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ORIGINAL INVESTIGATIONS

Dose of Jogging and Long-Term Mortality

The Copenhagen City Heart Study

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ABSTRACT

BACKGROUND People who are physically active have at least a 30% lower risk of death during follow-up compared with those who are inactive. However, the ideal dose of exercise for improving longevity is uncertain.

OBJECTIVES The aim of this study was to investigate the association between jogging and long-term, all-cause mortality by focusing specifically on the effects of pace, quantity, and frequency of jogging.

METHODS As part of the Copenhagen City Heart Study, 1,098 healthy joggers and 3,950 healthy nonjoggers have been prospectively followed up since 2001. Cox proportional hazards regression analysis was performed with age as the underlying time scale and delayed entry.

RESULTS Compared with sedentary nonjoggers, 1 to 2.4 h of jogging per week was associated with the lowest mortality (multivariable hazard ratio [HR]: 0.29; 95% confidence interval [CI]: 0.11 to 0.80). The optimal frequency of jogging was 2 to 3 times per week (HR: 0.32; 95% CI: 0.15 to 0.69) or ≤1 time per week (HR: 0.29; 95% CI: 0.12 to 0.72). The optimal pace was slow (HR: 0.51; 95% CI: 0.24 to 1.10) or average (HR: 0.38; 95% CI: 0.22 to 0.66). The joggers were divided into light, moderate, and strenuous joggers. The lowest HR for mortality was found in light joggers (HR: 0.22; 95% CI: 0.10 to 0.47), followed by moderate joggers (HR: 0.66; 95% CI: 0.32 to 1.38) and strenuous joggers (HR: 1.97; 95% CI: 0.48 to 8.14).

CONCLUSIONS The findings suggest a U-shaped association between all-cause mortality and dose of jogging as calibrated by pace, quantity, and frequency of jogging. Light and moderate joggers have lower mortality than sedentary nonjoggers, whereas strenuous joggers have a mortality rate not statistically different from that of the sedentary group. (J Am Coll Cardiol 2015;65:411-9) © 2015 by the American College of Cardiology Foundation.

The most famous case of sudden death in connection with running is that of Pheidippides, a professional running courier who in 490 B.C. is believed to have run from Marathon to Athens, Greece, a distance of approximately 25 miles, to bring news of the Athenian victory over the Persians. Upon reaching the Athenian Agora, he exclaimed "Nike!" ("victory"), collapsed, and died. Some historians, believing this is a myth, favor another version: that after his run from Marathon to Athens, Pheidippides continued to Sparta for military help. He ran the distance from Athens to Sparta, 137 miles, in 48 h (1).

In 1953, Morris et al. (2) published a paper showing that mortality from coronary heart disease (CHD) was more than twice as high in sedentary London bus

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ABBREVIATIONS AND ACRONYMS

CHD = coronary heart disease

CI = confidence interval

CV = cardiovascular

DM = diabetes mellitus

HR = hazard ratio

METs = metabolic equivalents

drivers compared with physically active conductors. This pioneering work gave rise to the hypothesis that physical activity might be of importance in prevention of CHD.

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As part of a report from the President's Council on Youth Fitness, a message in 1965 from President Lyndon B. Johnson stated the following: "Medical evidence tells us that our hearts, lungs, muscles and even our minds need the effects of regular and vigorous exercise" (3). Since then, numerous recommendations about physical fitness in leisure time have been published, and they have in general recommended that every adult should perform >30 min of moderate-intensity physical activity preferably every day of the week. National guidelines also call for a combination of moderate- and vigorous-intensity activity, such as walking briskly for 30 min twice a week and then jogging for 20 min on 2 other days. The data strongly support an inverse association between regular exercise and mortality. In longitudinal studies, physically active men and women have an approximately 30% lower risk of death during follow-up compared with inactive people. No upper threshold for physical activity has ever been recommended (4-6).

In 1969, the first running race in Europe (the Eremitage Race) took place in Denmark; 2,344 men and women finished the distance of 7.6 miles. Unfortunately, a 46-year-old naval officer died of a myocardial infarction during this event. As a result of this death, the event organizers hesitated to continue running races, reasoning that perhaps they were too strenuous and possibly dangerous for the general population. (The race has continued and has gained in popularity.) Subsequently, during the 1970s, when jogging gained momentum, several reports of deaths during jogging were published (7-13).

The Copenhagen City Heart Study (14,15) reported that the relative intensity of walking and cycling and not the duration was of most importance in relation to all-cause and CHD mortality. Subsequently, the Copenhagen City Heart Study showed that the increase in survival among joggers was 6.2 years in men and 5.6 years in women. This particular analysis was performed in a random sample of 1,878 joggers who were followed for up to 35 years and compared with 16,827 nonjoggers. Jogging up to 2.5 h per week at a slow or average pace and a frequency of ≤3 times per week was associated with the lowest mortality. Those who jogged >4 h per week, at a fast pace, and >3 times per week appeared to lose many of the longevity benefits noted with less strenuous doses of jogging (16). This finding was somewhat surprising.

In the present study, we explore in more detail whether a U-shaped association exists between mortality and dose of jogging as calibrated by pace, quantity, and frequency of jogging.

METHODS

STUDY POPULATION. The prospective Copenhagen City Heart Study is composed of a random sample of 19,329 white men and women between 20 and 93 years of age drawn from the Copenhagen Population Register as of January 1, 1976. The current study used the fourth examination from 2001 to 2003. All subjects from the original sample were invited to all subsequent examinations, and a new random sample of younger men and women was included. Details have been described elsewhere (1,17).

In the present analyses, we excluded participants with a history of CHD (n = 513), stroke (n = 262), and cancer (n = 469), leaving 5,048 men and women (1,098 healthy joggers and 3,950 healthy nonjoggers) for analyses.

SURVEY METHODS. Established procedures and examinations for cardiovascular (CV) epidemiological surveys were used (18). Physical activity in leisure time was graded as 1 of 4 levels in all 4 surveys using The Copenhagen City Heart Study Leisure Time Physical Activity Questionnaire (1). Levels of activity were defined as follows: group I, almost entirely sedentary (e.g., reading, watching television or movies, engaging in light physical activity, such as walking or biking for <2 h per week); group II, light physical activity for 2 to 4 h per week; group III, light physical activity for more than 4 h per week or more vigorous activity for 2 to 4 h per week (e.g., brisk walking, fast biking, heavy gardening, sports that cause perspiration or exhaustion); and group IV, high vigorous physical activity for more than 4 h per week or regular heavy exercise or competitive sports several times per week. The activity questionnaire has been shown to discriminate between sedentary people and their more active counterparts with respect to maximal oxygen uptake (19).

In the 2001 to 2003 survey, we included questions on the weekly quantity of jogging, frequency of jogging, and the subject's own perception of pace (slow, average, fast). We found that a relative scale of pace (intensity) is more appropriate than an absolute scale when the age span is very wide (20 to 95 years) and when the participants have wide differences in levels of physical fitness. Compared with the

TABLE 1 Joggers Categorized as Light Joggers, Moderate Joggers, or Strenuous Joggers on the Basis of Self-Reported Pace, Quantity, and Frequency of Jogging

	Jogging Pace								
	Slow			Average			Fast		
	<2.5 h/week	2.5–4 h/week	>4 h/week	<2.5 h/week	2.5–4 h/week	>4 h/week	<2.5 h/week	2.5–4 h/week	>4 h/week
Frequency of jogging									
≤3 times/week	Light	Moderate	Moderate	Light	Moderate	Moderate	Moderate	Moderate	Strenuous
>3 times/week	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Strenuous	Strenuous

nonjoggers in group I (almost entirely sedentary), the hazard ratio (HR) of mortality for joggers by pace, quantity, and frequency of jogging was calculated. The joggers also were subdivided into 3 groups according to dose of jogging (Table 1). Light joggers had a slow or average pace, approximately 5 miles per hour (corresponding to 6 metabolic equivalents [METs]), and <2.5 h of jogging per week with a frequency of ≤3 times per week. Moderate joggers had a slow or average pace, ≥2.5 h of jogging per week with a frequency of ≤3 times per week or fast pace, ≤4 h of jogging per week with a frequency of ≤3 times per week or slow or average pace with a frequency of >3 times per week or fast pace, <2.5 h of jogging per week with a frequency of >3 times per week. Strenuous joggers had a fast pace of more than 7 miles per hour (≥12 METs) and either >4 h of jogging per week or ≥2.5 h of jogging per week with a frequency of >3 times per week.

A self-administered questionnaire regarding physical activity, smoking, alcohol consumption, socioeconomic status, CHD, stroke, lung disease, cancer, diabetes mellitus (DM), and family history was completed and reviewed. Height, weight, and blood pressure (London School of Hygiene sphygmomanometer) as well as results of electrocardiography and data from a comprehensive investigation of a blood sample were obtained (17).

The Committee on Biomedical Research Ethics for the Capital Region in Denmark (H-KF-01-144/01) approved the study. All participants gave written consent.

ENDPOINTS. Participants were followed up from their first examination to April 2013 or death by using their unique personal identification number in the national Danish Central Person Register (all-cause deaths). During the observation period, Denmark shifted from the 8th revision of the International Classification of Diseases to the 10th revision. All hospital admissions were obtained from the national Danish Patient Registry from 1977 to April 2013 for CHD codes 410 to 414 until January 1994 and thereafter codes I20 to I25, for stroke codes 430 to 438 and I60 to I68 or G45, and for cancer codes 140 to 209 and C00 to D09. The completion rate of follow-up for death was nearly 100%.

STATISTICAL ANALYSIS. For demographics, Fisher exact test was used for categorical variables and analysis of variance for continuous variables of pace, quantity, and frequency of jogging.

In the multivariable analyses, we adjusted for the following potential confounders: age, sex, smoking (never, former, 1 to 14 g/day of tobacco, ≥15 g/day of tobacco; 1 cigarette = 1 g of tobacco, 1 cheroot = 3 g of tobacco, and 1 cigar = 5 g of tobacco), alcohol intake (never, 1 to 21 drinks/week for men and 1 to 14 drinks/week for women, >21 drinks/week for men and >14 drinks/week for women), education (<8 years, 8 to 10 years, >10 years in school), and DM (self-reported or a nonfasting blood glucose level ≥200 mg/dl).

The association between jogging and all-cause mortality was examined with Cox proportional hazards regression analysis, with age as the underlying time scale and delayed entry accordingly. The assumption of proportionality in the Cox regression model was tested with the Lin, Wei, and Ying score process test (20).

RESULTS

Baseline characteristics at the 2001 to 2003 examination of the sedentary nonjoggers and joggers, stratified by their quantity, frequency, and pace of jogging, are presented in Table 2. At baseline, 1,098 were joggers (593 men and 505 women) and 413 were sedentary nonjoggers. The latter group represented 9% of our population 50 years of age and older. We registered 28 deaths among joggers and 128 deaths among sedentary nonjoggers. In general, the joggers were younger, had lower blood pressure and body mass index, and had a lower prevalence of smoking and DM. There was a massive overlap in age range between joggers (20 to 86 years) and sedentary nonjoggers (21 to 92 years). The flexible age adjustment ensured by the Cox model made comparisons

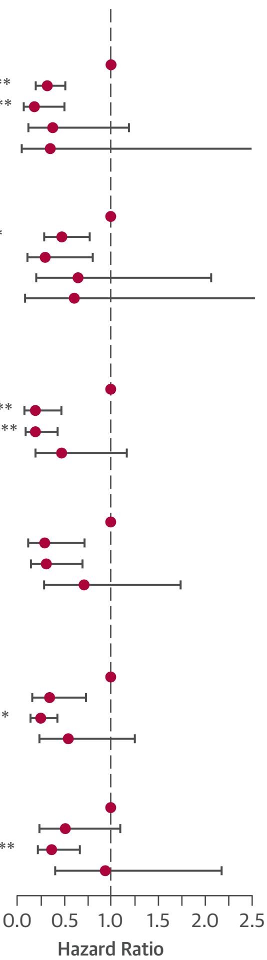
TABLE 2 Baseline Characteristics for the 1,098 Joggers and 413 Sedentary Nonjoggers in the Copenhagen City Heart Study

	Sedentary Nonjoggers	Joggers: Quantity of Jogging (h/week)					Joggers: Frequency of Jogging (times/week)				Joggers: Jogging Pace				Joggers: Combination of Quantity/Frequency/Pace			
	(n = 413)	≤1 (n = 640)	1–2.4 (n = 286)	2.5–4 (n = 122)	>4 (n = 50)	p Value	≤1 (n = 323)	2–3 (n = 474)	>3 (n = 84)	p Value	Slow (n = 178)	Average (n = 704)	Fast (n = 201)	p Value	Light (n = 576)	Moderate (n = 262)	Strenuous (n = 40)	p Value
Age, yrs	61.3 ± 16.2	44.2 ± 13.9	40.5 ± 13.6	40.2 ± 13.0	38.8 ± 13.1	<0.001	41.3 ± 13.3	41.2 ± 13.3	45.7 ± 15.2	0.02	45.1 ± 14.9	42.9 ± 13.4	38.4 ± 12.9	<0.001	42.3 ± 13.6	40.9 ± 13.2	37.0 ± 13.9	0.03
Men	178 (43.1)	331 (51.7)	150 (52.4)	76 (62.3)	36 (72.0)	0.009	189 (58.5)	251 (53.0)	51 (60.7)	0.19	58 (32.6)	375 (53.3)	153 (76.1)	<0.001	283 (49.1)	176 (67.2)	32 (80.0)	<0.001
Smoking						0.24				0.09				0.02				0.06
Never	105 (26.0)	294 (46.6)	136 (48.1)	52 (45.2)	24 (51.1)		157 (49.5)	221 (47.6)	38 (47.5)		75 (42.4)	314 (45.3)	112 (58.3)		267 (46.8)	123 (48.8)	24 (66.7)	
Former	106 (26.2)	171 (27.1)	85 (30.0)	42 (36.5)	10 (21.3)		85 (26.8)	135 (29.1)	29 (36.3)		50 (28.2)	202 (29.1)	50 (26.0)		159 (27.8)	83 (32.9)	6 (16.7)	
1–14 g/day of tobacco	53 (13.1)	92 (14.6)	38 (13.4)	10 (8.7)	10 (21.3)		34 (10.7)	70 (15.1)	6 (7.5)		30 (16.9)	101 (14.6)	18 (9.4)		82 (14.4)	24 (9.5)	5 (13.9)	
≥15 g/day of tobacco	140 (34.7)	74 (11.7)	24 (8.5)	11 (9.6)	3 (6.4)		41 (12.9)	38 (8.2)	7 (8.8)		22 (12.4)	76 (11.0)	12 (6.2)		63 (11.0)	22 (8.7)	1 (2.8)	
Years of education						0.02				0.006				0.10				0.53
<8	133 (32.6)	26 (4.1)	8 (2.8)	1 (0.8)	2 (4.0)		11 (3.4)	10 (2.1)	9 (10.7)		5 (2.8)	23 (3.3)	6 (3.0)		19 (3.3)	8 (3.1)	2 (5.0)	
8–10	144 (35.3)	147 (23.0)	43 (15.0)	27 (22.1)	6 (12.0)		64 (19.8)	88 (18.6)	19 (22.6)		44 (24.7)	147 (20.9)	28 (13.9)		116 (20.1)	52 (19.8)	4 (10.0)	
>10	131 (32.1)	467 (73.0)	235 (82.2)	94 (77.0)	42 (84.0)		248 (76.8)	376 (79.3)	56 (66.7)		129 (72.5)	534 (75.9)	167 (83.1)		441 (76.6)	202 (77.1)	34 (85.0)	
Alcohol consumption						0.59				0.08				0.003				0.81
Never	125 (30.5)	105 (16.4)	38 (13.3)	16 (13.1)	10 (20.0)		40 (12.4)	67 (14.1)	19 (22.6)		42 (23.7)	104 (14.8)	19 (9.5)		79 (13.7)	42 (16.0)	4 (10.0)	
1–14/1–21 drinks/week	223 (54.4)	434 (67.9)	203 (71.0)	91 (74.6)	31 (62.0)		229 (70.9)	346 (73.0)	51 (60.7)		107 (60.5)	491 (69.7)	153 (76.1)		414 (71.9)	182 (69.5)	29 (72.5)	
>14/>21 drinks/week	62 (15.1)	100 (15.6)	45 (15.7)	15 (12.3)	9 (18.0)		54 (16.7)	61 (12.9)	14 (16.7)		28 (15.8)	109 (15.5)	29 (14.4)		83 (14.4)	38 (14.5)	7 (17.5)	
Body mass index, kg/m^2	27.5 ± 5.5	24.3 ± 3.3	23.7 ± 2.9	24.3 ± 2.9	24.3 ± 3.0	0.05	24.1 ± 3.2	24.0 ± 3.1	24.0 ± 2.8	0.85	24.8 ± 3.7	24.2 ± 3.2	23.5 ± 2.3	<0.001	24.1 ± 3.2	24.1 ± 2.9	23.2 ± 1.7	0.22
Systolic blood pressure, mm Hg	139.2 ± 22.8	124.8 ± 17.5	124.7 ± 18.4	124.4 ± 14.6	127.3 ± 17.0	0.78	124.4 ± 16.6	124.3 ± 17.7	127.4 ± 18.6	0.33	125.0 ± 21.0	124.5 ± 17.1	125.6 ± 14.9	0.75	123.8 ± 17.9	126.7 ± 16.4	123.3 ± 14.5	0.07
Diastolic blood pressure, mm Hg	78.9 ± 12.3	75.5 ± 10.9	74.6 ± 11.8	75.1 ± 9.9	79.3 ± 12.7	0.06	75.3 ± 11.1	74.9 ± 11.4	76.6 ± 11.4	0.44	75.3 ± 11.7	75.5 ± 11.3	74.8 ± 10.0	0.76	74.8 ± 11.6	76.2 ± 10.5	74.7 ± 11.1	0.26
Use of blood pressure medication	80 (19.6)	17 (2.7)	10 (3.5)	4 (3.3)	3 (6.0)	0.46	9 (2.8)	14 (3.0)	4 (4.8)	0.59	9 (5.1)	21 (3.0)	2 (1.0)	0.05	16 (2.8)	9 (3.5)	0 (0.0)	0.66
Diabetes mellitus	32 (7.8)	12 (1.9)	4 (1.4)	0 (0.0)	0 (0.0)	0.52	6 (1.9)	9 (1.9)	1 (1.2)	>0.99	2 (1.1)	13 (1.8)	1 (0.5)	0.43	14 (2.4)	2 (0.8)	0 (0.0)	0.27

Values are mean ± SD or n (%).

FIGURE 1 Jogging Variables

Jogging variable	No. of Participants	All-cause mortality: Deaths	HR (95% CI)
Quantity of jogging			
Adjusted for age and sex			
Sedentary nonjogger (reference)	413	128	1.00
<1 hour/week	640	20	0.32 (0.20-0.51)****
1-2.4 hours/week	286	4	0.18 (0.07-0.50)****
2.5-4 hours/week	122	3	0.38 (0.12-1.19)*
>4 hours/week	50	1	0.35 (0.05-2.54)
Adjusted for age, sex, smoking, alcohol intake, education, and diabetes			
Sedentary nonjogger (reference)	394	120	1.00
<1 hour/week	629	20	0.47 (0.29-0.77)***
1-2.4 hours/week	282	4	0.29 (0.11-0.80)**
2.5-4 hours/week	115	3	0.65 (0.20-2.07)
>4 hours/week	47	1	0.60 (0.08-4.36)
Frequency of jogging			
Adjusted for age and sex			
Sedentary nonjogger (reference)	413	128	1.00
≤1 time/week	323	5	0.19 (0.08-0.47)****
2-3 times/week	474	7	0.20 (0.09-0.43)****
>3 times/week	84	5	0.48 (0.19-1.17)
Adjusted for age, sex, smoking, alcohol intake, education, and diabetes			
Sedentary nonjogger (reference)	394	120	1.00
≤1 time/week	317	5	0.29 (0.12-0.72)***
2-3 times/week	463	7	0.32 (0.15-0.69)***
>3 times/week	80	5	0.71 (0.29-1.75)
Jogging pace			
Adjusted for age and sex			
Sedentary nonjogger (reference)	413	128	1.00
Slow	178	7	0.34 (0.16-0.73)***
Average	704	15	0.25 (0.14-0.43)****
Fast	201	6	0.54 (0.24-1.26)
Adjusted for age, sex, smoking, alcohol intake, education, and diabetes			
Sedentary nonjogger (reference)	394	120	1.00
Slow	176	7	0.51 (0.24-1.10)*
Average	692	15	0.38 (0.22-0.66)****
Fast	192	6	0.94 (0.40-2.18)



Quantity, frequency, and pace of jogging in relation to all-cause mortality. HR = hazard ratio. *p < 0.10; **p < 0.05; ***p < 0.01; ****p < 0.001.

between joggers and sedentary nonjoggers feasible, although there were large differences in mean age in these groups. The average number of years of jogging was 10.1. There was no interaction between sex and either pace (p = 0.27), quantity (p = 0.26), or frequency (p = 0.25) of jogging.

QUANTITY, FREQUENCY, AND PACE OF JOGGING AND RISK OF MORTALITY. Figure 1 shows the all-cause mortality HRs, adjusted for age and sex and multivariable adjusted for joggers compared with sedentary nonjoggers.

Jogging from 1 to 2.4 h per week was associated with the lowest mortality (multivariable HR: 0.29; 95% confidence interval [CI]: 0.11 to 0.80). The risk estimates for the subgroups with greater quantities of jogging were not significantly different from those for the sedentary group; jogging from 2.5 to 4 h per week yielded an HR of 0.65 (95% CI: 0.20 to 2.07).

The optimal frequency of jogging was 2 to 3 times per week (HR: 0.32; 95% CI: 0.15 to 0.69) or ≤1 time per week (HR: 0.29; 95% CI: 0.12 to 0.72). The risk estimates for jogging >3 times per week were not statistically different from those for the sedentary group.

Lower mortality rates were associated with a slow jogging pace (HR: 0.51; 95% CI: 0.24 to 1.10) and moderate jogging pace (HR: 0.38; 95% CI: 0.22 to 0.66). Notably, the group of fast-paced joggers had almost the same risk of mortality as the sedentary nonjoggers (HR: 0.94; 95% CI: 0.40 to 2.18).

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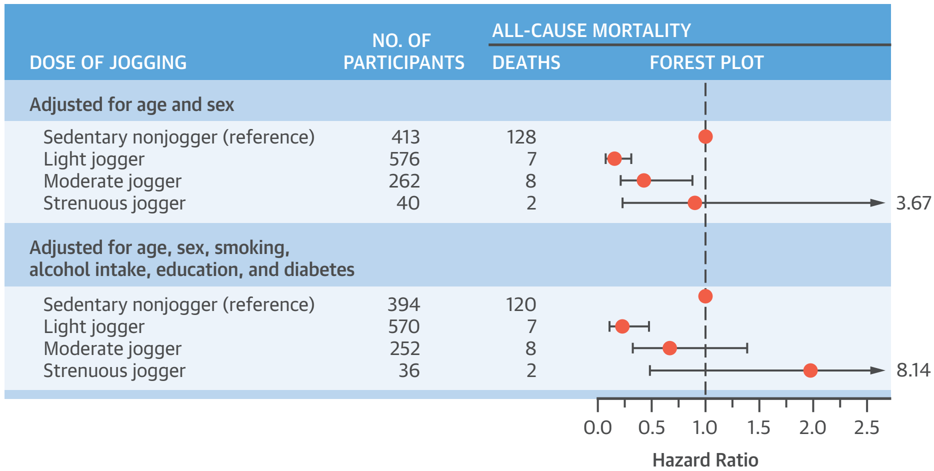
CENTRAL ILLUSTRATION **Dose of Jogging and Long-Term Mortality**



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Forest plot indicating all-cause mortality in light, moderate, and strenuous joggers compared with sedentary nonjoggers.

SURVIVAL IN LIGHT, MODERATE, AND STRENUOUS JOGGERS. The joggers were divided into 3 groups (light, moderate, and strenuous joggers), which were then compared with the sedentary nonjoggers group. The Central Illustration shows that light joggers had the most favorable fully adjusted HR for all-cause mortality (0.22; 95% CI: 0.10 to 0.47); the HR for moderate joggers was 0.66 (95% CI: 0.32 to 1.38) and for strenuous joggers was 1.97 (95% CI: 0.48 to 8.14). Compared with light joggers, the moderate and strenuous joggers had significantly higher adjusted HRs (3.06 [95% CI: 1.11 to 8.45] and 9.08 [95% CI: 1.87 to 44.01], respectively). These findings suggest that there is a U-shaped association between jogging and mortality.

CAUSES OF DEATHS AMONG JOGGERS AND SEDENTARY NONJOGGERS. The small number of deaths in each group made it impossible to report different causes of deaths, but we previously presented cause-specific mortality among 1,878 joggers and 16,423 nonjoggers followed up for a maximum of 35 years (16). The adjusted HRs for CHD were 0.32 for men (95% CI: 0.15 to 0.67) and 0.48 for women (95% CI: 0.12 to 1.96), for respiratory diseases were 0.85 for men (95% CI: 0.39 to 1.83) and 0.87 for women (95% CI: 0.27 to 2.84), for stroke were 0.95 for men (95% CI: 0.42 to 2.18) and 0.85 for women (95% CI: 0.21 to 3.42), and for cancer were 0.82 for men (95% CI: 0.58 to 1.16) and 0.68 for women (95% CI: 0.38 to 1.23).

DISCUSSION

In this prospective, observational study, which included 1,098 healthy joggers between 20 and 86 years of age who were followed up for 12 years, we compared the long-term all-cause mortality rates of light, moderate, and strenuous joggers with the long-term mortality rate of sedentary nonjoggers. We found a U-shaped association between jogging and mortality. The lowest mortality was among light joggers in relation to pace, quantity, and frequency of jogging. Moderate joggers had a significantly higher mortality rate compared with light joggers, but it was still lower than that of sedentary nonjoggers, whereas strenuous joggers had a mortality rate that was not statistically different from that of sedentary nonjoggers (Central Illustration).

It should be emphasized that even slow jogging (6 METs) corresponds to vigorous exercise and strenuous jogging corresponds to very heavy vigorous exercise (≥12 METs), which when performed for decades could pose health risks, especially to the CV system.

A recently published study of 55,000 adults between 18 and 100 years of age who were followed up for a mean of 15 years, using comprehensive analyses that controlled for potential confounding factors, reported that runners as compared with nonrunners had 30% and 45% lower risks of all-cause and CV mortality, respectively, with a mean improvement in life expectancy of 3 years (21).

Again, however, maximal CV longevity benefits were noted with moderate doses of running (specifically 6 to 12 miles per week), running durations of approximately 50 to 120 min per week, a running frequency of approximately 3 times per week, and a modest pace of approximately 6 to 7 miles per hour. Our findings are aligned in that a U-shaped or reverse J-shaped relationship was noted, whereas higher doses of running were associated with loss of approximately one-third to one-half of the CV mortality benefits linked to moderate doses of running. In fact, the most favorable running regimen for reducing CV mortality in that study was 6 miles per week, 3 running days per week, and a pace of 7 miles per hour.

Other studies that did not focus solely on joggers but instead on cumulative doses of exercise have also reported U-shaped or reverse J-shaped curves depicting the relationship between leisure-time physical activity and mortality (22–24). A number of large studies have found an inverse association between physical activity in leisure time and morbidity/mortality from CHD and all-cause mortality (4–6,25–33). However, even the first such landmark study by Paffenbarger et al. (22) found that death rates declined steadily as energy expended on physical activity increased from <500 kcal per week to 3,500 kcal per week, beyond which mortality rates increased again. A weekly energy expenditure of 3,500 kcal is approximately equivalent to that required for running 35 miles, which is in the range of the upper limits for incremental health benefits from strenuous exercise identified by several recent large epidemiological reports (34–37). These studies found that a weekly cumulative dose of approximately 30 miles of running or 46 miles of walking is approximately the safe upper limit for optimizing long-term CV health and life expectancy (34–37).

Over the past 35 years, the number of Americans who jog has risen 20-fold. In 2013, the number of U.S. joggers was estimated to be 54 million. The number of marathon finishers has risen from 25,000 in 1976 to 541,000 in 2013, and approximately 1,960,000 people completed a half-marathon in 2013 (38). The incidence of sudden cardiac death in these endurance races was very low in absolute numbers, although the rate was significantly higher (almost 4-fold) in marathons (1.01 per 100,000; 95% CI: 0.72 to 1.38) than in half-marathons (0.27; 95% CI: 0.17 to 0.43) (14). Triathlons, which can involve even higher doses of strenuous exercise than marathons, also have been growing rapidly in popularity. In 1999, there were 127,824 members of USA Triathlon; this number grew to 510,859 in 2012 (39).

Long-term strenuous endurance exercise may induce pathological structural remodeling of the heart and large arteries. Emerging data suggest that long-term training for and competing in extreme endurance events such as marathons, ultra-marathons, ironman distance triathlons, and very long distance bicycle races can cause transient acute volume overload of the atria and right ventricle, with transient reductions in right ventricular ejection fraction and elevation of cardiac biomarker levels (40). Months to years of repetitive injury in some people may lead to patchy myocardial fibrosis, particularly in the atria, interventricular septum, and right ventricle, creating a substrate for atrial and ventricular arrhythmias (41). Additionally, long-term excessive exercise may be associated with coronary artery calcification, diastolic dysfunction, and large artery wall stiffening (42). To our knowledge, there has been no study of the longevity of marathon, half-marathon, or triathlon participants, but such studies would clearly be informative.

Higher doses of running are associated with progressively better cardiorespiratory fitness as well as dose-dependent improvements in many CV risk factors, such as abdominal adiposity, glucose metabolism, and high-density lipoprotein cholesterol level, along with preservation of youthful levels of left ventricular compliance (43). Even so, accumulating evidence suggests that activity patterns that are ideal for promoting long-term CV health and enhancing life expectancy may differ from the high-intensity, high-volume endurance training regimens used for developing peak cardiac performance and maximum cardiorespiratory fitness (44).

STUDY LIMITATIONS. The strengths include the random population sample, prospective design, detailed information about potential confounding variables, and almost 100% complete follow-up. The limitations include the fact that the information about jogging used in the present analyses was solely obtained at the fourth examination (between 2001 and 2003); repeated assessments of jogging during follow-up would have strengthened the design. Even so, previous analyses suggest that jogging seems to be a fairly stable habit among Copenhagen residents (16). However, because our study was observational and not randomized, we can only show associations and not casual relationships. Through exclusion of all participants who had CHD, stroke, or DM, we partly ruled out a self-selection bias against jogging among sick subjects. Furthermore, we repeated the analyses after excluding all deaths within the first 2 years of follow-up and found similar results.

CONCLUSIONS

Our results, which were obtained by using a large random sample of men and women, showed that although joggers as a group appear to live longer than sedentary nonjoggers, light joggers and moderate joggers have lower mortality rates than sedentary nonjoggers, whereas strenuous joggers have a mortality rate that is not statistically different from that of the sedentary group. The U-shaped association suggests the existence of an upper limit for exercise dosing that is optimal for health benefits. This hypothesis should be investigated further and, if confirmed, may eventually need to be incorporated into healthy physical activity guidelines for the general public.

On the basis of current knowledge, if the goal is to decrease the risk of death and improve life expectancy, going for a leisurely jog a few times per week at a moderate pace is a good strategy. Higher doses of running are not only unnecessary but may also erode some of the remarkable longevity benefits conferred by lower doses of running. In this study, the dose of running that was most favorable for reducing mortality was jogging 1 to 2.4 h per week, with no more than 3 running days per week, at a slow or average pace. Many adults will perceive this to be a goal that is practical, achievable, and sustainable.

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PERSPECTIVES

COMPETENCY IN MEDICAL KNOWLEDGE: Compared with more sedentary people, people who jog regularly exhibit a significantly lower all-cause mortality rate. Those who jog lightly or moderately appear to benefit more than strenuous joggers, whose long-term mortality rate is similar to that of sedentary people.

COMPETENCY IN PATIENT CARE: When prescribing exercise to improve longevity, strenuous exercise is not necessary and might reduce the health benefits of light to moderate physical activity.

TRANSLATIONAL OUTLOOK: Further studies are needed to explore the mechanisms by which excessively strenuous exercise adversely affects longevity before the pattern of association between exercise intensity and long-term mortality can be incorporated into physical activity recommendations for the general public.

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