Published in final edited form as:

J Hypertens. 2008 June ; 26(6): 1085–1093. doi:10.1097/HJH.0b013e3282fb81dc.

A cohort study of incident hypertension in relation to changes in vigorous physical activity in men and women

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Abstract

Objective—To assess the dose–response relationship between changes in vigorous exercise (running distance, Δ km per week) and physician-diagnosed hypertension.

Design—Twenty-four thousand, five hundred and fifty men and 10 113 women were followed prospectively for (mean $\pm$ SD) 7.8 ± 1.8 and 7.5 ± 2.0 years, respectively.

Results—Among those who maintained their running distance within ± 5 km per week (5841 men), logistic regression showed that the log odds for hypertension was significantly lower for those who ran longer distances (coefficient $\pm$ SE: -0.019 ± 0.003 per km per week; $P < 0.0001$) even when adjusted for body mass index (-0.010 ± 0.003 per km per week; $P = 0.002$). Analyses of all 24 550 male and 10 113 female runners showed that the log odds for hypertension declined significantly in relation to Δ km per week in men (-0.009 ± 0.001 ; $P < 0.0001$) and women (-0.006 ± 0.003 ; $P = 0.03$), which remained significant when adjusted for body mass index in men (-0.005 ± 0.001 ; $P < 0.0001$) but not in women (-0.004 ± 0.003 ; $P = 0.13$). In both sexes, the decline was related to the distance run at the end of follow-up but not at baseline. Compared with men who ran less than 8 km per week, the age-specific rate for incident hypertension in those who ran more than 40 km per week at the end of follow-up was 80% lower in those aged between 35 and 44 years, 66% lower in those between 45 and 54 years, 69% lower in those aged between 55 and 64 years (all $P < 0.0001$), and 57% lower in those older than 65 years ($P = 0.08$).

Conclusion—The odds of developing hypertension are reduced in those who remain vigorously active and increase in those whose vigorous activity declines. These effects are dependent on the exercise dose and are due in part to metabolic processes associated with body weight.

Keywords

body weight; hypertension; physical activity; prevention

INTRODUCTION

Hypertension is a common, treatable, risk factor for cardiovascular disease. Nationally, an estimated 50 million Americans should be treated for high blood pressure and, internationally, the number may approach 1 billion [1,2]. High blood pressure is estimated to account for 62% of cerebrovascular disease and 49% of ischemic heart disease [2]. Those who are normotensive at age 55 have a 90% chance of developing hypertension during their lifetime [3]. Preventing or delaying age-related increases in blood pressure could substantially reduce the number of premature deaths [4]. Sedentary lifestyle and excess body weight contribute to the risk of

developing hypertension [5–11]. The Seventh Report on the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure recommends 30 min of regular exercise such as brisk walking on most days of the week [4]. These recommendations are consistent with the guidelines of the National Institutes of Health, the Centers for Disease Control (<http://apps.nccd.cdc.gov/brfss/index.asp> and <http://apps.nccd.cdc.gov/brfss/Trends/TrendData.asp>), and the American College of Sports Medicine [10,12,13].

The current guidelines were designed to provide attainable goals to a vast majority of sedentary individuals and therefore, are pragmatically useful. Nevertheless, the benefits of greater doses of more vigorous exercise are relevant to 47.9% of American women and 50.7% of American men who meet or exceed the guideline levels (<http://apps.nccd.cdc.gov/brfss/index.asp> and <http://apps.nccd.cdc.gov/brfss/Trends/TrendData.asp>). The National Runners' Health Study was specifically designed to assess the relationship between vigorous physical activity and health [8,11,14–21]. As the energy expended while running is between seven and 18 times more than that expended while sitting quietly (7–18 metabolic equivalents), running qualifies as being vigorous (i.e., >6 metabolic equivalents) [22]. The exercise doses and intensities examined in this study are generally poorly represented in other geographically or occupationally based cohorts.

The present study relates running distance at baseline and at the end of follow-up to self-reported, physician-diagnosed hypertension in vigorously active men and women who were generally lean and ostensibly at low risk of hypertension. The analyses parallel those applied to baseline and follow-up exercise levels in our earlier study of diabetes in this cohort [21]. Specific hypotheses to be tested are whether maintenance of vigorous exercise reduces the risk of incident hypertension in relation to the exercise dose, whether men and women who decrease their activity are at greater risk of developing hypertension, and whether end of follow-up running distance is more predictive of hypertension than baseline distance, suggesting a causal, proximal effect. Elsewhere, we have shown that greater body weight is inversely related to vigorous exercise [14–20] and increases the risk of developing hypertension even among generally lean vigorously active men and women [8]. The leanness of runners may be either due to the exercise or due to initially lean men and women choosing to be active [19]. Therefore, we also test whether body weight mediates the effects of vigorous exercise on hypertension and whether this effect is attributable to self-selection.

METHODS

The survey instruments and baseline characteristics of the National Runners' Health Survey are described elsewhere [8,11,14–21]. Briefly, a two-page questionnaire, distributed nationally at races and to subscribers of a popular running magazine (Runners' World, Emmaus, Pennsylvania, USA), solicited information on demographics, running history, weight history, smoking habits, prior history of heart attacks and cancer, and medications for blood pressure, thyroid conditions, high cholesterol, and diabetes. Recruitment took place between 1991 and 1994 (primarily 1993) and follow-up between 1999 and 2002. We estimate that approximately 15% of the participants who received questionnaires responded to our survey (the number is approximate because we do not know the number of survey questionnaires actually distributed and the proportion of individuals who received multiple questionnaires). All applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during this research. The study protocol was approved by the University of California Committee for the Protection of Human Subjects, and all participants signed committee-approved informed consents.

BMI was calculated as weight in kilograms divided by the square of height in meters. Waist circumference was self-reported. Elsewhere, we have reported the correlations between self-reported and clinically measured heights ($r=0.96$), weights ($r=0.96$), and waist circumferences ($r=0.68$) [18], and the self-reported running distances vs. self-reported BMIs in cross-sectional analyses [20]. Repeat questionnaires in 110 men also showed that pre-exercise self-reported body weights (i.e., at the start of running 12 or more miles per week) had a test-retest correlation of $r=0.97$. Physical activity was reported as usual miles run per week. Self-reported distance run has been found to be highly reliable (test-retest correlations of $r=0.89$ [18]). Although other leisure-time physical activities were not recorded for this cohort, data from runners recruited after 1998 (when the survey question was introduced) show that running represented [median (25th, 75th percentiles)] 78.6% (60, 92.8%) and 73.3% (53.4, 89.9%) of their total reported leisure-time physical activity (kilocalories) and 100% (100%, 100%) and 100% (73%, 100%) of all vigorously intense activity (kilocalories).

Intakes of meat, fish, and fruit were based on the questions 'During an average week, how many servings of beef, lamb, or pork do you eat', '...serving of fish do you eat', and '...pieces of fruit do you eat'. Alcohol intake was estimated from the corresponding questions for 4-oz. (112 ml) glasses of wine, 12-oz. (336 ml) bottles of beer, and mixed drinks and liqueurs. Alcohol was computed as 14.2 ml per 4-oz glass of wine, 14.2 ml per 12-oz. bottle of beer, and 17.7 ml per mixed drink. Correlations between these responses and values obtained from 4-day diet records in 110 men were $r=0.65$ for alcohol intake, $r=0.46$ for red meat, $r=0.38$ for fruit, and $r=0.19$ for fish. These values agree favorably with published correlations between food records and more extensive food frequency questionnaires for red meat ($r=0.50$), wine ($r=0.66$), beer ($r=0.70$), and mixed drinks ($r=0.72$), somewhat less favorably for fruit intake ($r=0.50$) and less favorably for fish intake ($r=0.51$) [23].

Follow-up questionnaires were sent by mail requesting information on current running levels, body weight, and medical condition. Multiple follow-up survey questionnaires were sent and telephone calls made until a priori determined response rate of 80% of the 54 956 participants of the National Runners' Health Study provided the follow-up information or were known to be deceased. Participants reported whether a physician had told them they had high blood pressure since their baseline questionnaire and whether they took medications for high blood pressure at baseline and at the end of follow-up. Incident hypertension is defined as physician diagnosis or starting medications for these conditions subsequent to their baseline questionnaire. Using repeated surveys and confirmed diagnosis from medical records, self-reported hypertension has been demonstrated by others as being generally reliable [24] and is reported by other major cohort studies [9,25]. Self-reported physician diagnosis of hypertension has also been shown to be a strong predictor of myocardial infarction and stroke in the Nurses' Health Study [26].

STATISTICS

We employed logistic regression analyses to test whether changes in distance run per week were related to the incidence of hypertension. All results (except those in Table 1) include adjustment for the average age during follow-up (age and age²), follow-up duration, and the average weekly intakes of alcohol, meat, fish, and fruit at baseline and at the end of follow-up. The results presented are adjusted simultaneously for BMI at baseline and at the end of follow-up (BMI_{exercise} adjustment), for BMI when they first began running 12 or more miles per week (BMI_{preexercise} adjustment), and simultaneously for waist circumference at baseline and at the end of follow-up (waist circumference_{exercise} adjustment). Throughout this study, average running distance or intakes of foods refer to the average of the baseline and the follow-up survey values. Weekly running distance is referred to as being maintained if the difference between the baseline and follow-up distances remain within ± 5 km per week (Fig. 1) and as

increased or decreased if the difference between the follow-up and the baseline distance is more than 5 or less than -5 km per week, respectively. The odds of developing hypertension are analyzed relative to weekly running distance as a continuous variable in the tables and relative to categories of running distance in the figures. The categories were chosen to insure adequate sample size within each category and, where possible, emphasize the effects of changes in running distance between 0 and 8km per week (shown elsewhere to cause significantly greater weight gain than other equivalent reductions in running distance [27]).

We used logistic regression analyses to estimate the incidence of hypertension within five age intervals 18–34, 35–44, 45–54, 55–64, and 65–74 years old. Incident hypertension was used as the dependent variable and age intervals as the independent variables in a zero intercept logistic regression analyses in which an individual's log odds for developing hypertension were the sum of the time spent between the baseline and the end of follow-up survey within each interval [17]. For example, the log odds of a person who was 32 years of age at baseline and 49 years at the end of follow-up would be 3/17 of the estimated log odds between 17 and 35 years old, all (10/10) of the estimated log odds between 35 and 45 years old, and 4/10 of the estimated log odds between 45 and 55 years old. Thus, '0' or '1' is the value for the dependent variable and 3/17, 10/10, 4/10, 0, and 0 are the values for the independent variables, that is, the residence time within each age class. Annual incidence was calculated by dividing the regression estimates of the incidence associated with the age interval by the number of years included in the interval.

RESULTS

The baseline running distance, height, and weight were provided by 27 460 men and 11 721 women who were nonsmokers, nonvegetarian, without diabetes, and without hypertension at baseline. From these, we excluded 1896 men and 984 women who completed only one side of their follow-up survey questionnaire, 758 men and 453 women who did not provide their end of follow-up running distance (which probably implies they had stopped running), and 256 men and 171 women who did not report their end of follow-up BMI. Relative to the original baseline cohort who were nonsmokers, nonvegetarian, without diabetes, and without hypertension, those who were excluded or lost to the follow-up were younger (excluded vs. included, mean $\pm$ SE: men, 43.7 ± 0.1 vs. 44.1 ± 0.1 years, $P=0.0005$; women, 37.9 ± 0.1 vs. 38.3 ± 0.1 years, $P=0.02$), heavier (men, 24.11 ± 0.03 vs. 23.82 ± 0.02 kg/m²; women, 21.44 ± 0.04 vs. 21.26 ± 0.02 kg/m², both $P<0.0001$), had run fewer years at baseline (men, 12.1 ± 0.1 vs. 13.1 ± 0.05 years; women, 9.36 ± 0.09 vs. 9.93 ± 0.06 years, both $P<0.0001$) and had run longer distances if men (men, 38.8 ± 0.2 vs. 37.8 ± 0.1 km per week, $P=0.0005$; women, 35.9 ± 0.3 vs. 35.8 ± 0.2 km per week, $P=0.83$). The characteristics of the remaining sample used in these analyses are presented in Table 1. Two thousand one hundred and forty men (8.72%) and 429 women (4.24%) developed hypertension during follow-up, representing annual incidence rates of 1.12 and 0.54%, respectively. The table shows that changes in weekly distance run were associated with age, education, follow-up duration, baseline and changes in BMI, intake of fruit, alcohol, and meat (women only), and the incidence of hypertension (men only).

Stable runners

The sample included 5841 men and 2451 women who maintained their running distance within ± 5 km per week between baseline and follow-up. Table 2 shows that the log odds of incident hypertension in men declined in proportion to their average running distance, even in the absence of any change in distance. The coefficient remained significant when adjusted for BMI at baseline and follow-up (BMI_{exercise}) but was reduced by one-half, whereas adjusting for preexercise BMI had no effect. Adjustment for waist circumference gave similar results as

adjustment for BMI. Figure 1 shows that men who maintained distances more than 64 km per week during follow-up were at less than one-third the odds of developing hypertension than those who maintained levels of less than 8 km per week, and that the decline in the odds was approximately linear for the maintenance of intermediate distances. BMI accounted for a portion of the odds reduction, whereas the preexercise BMI did not. In women, the relationship between hypertension and the distance run did not achieve statistical significance (Table 2).

All runners

Table 3 and Figs 2 and 3 present the analyses of all 24 550 male and 10 113 female subjects. Two formulations of the regression model are presented that differ in whether the baseline and follow-up distances are entered directly (model 2) or used to compute their difference and average (model 1). Specifically, model 2 includes both the baseline and follow-up distances together as independent variables along with the covariates (mean age, education, follow-up duration, reported intakes of meat, fish, fruit, and alcohol, and BMI) and model 1 includes both the average distance and the difference between the baseline and follow-up distances together as independent variables with the covariates.

In model 1 (Table 3), change in running distance was reciprocally related to the log odds of developing hypertension in both sexes. The greater the decline in the running distance, the greater the increase in the incidence. Men who decreased their weekly running distance by 5–15 km per week were at significantly greater odds of developing hypertension than those who increased their distance by at least 5 km per week (Fig. 2). Table 3 shows that adjustment for BMI reduced the coefficient by about one-third in both men and women, eliminating the significance in women but not in men.

In model 2, the significance levels refer to the significance of the follow-up kilometer per week run when adjusted for baseline distance and the significance of the baseline kilometer per week run when adjusted for follow-up distance. In both men and women, the incidence of hypertension was inversely related to running distance at follow-up but not at baseline. The corresponding odds ratios are given in Fig. 3. Adjusting follow-up distance for BMI_{exercise} reduced the coefficient by over one-half, whereas adjustment for BMI_{preexercise} had little effect.

Our sample included 1092 men and women who reported zero kilometers per week at baseline. When adjusted for sex, age, education, and diet, increases in running distance were associated with significant decreases in the log odds of developing hypertension (coefficient $\pm$ SE: -0.016 ± 0.007 , $P=0.02$), one-half of which appears to be attributed to BMI_{exercise} (adjusted coefficient $\pm$ SE: -0.009 ± 0.007 , $P=0.23$).

Finally, in Fig. 4 the data are analyzed to assess the effects of running distance on the increase in hypertension with age. The data were stratified by running distances at the end of follow-up and the log odds for incident hypertension in those aged less than 35, 35–44, 45–54, 55–64 years were calculated within each stratum as described in Methods. The distance categories were chosen to provide adequate sample size within stratum or combine categories of similar response to simplify the presentation (i.e., women who ran >12 km per week). Significance levels represent the difference between women who ran more than 12 km per week and those who ran less than or equal to 12 km per week and the trend of declining incidence with greater running distance in men. These data demonstrate that incident hypertension declined with running distance and running longer distances attenuated the age-related increases in the incidence of hypertension in men aged less than 65 years.

DISCUSSION

The simplest prospective analyses compare the incidence of disease to the baseline risk factor levels. When both baseline and follow-up factor levels are available and when the disease is unlikely to affect the risk factor, more detailed analyses are possible that relate changes in the risk factor to the incidence. Application of these more detailed analyses showed that maintenance of vigorous exercise reduced the risk of incident hypertension in relation to the exercise dose (km per week), men and women who decreased their vigorous activity were at greater risk of developing hypertension, and running distance at follow-up was more predictive of hypertension than that at baseline, consistent with a causal effect depending more on recent exercise levels than on long-term participation.

Stable runners

Men and women whose running level remained relatively constant were used to test whether the dose of exercise, independent of exercise change, affected the incidence of hypertension. This approach corresponds most closely to the idealized conditions of a prospective epidemiological cohort study in that the risk factor level remains constant during the follow-up. These analyses demonstrated a progressive odds reduction with higher doses of vigorous activity (Fig. 1). In the absence of interim surveys, it is not possible to assert that exercise did not fluctuate between baseline and follow-up; however, for most subjects, we expect that the variation would not be extreme. It is worth noting in reference to other prospective studies of physical activity and health that only a small proportion of our sample maintained the same activity level during the follow-up, with the majority reporting some decline in their activity. This suggests that exercise recidivism may cause traditional prospective cohort studies to substantially underestimate the health benefits of being physically active.

Exercise recidivism

To our knowledge, these analyses are unique in their focus on the health consequences of exercise recidivism in vigorously active men and women. Current public health guidelines recommend 30 min of moderately intense physical activity on most days of the week, which can be achieved by walking briskly 2 miles, 5 days a week (the energy equivalent of running 10 to 11 km per week) [22]. Although only 47.9% of American women and 50.7% of American men currently meet these guideline levels (<http://apps.nccd.cdc.gov/brfss/index.asp> and <http://apps.nccd.cdc.gov/brfss/Trends/TrendData.asp>), 88.5% of men and 87% of women in our sample meet or exceed the guideline levels by running alone. At the end of the follow-up, these percentages declined to 70% for male and 65.5% for female cohort members.

Table 3 and Fig. 2 show that changes in weekly running distance were inversely related to the incidence of hypertension. Although some runners increased their weekly distance, for the majority, change represented a decrease in distance (Table 1). Thus, recidivism increases the odds of developing hypertension (Fig. 2). Success in motivating the population to become more active will not yield its expected health benefits if the activity is not sustained. Elsewhere [15,16], we have also demonstrated significant weight gains in runners that decrease their running distance or quit running altogether. In fact, the effects of increasing and decreasing running distance appear asymmetric, with the amount of weight gain owing to a reduction in running distance being greater than the weight loss owing to an increase in distance [27].

The odds of developing hypertension depended on the follow-up running distance without regard to baseline activity. If the odds of developing hypertension are related to the short-term effects of running and the effect is causal, then hypertension will be related to the end of follow-up distance without regard to baseline levels, as observed. If vigorous exercise and hypertension were only secondarily related because men and women who chose to run longer

distances were also at lower risk of developing hypertension, then we would expect this association to be reflected in the baseline activity level as well, which was not observed. The majority of the sample was on a trajectory of declining activity over time, and the follow-up activity was probably more reflective of the activity level that triggered the emergence of hypertension than the activity at baseline.

Mediating effects of weight gain

Excess body weight is an important determinant of the risk of hypertension [4–8]. In our data, adjustment for BMI_{exercise} (i.e., including both baseline and follow-up BMI as covariates) substantially reduced the effect of distance run on the odds for developing hypertension. Similar results were obtained by adjusting for waist circumference. A series of earlier studies established that exercise affects body weight in two ways: first, vigorous exercise prevents age-related weight gain in proportion to the exercise dose [17]; and second, changes in the dose of vigorous exercise acutely affect weight in relation to starting and ending activity levels [27]. Even when statistically adjusted for the effects of body weight, the relationship between distance run and hypertension remained significant (Table 2 and Fig. 1). Although this finding may suggest that there are effects of vigorous exercise on hypertension that are independent of body weight, there are several important caveats to this interpretation. To the extent that BMI is measured (or recalled) with error, its adjustment will underestimate the proportion attributable to BMI. Height and weight, however, are recalled relatively precisely and therefore the bias is probably small. Second, statistical adjustment assumes that the relationships between the independent variables are parallel for all percentiles of the dependent variable. We, however, have shown in men that the regression slope relating distance run to the 90th percentile of BMI is 2.5-fold larger than its regression slope to the 10th percentile of BMI [20].

A primary difficulty in the interpretation of observational data is distinguishing cause and effect. We have previously reported that 26% of the relationship between running distance and BMI is attributable to preexercise BMI in men and 58% in women [19]. This suggests that some of the relationship between body weight and running distance is due to self-selection [19]. Nevertheless, adjustment for preexercise BMI had no effect on the dose–response relationships between vigorous exercise and hypertension (Tables 2 and 3), suggesting that their relationship is not due to self-selection based on preexercise BMI.

Aging

Age-related increases in the risk of developing hypertension results in 50% prevalence between 60 and 69 years old and 75% prevalence over age 70 [1]. Normotensive men and women at age 55 years have a 90% chance of developing hypertension by the age of 90 years [3]. The graphs of Fig. 4 suggest that exercising at higher doses may have attenuated the age-related increase in incidence rates. Specifically, 45–75-year-old men who run more than 40 km per week had incidence rates that correspond to that of 40-year-old men who report running less than 8 km per week. Incidence rates in women who run at least 12 km per week have rates that appear to correspond to that of women who are a decade younger and run less than 12 km per week. One interpretation of these observations is that the classification of ‘age’ as an unalterable risk factor for hypertension may not be entirely correct. The apparent decline in incident hypertension among those above 65 years of age in the figure could signify that by this age most of the men at risk of hypertension are already diagnosed; however, this age group represented only 4.3% of the sample and thus there is limited statistical power for drawing inference.

Caveats

There are important limitations of these results that warrant recognition. The cohort does not necessarily represent a random sample of all runners given that only 15% of the targeted sample was recruited. Men and women who run regularly may differ from others genetically, socio-economically, psychologically, and with respect to other health behaviors. Despite the select nature of the sample, we expect the biological processes that relate hypertension to changes in exercise and adiposity to be similar in runners and nonrunners. Our analyses do not prove cause and effect because they are not based on a randomized controlled experiment. For example, other studies suggest that beta-blocker therapy may decrease physical work capacity and/or the ability to sustain submaximal exercise [28]. Nevertheless, the association shown here between incident hypertension and change in vigorous exercise and between hypertension and baseline-adjusted follow-up distance, strengthens the evidence for causality.

These analyses are based on self-reported running distances and physician diagnosis of hypertension, which despite their validation and use in other epidemiological studies [9,24–26], could bias the results. Undoubtedly, some undiagnosed hypertensive patients are included in the sample. We do not believe that the decline in hypertension with increasing distance is due to fewer opportunities for diagnosis in the more athletic men, for presumably this would be reflected in the baseline measurements as well. The Health Professionals Study reported that their more vigorously active participants had more routine medical checkups than less active men [29] and there was no difference in routine medical checkup by activity level in the Nurses' Health Study [30].

Our study also lacked serial measurements on physical activity and hypertension, preventing verification of the consistency of exercise between baseline and follow-up in our analyses of stable runners or assessment of the duration of the impact of physical activity on blood pressure when activity is reduced. Although the current analyses do not show whether running prevents the increase in systolic blood pressure, diastolic blood pressure, or both, our earlier cross-sectional study showed that both systolic and diastolic blood pressures declined with greater running distance [14].

Summary

Our analyses describe the effects of changing levels of vigorous physical activity in a cohort selected specifically because they ran at recruitment, and, therefore, pertains to a subset of individuals poorly represented in other population studies. The associations presented here are consistent with meta-analyses showing that aerobic exercise decreases systolic and diastolic blood pressures [31] and our previous observations that lower prevalence of hypertension in vigorously active men and women is partly attributed to their leanness [11]. The mediating effects of body weight do not diminish the importance of promoting vigorous physical activity, because the leanness of runners is largely due to vigorous exercise per se [14–20]. Others have shown prospectively that greater physical activity diminishes the risk of hypertension in different geographical and racial groups [32–35]. Meta-analyses of 72 randomized controlled studies showed that training-induced blood pressure reductions are likely to be achieved through a variety of endurance training regimens in that frequency, intensity or mode were unrelated to outcome [36]. Future public health guidelines would benefit by acknowledging more directly that the health benefits of vigorous exercise accrue through at least 64 km per week and emphasizing the health consequences of recidivism for those currently active.

Acknowledgments

The study was supported in part by grants HL-45652, HL-072110, and DK066738 from the National Heart Lung and Blood Institute, and was conducted at the Ernest Orlando Lawrence Berkeley Laboratory (Department of Energy DE-AC03-76SF00098 to the University of California). There is no conflict of interest.

Abbreviations

BMI	body mass index
METs	metabolic equivalents

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Figure 1.

Prospective analyses of incident hypertension in 5841 men who maintained their running distance within ± 5 km per week of their baseline running distance during follow-up. Adjusted for follow-up duration and average age (age and age²), education, and average weekly intakes of meat, fish, and fruit during follow-up. Average kilometer per week is the average of the baseline and follow-up reported running distances. Additional adjustment for BMI_{exercise} (BMI at baseline and BMI at the end of follow-up) and BMI_{preexercise} (calculated from self-reported weight when started running ≥ 12 miles per week) where indicated. Adjustment for waist circumference produced odds ratios similar to adjustment for BMI_{exercise} (not displayed). Significant odds reductions relative to men averaging less than 8 km per week are coded: *P<0.05; †P<0.01; ‡P<0.001; and §P<0.0001.

Figure 2. Odds ratio of incident hypertension in relation to concurrent changes in weekly running distance in 24 500 men during 7.8 years of follow-up. See legend to Fig. 1.

Figure 3.

Odds ratio of incident hypertension in relation to baseline (adjusted for the end of follow-up) and the end of follow-up (adjusted for baseline) weekly running distance. See legend to Fig. 1.

Figure 4.

Incidence of hypertension by age classes stratified by reported running distance (kilometer per week) at the end of follow-up. Significance levels refer to the significance for the trend from lowest to highest running distance (men) or the difference between at least 12 vs. less than 12 km per week (women).

Table 1

Characteristics (means $\pm$ SD) of men and women by reported change in weekly running distance between baseline and follow-up

	Increased running distance (>5 km per week)	No change(5 km per week)	Decreased running distance			ANOVA Or Chi ² (P)
			-5 to -15 km/wk	-15 to -25 km/wk	< -25 km/wk	
Men						
N	3644	5841	5022	5186	4857	
Education (years)	16.6 ± 2.4	16.7 ± 2.4	16.6 ± 2.4	16.5 ± 2.4	16.2 ± 2.5	<0.0001
Baseline BMI (kg/m ²)	23.8 ± 2.6	24.0 ± 2.6	23.9 ± 2.6	23.8 ± 2.5	23.4 ± 2.4	<0.0001
ΔBMI (kg/m ²)	0.42 ± 1.41	0.79 ± 1.41	1.09 ± 1.59	1.38 ± 1.62	1.93 ± 2.04	<0.0001
Average meat (servings per week)	2.9 ± 3.3	3.0 ± 3.2	2.9 ± 3.1	2.9 ± 3.2	3.0 ± 3.5	0.23
Average fish (servings per week)	1.6 ± 1.3	1.6 ± 1.3	1.5 ± 1.2	1.6 ± 1.4	1.5 ± 1.3	0.64
Average fruit (pieces per week)	11.1 ± 8.0	10.5 ± 7.5	10.5 ± 7.3	10.4 ± 7.2	10.8 ± 8.0	<0.0001
Average alcohol (ml per week)	77.2 ± 99.8	86.3 ± 105.7	85.7 ± 105.2	86.3 ± 103.6	85.3 ± 107.9	0.0002
Percentage with hypertension (N)	5.98 (218)	7.85 (459)	8.98 (451)	9.23 (479)	10.97 (533)	<0.0001
Follow-up duration (years)	7.41 ± 1.86	7.45 ± 1.81	7.72 ± 1.76	7.98 ± 1.72	8.40 ± 1.70	<0.0001
Average age (years)	46.51 ± 9.70	48.55 ± 9.79	48.99 ± 9.80	48.45 ± 10.07	47.07 ± 10.88	<0.0001
Average running distance (km/wk)	37.85 ± 20.01	27.99 ± 19.65	29.23 ± 18.31	31.28 ± 19.76	35.16 ± 19.00	<0.0001
Women						
N	1710	2451	2010	2112	1830	
Education (years)	15.9 ± 2.3	16.0 ± 2.4	16.0 ± 2.3	15.9 ± 2.3	15.7 ± 2.4	0.004
Baseline BMI (kg/m ²)	21.1 ± 2.3	21.4 ± 2.5	21.4 ± 2.3	21.2 ± 2.3	21.0 ± 2.2	<0.0001
ΔBMI (kg/m ²)	0.34 ± 1.42	0.79 ± 1.63	0.94 ± 1.77	1.17 ± 2.01	1.49 ± 2.32	<0.0001
Average meat (servings per week)	1.3 ± 1.6	1.5 ± 1.9	1.4 ± 1.7	1.3 ± 1.6	1.3 ± 1.8	0.005
Average fish (servings per week)	1.4 ± 1.3	1.3 ± 1.2	1.4 ± 1.1	1.3 ± 1.1	1.3 ± 1.3	0.10
Average fruit (pieces per week)	11.7 ± 7.7	11.2 ± 6.8	11.4 ± 7.0	11.0 ± 6.4	11.0 ± 6.9	0.007
Average alcohol (ml per week)	49.1 ± 66.1	52.7 ± 68.2	53.5 ± 68.8	56.0 ± 72.0	52.5 ± 71.6	0.05
Percentage with hypertension (N)	3.51 (60)	3.92 (96)	4.13 (83)	4.55 (96)	5.14 (94)	0.27
Follow-up duration (years)	7.36 ± 2.03	7.24 ± 2.03	7.38 ± 2.06	7.77 ± 1.96	8.06 ± 1.98	<0.0001
Average age (years)	41.06 ± 9.07	43.29 ± 9.69	43.00 ± 9.57	41.86 ± 9.82	40.47 ± 10.39	<0.0001

	Increased running distance (>5 km per week)	No change(5 km per week)	Decreased running distance			ANOVA Or Chi ² (P)
			-5 to -15 km/wk	-15 to -25 km/wk	< -25 km/wk	
Average running distance (km/wk)	37.55 ± 19.56	27.63 ± 19.33	27.04 ± 17.11	29.73 ± 19.65	33.82 ± 17.68	<0.0001

Average age and average running distance are the average of the baseline and follow-up values. Significance of difference by ANOVA (confirmed by Wilcoxon sign rank test) except for the proportion of hypertensive patients by Chi square

Table 2

Logistic regression analyses of incident hypertension vs. running distance in 5841 male and 2451 female stable runners (i.e., ± 5 km per week between baseline and end of follow-up)

	Intercept	Average km per week (coefficient $\pm$ SE)
Men		
<i>Unadjusted</i>	-1.950	$-0.019 \pm 0.003^{\S}$
<i>BMI_{exercise} adjusted</i>	-2.322	$-0.010 \pm 0.003^{\ddagger}$
<i>BMI_{preexercise} adjusted</i>	-2.039	$-0.020 \pm 0.003^{\S}$
<i>Waist circumference_{exercise} adjusted</i>	-2.215	$-0.011 \pm 0.003^{\ddagger}$
Women		
<i>Unadjusted</i>	-3.319	-0.005 ± 0.006
<i>BMI_{exercise} adjusted</i>	-3.652	0.003 ± 0.006
<i>BMI_{preexercise} adjusted</i>	-3.432	-0.005 ± 0.006
<i>Waist circumference_{exercise} adjusted</i>	-3.638	0.005 ± 0.006

The intercept term includes the adjustment to the mean age, follow-up duration, education, and reported intakes of meat, fish, fruit, and alcohol. Additional adjustment for BMI_{preexercise} (i.e., when they began running ≥ 12 km per week), BMI during exercise (BMI_{baseline} and BMI_{follow-up}), and waist circumference during exercise (waist circumference_{exercise}) as indicated. Average kilometer per week is the average of the baseline and follow-up reported running distances. Significance levels for logistic regression coefficients are coded:

* P<0.05,
[†] P<0.01,
[‡] P<0.001,
[§] P<0.0001.

Table 3

Logistic regression analyses of incident hypertension vs. running distance at baseline and follow-up in all 24,550 male and 10,113 female runners

	Model 1 (coefficients±SE)			Model 2 (coefficients±SE)		
	Intercept	Change (Δkm per week)	Average (km per week)	Intercept	Baseline (km per week)	Follow-up (km per week)
Men						
<i>Unadjusted</i>	-2.124	-0.009 ± 0.001§	-0.012 ± 0.001§	-2.124	0.002 ± 0.001	-0.015 ± 0.001§
<i>BMI_{exercise} adjusted</i>	-2.519	-0.005 ± 0.001§	-0.002 ± 0.001	-2.519	0.004 ± 0.001†	-0.006 ± 0.002§
<i>BMI_{preexercise} adjusted</i>	-2.236	-0.008 ± 0.001§	-0.011 ± 0.001§	-2.236	0.002 ± 0.001	-0.014 ± 0.001§
<i>Waist circumference_{exercise} adjusted</i>	-2.443	-0.008 ± 0.001§	-0.004 ± 0.002†	-2.443	0.006 ± 0.001§	-0.010 ± 0.002§
Women						
<i>Unadjusted</i>	-3.162	-0.006 ± 0.003*	-0.008 ± 0.003†	-3.162	0.002 ± 0.003	-0.010 ± 0.003†
<i>BMI_{exercise} adjusted</i>	-3.452	-0.004 ± 0.003	-0.000 ± 0.003	-3.452	0.004 ± 0.003	-0.004 ± 0.003
<i>BMI_{preexercise} adjusted</i>	-3.215	-0.005 ± 0.003	-0.008 ± 0.003†	-3.215	0.001 ± 0.003	-0.009 ± 0.003†
<i>Waist circumference_{exercise} adjusted</i>	-3.440	-0.005 ± 0.003	-0.000 ± 0.003	-3.440	0.005 ± 0.003	-0.005 ± 0.003

The intercept term includes the adjustment to the mean age, follow-up duration, education, and reported intakes of meat, fish, fruit, and alcohol. Additional adjustment for BMI_{preexercise} (i.e., when they began running ≥12 km per week), BMI_{exercise} (at both baseline and follow-up) and waist_{exercise} (waist circumference at both baseline and follow-up) where indicated. Average kilometer per week is the average of the baseline and follow-up running distances. Significance levels for logistic regression coefficients are coded:

- * P<0.05;
- † P<0.01;
- ‡ P<0.001;
- § P<0.0001.