \pm 0.187	0.02
24–48 km/wk	0.275 \pm 0.039	< 0.0001	0.431 \pm 0.107	0.0001
48–72 km/wk	0.139 \pm 0.059	0.02	0.304 \pm 0.174	0.08
> 72 km/wk	0.253 \pm 0.107	0.02	0.605 \pm 0.275	0.03
Waist circumference (cm) per weekly servings of fruit				
All runners	–0.061 \pm 0.008	< 0.0001	–0.017 \pm 0.021	0.41
0–24 km/wk	–0.054 \pm 0.022	0.01	–0.005 \pm 0.053	0.93
24–48 km/wk	–0.049 \pm 0.012	0.0001	–0.017 \pm 0.028	0.53
48–72 km/wk	–0.033 \pm 0.014	0.02	0.030 \pm 0.039	0.45
> 72 km/wk	–0.025 \pm 0.020	0.21	0.002 \pm 0.059	0.98

race are similar in runners consuming conventional Western and vegetarian diets (43). To our knowledge, however, the dose-response relations between weekly running distance and chronic CAD risk factor status in vegetarians are unknown.

Men and women who drink alcohol are at less risk of cardiovascular disease than nondrinkers (44). The decreased risk may be due to elevated HDL₂ and HDL₃ (45). With few exceptions (6), studies in runners show that alcohol increases HDL cholesterol (7). Our findings suggest that running distance and alcohol intake contribute independently and additively to the production of high HDL-cholesterol concentrations in runners. Men who ran > 72 km and drank > 177 mL (6 oz) alcohol/wk were five times more likely to have HDL-cholesterol concentrations \geq 1.55 mmol/L than were nondrinkers running < 24 km/wk. Our physician-supplied HDL-cholesterol values do not discriminate between HDL₂ and HDL₃. Both HDL fractions are reported to increase with exercise and alcohol; however, exercise exerts a more consistent effect on HDL₂ than on HDL₃ (5, 46)

whereas alcohol may more consistently involve HDL₃ (25, 47–50) than HDL₂. (These results may differ depending on whether the fractions are separated by density or by size, or are measured in terms of mass, protein, or cholesterol.) Acute increases in HDL cholesterol with alcohol intake are reported to involve HDL₃ in runners and HDL₂ in sedentary men (51). The chronic effects of alcohol on HDL fractions could be different in runners on the basis of the distances they run while having the same dose-response relation with total HDL cholesterol at all distances run. We found no significant increase in plasma triacylglycerols with alcohol intake at any running distance. This finding is consistent with Hartung et al's (51) observation that alcohol produces less of an increase in triacylglycerol in runners than in sedentary men. There is substantial literature documenting the increase in blood pressure by alcohol in nonrunners (52), an increase unabated by running (Table 4).

Our assessment of diet was limited in that we only questioned participants about their weekly intakes of three food items: red meat, fish, and fruit. We found that runners who

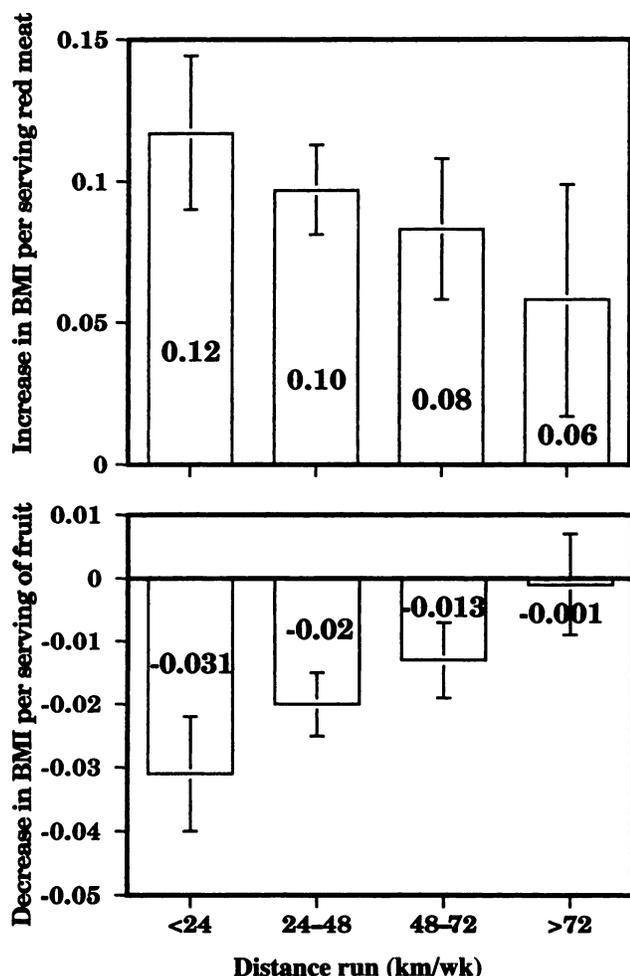


FIGURE 4. Regression slopes for BMI per serving of red meat or fruit in 7054 omnivorous men stratified by weekly running distance. The concordant relation between BMI and red meat intake and the discordant relation between BMI and fruit intake appear to diminish at greater running distances.

reported high intakes of red meat and low intakes of fruit tended to have a high BMI. Our lack of data on other food or specific nutrients prevents us from concluding that red meat or fruit per se was the cause of the observed association. High red meat and low fruit intakes could be indicators of high-energy-density diets that lead to higher energy intake before satiety (53). Alternatively, the association may reflect a dietary preference for meat in overweight men (54) rather than a causal relation between dietary composition and adiposity. The association between meat consumption and BMI was reduced at higher weekly running distances, suggesting that longer distances run may attenuate the fattening effect of red meat or the preference for red meat in heavier men.

Caveats and limitations

We note that the association reported here among diet, distance run, and CAD risk factors was based on conventional clinical measurements, which are expected to be less precise than measurements made under usual research conditions. A larger measurement error of the dependent variable does not

bias the regression slope between diet, distance run, and risk factor levels. The added error will increase the probability of a type II statistical error (ie, false-negative result) rather than a type I error (ie, false-positive result). We also note that an unbiased estimate of the dose-response relation between CAD risk factors and distance run does not require that the runners be selected at random with respect to running distance. However, volunteers are expected to differ from nonvolunteers and therefore caution is warranted when extrapolating our estimates to all runners. Only 56 000 of the $\approx 290\,000$ subjects mailed questionnaires responded, and of these, 9242 were used in the analysis.

Official guidelines from the Centers for Disease Control and Prevention assert that the majority of health benefits from physical activity can be obtained by walking 16–23 km/wk (55), the energy equivalent of running 8–12 km (56). Ninety-five percent of the male and 93% of the female vegetarian runners exceeded this minimum recommended amount. As suggested by the data in Table 2, vegetarians who exceed the recommended activity level may significantly increase their HDL-cholesterol concentration and lose significant amounts of weight. Our analyses suggest that vigorous exercise provides important health benefits beyond those obtained by eating vegetarian diets or consuming moderate amounts of alcohol alone. ■

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