Outrunning major weight gain: a prospective study of 8,340 consistent runners during 7 years of follow-up.

Paul T. Williams, Ph.D.

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Running title: Outrunning age-related weight gain

Abbreviations: BMI: body mass index; km kilometer;

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Paul T. Williams, Ph.D., Life Sciences Division, Lawrence Berkeley Laboratory, Donner Laboratory, Berkeley, CA. 94720

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Background: Body weight increases with aging. Short-term, longitudinal exercise training studies suggest that increasing exercise produces acute weight loss, but it is not clear if the maintenance of long-term, vigorous exercise attenuates age-related weight gain in proportion to the exercise dose.

Methods: Prospective study of 6,119 male and 2,221 female runners whose running distance changed less than 5 km/wk between their baseline and follow-up survey 7 years later.

Results: On average, men who ran modest (0-24 km/wk), intermediate (24-48 km/wk) or prolonged distances (•48 km/wk) all gained weight through age 64, however, those who ran •48 km/wk had one-half the average annual weight gain of those who ran <24 km/wk. Age-related weight gain, and its reduction by running, were both greater in younger than older men. In contrast, men's gain in waist circumference with age, and its reduction by running, were the same in older and younger men. Women increased their body weight and waist and hip circumferences over time, regardless of age, which was also reduced in proportion to running distance. In both sexes, running did not attenuate weight gain uniformly, but rather disproportionately prevented more extreme increases.

Conclusion: Men and women who remain vigorously active gain less weight as they age and the reduction is in proportion to the exercise dose.

Men and women gain weight as they age (3) [1], and reducing this tendency is critical in to preventing adult obesity. The National Institute of Medicine currently recommends sixty minutes of walking per day, or its energy equivalent, to maintain healthy weight (8)[2]. Multiple studies have examined the effect of short-term exercise training on body weight and support the NIM's recommendations [3-7] (1,5,6,15,23). Few studies, however, have examined the effects of long-term exercise on body weight and we are unaware of exercise studies of sufficient duration to examine the effect of sustained vigorous exercise on annual weight gain per se.

The National Runner' Health Study includes 8,340 runners whose reported weekly running distance changed less than 5 km/wk between their baseline and 7 year follow-up surveys. This sample allows us to test prospectively whether vigorous exercise diminishes annual weight gain in relation to the exercise dose. The hypothesis to be tested in not whether increases in energy expenditure causes weight loss, rather whether sustained exercise affects the trajectory of age-related weight gain.

Methods

The survey instruments and baseline characteristics of the National Runners' Health Survey are described elsewhere ({9-11}. Approximately 80% of the baseline cohort provided follow-up questionnaires. This paper specifically focuses on those runners whose follow-up weekly running distances were within 5 km/wk of their reported baseline value. In addition, runners were excluded if they smoked, followed strict vegetarian diets, or used thyroid or diabetes medications because of their possible influence on adiposity. The study protocol was approved by the Committee for the Protection of Human Subjects and all participants signed committee approved informed consents.

Change in body mass index (BMI) was calculated as the change in weight (kg) between the first and second questionnaire divided by the square of the average height (m) from the two questionnaires. Self-reported waist and hip circumferences were elicited by the question "Please provide, to the best of your ability, your body circumference in inches" without further instruction. Elsewhere, we have reported the strong correlations between repeated questionnaires for self-reported running distance (r=0.89){12}, between self-reported and clinically measured height (r=0.66), weight (r=0.96) and waist circumference (r=0.68){12}, and between self-reported running distance and BMI and waist circumference from questionnaires in cross-sectional analyses {10-13}.

Statistical analyses Results are given as means±SE or slopes±SE except where noted. We used multiple linear regression to estimate the annual mean changes in adiposity by age intervals. Weight change was used as the dependent variable and age intervals as the independent variables in a zero intercept model, where contribution of an individual's weight change was proportional to the amount of time spent between the baseline and follow-up survey within each interval {9}. Bootstrap resampling was used to estimate standard errors for the difference in percentiles between distance categories and their statistical significance {14}. Bootstrap resampling was also used to test whether the dose-response relationship between physical activity and annual changes in weight and regional adiposity were the same for all percentiles of weight change or was disproportionately greater for higher or lower percentiles of weight gain {12,15}.

Results

There were 6,119 men and 2,221 women who reported running within ±5 km/wk of their baseline running distance. Men and women, respectively, on the baseline surveys were on average middle-aged (mean±SD: 45.3±10.1 and 39.6±9.7 years), relatively lean (BMI of 24.1±2.7 and 21.5±2.7 kg/m^2), narrow-waisted (85.1±6.3 and 69.3±7.3 cm) and had run for 13.8±8.0 and 10.4±5.9 years. Women's baseline hip circumference averaged a slender 91.9±7.0 cm. The men gained 0.33±0.64 kg and added 0.30±0.71 cm around their waists annually during 7.5±3.2 years of follow-up. Women fared no better, annually gaining an average of 0.31±0.69 kg in weight, 0.36±1.07 cm in waist circumference, and 0.26±1.08 cm in hip circumference during their 7.2±2.3 years of follow-up.

Average body weight, BMI, waist circumference, and hip circumference (women only) increased significantly over time for all age classes regardless of distance run (Table 1, Column 1). Young adults (18 to 24 years old men and 18 to 30 year old women) experienced the greatest annual increases in body weight, BMI, waist circumference, and hip circumference. In men, the rate of increase was diminished by over half after age 25 and by two-thirds after age 45 relative to the increases in young men. In women, annual increases in waist and hip circumferences rates diminished by over half after age 29.

Individuals running modest (0-24 km/wk), intermediate (24-48 km/wk) or prolonged distances (•48 km/wk) also demonstrated statistically significant annual increases in body weight, BMI and waist circumferences through age 64 in men and in all age groups in women (Table 1, Columns 2-4). However, between ages 25-54 in men and 30-49 in women, the average annual gain in weights and BMI diminished for those who ran intermediate and longer distances. Those running ≥ 48 km/wk experienced only half the average annual increase in total weight and BMI as those who ran < 24 km/wk. Waist circumference in men 25 years and older also tended to increased significantly less for those running •48 km/wk vs <24 km/wk.

Table 2 presents the regression slopes for annual changes in body weight, BMI and waist circumference per km/wk run within age groups. Annual increases in adiposity decreased significantly with running distance in young to middle-aged men (25 to 54 years), but not in older men. Running produced progressively less attenuation of annual weight gain as the men got older. This was confirmed by the statistically significant interaction between the effects of age and running distance on annual changes in weight and BMI. In contrast, annual increases in waist circumference decreased with running distances in men 25 and older regardless of age, and there was no significant interaction between age and distance. This suggests that the attenuation of the annual gains in waist circumference can be estimated by the single slope for pooled data adjusted for age (-0.004±0.001 cm per km/wk, P<0.0001), rather than separate coefficients for each age group.

In women under fifty, running longer distances significantly reduced annual increases in total weight and BMI. (Table 2) The inhibition of age-related weight gain was not significant in older women, but this may be in part due to limited statistical power, since there was no significant interaction between age and running distance. The pooled data adjusted for age suggest that each km/wk run attenuated the annual increases in body weight by -0.006±0.001 kg, in BMI by -0.002±0.000 kg/m^2, and in waist circumference by -0.003±0.001 cm.

Running longer distances also attenuated annual increases in hip circumference in women 30 to 39 years old (-0.006±0.002 cm/km, P=0.02), and 40 to 49 years old (-0.007±0.002 cm/km, P=0.002), but not younger (-0.004±0.006 cm/km, P=0.50) or older women (-0.005±0.003 cm/km, P=0.07). However, there was again no significant interaction between age and distance, and the pooled slope for the annual change in hip circumference per km/wk run adjusted for age was -0.006±0.001, P<0.0001.

Figures 1 and 2 present the differences in the annual changes in body mass, BMI and waist circumference between those who ran less than 24 km/wk versus 24-47 km/wk (left panels) and those who ran less than 24 km/wk versus •48 km/wk (right panels). Negative heights mean smaller annual increases in high- versus low-mileage runners. The differences are presented separately by age (X-axis) and by percentile of weight or circumference change (see legend). For example, the differences in the 90th percentile of BMI change is the 90th percentile of ΔBMI among runners who ran •48 km/wk minus the 90th percentile of among runners who ran <24 km/wk. The bars for the 10th, 25th, 50th, 75th and 90th percentiles of ΔBMI change would be all the same height if running further produced the same expected reduction in annual weight gain across all individuals (i.e., translated the distribution of ΔBMI by a fixed amount). In contrast, the left-middle panel of Figure 1 shows that in 25 to 35 year old men, the 50th, 75th and 90th percentiles of the annual change in BMI were significantly less for those who ran over 48 km/wk than those who ran under 24 km/wk, whereas the 10th and 25th percentiles of BMI change did not differ significantly between the higher and lower mileage runners. The length of the bars increase progressively from the 10th through the 90th percentiles and this trend is statistically significant (P=0.008), suggesting further that running does not diminish weight gain uniformly, but rather the attenuation increases linearly with the percentile of ΔBMI.

Figure 1 shows that men 35 to 55 years old who consistently ran between 24 - 47 km/wk were less likely to have larger annual increases in weight and BMI than men who ran <24 km/wk. Moreover, the attenuation of weight gain depended upon the amount of exercise, the percentile of weight gain and the age of the men. Specifically, the impediment to weight gain increased progressively from the lowest to highest Δweight and ΔBMI percentile (percentile effect). These effects were more pronounced when men who ran •48 km/wk are compared to those who ran <24 km/wk (Fig 1 right panels) than when men who ran 24-47 km/wk are compared to those who ran <24 km/wk, (left panel, exercise dose effect). Exercise's inhibition of weight gain was similar in younger and older men, but the effects were only marginally significant in younger men unless running distance exceeded 48 km/wk. Inhibition of weight gain was also evident when 55 to 64 year old men who exceeded 47 km/wk are compared to those that ran <24 km/wk. In men, there is a clear trend for age to reduce the attenuating effects of exercise on annual gains in the 50th, 75th and 90th percentiles of Δweight and ΔBMI. Figure 1 also shows that annual increases in waist circumference were attenuated by running, and that the degree of attenuation was greatest at the 90th percentile of Δwaist circumference, intermediate at the 75th percentile, and modest but significant at the 50th percentile □□ Δwaist circumference. The degree of attenuation was similar across age groups after age 35 (i.e., no age effect for Δwaist circumference in middle-aged and older men).

The effects of exercise on the percentiles of Δweight and ΔBMI in women are generally consistent with those observed in men (Figure 2). Women 30 to 49 years old who consistently ran between 24 and 47 km/wk or •48 km/wk had smaller annual increases in weight and BMI than those who ran <24 km/wk. Also, the attenuation of weight gain increased progressively from the lowest to highest Δweight and ΔBMI percentile. The difference between 24 to 48 km/wk and •48 km/wk were less evident for women than men. Age-related increases in the 50th, 75th and 90th percentiles of waist circumferences were also diminished in women 30 to 39 years old by running at least 24 km/wk, and in women 40 to 49 years old by running at least 48 km/wk.

Discussion

Our analyses confirm prospectively that middle-age weight gain occurs even among vigorously active men {10} and suggest that weight gain is an intrinsic property of aging. Previously, in our initial cross-sectional analyses of 7,059 men, we concluded that the increase in BMI with age was constant regardless of the activity level {10}. More recent cross-sectional analyses of over 60,000 men suggest that the rate of weight gain with age diminishes at higher activity levels {11}. Although suggestive, these cross-sectional studies could not distinguish aging and weight change (dynamic processes) from individual preferences to choose a level of vigorous activity based on their age and weight (self-selection).

The present results demonstrate an inverse, dose-response relationship between the amount of exercise sustained over 7 years and weight gain. The prospective design ensures that the effects were related to weight change per se. Unlike prospective analyses presented by others {16-21}, ours was restricted to vigorously active men and women who maintained the same exercise level at baseline and follow-up. This was done to eliminate the effects of change in physical activity, which is already known to produce weight loss {22,23}. Our analyses show the benefits of vigorous exercise on weight extend beyond the acute weight loss following greater energy expenditure, i.e., it also reduces in the rate of weight gain that occurs with aging.

Individuals vary greatly in their tendency to gain weight with age, which may be due to behavioral differences, but also to genetic or environmental variation {24}. Particularly at risk are individuals that gain weight most rapidly. Our analyses suggest that exercise was particularly efficacious at preventing more rapid weight gain. Exercise had less impact on age-related increases in body weight and BMI in older than younger men, while the attenuation of age-related increases in waist circumference were similar in older and younger men. These effects seem reflective of the expected changes in men’s body weight, BMI and waist circumference with age, i.e., the tendency for body weight to increase through age fifty and remain constant thereafter and for waist circumference to continue to increase until later in life.

Our findings suggest two component framework for describing the effects of physical activity on long-term changes in body weight: 1) a trajectory component that is attenuated by physical activity (demonstrated in this report); and 2) an acute component that is due to change in the energy balance, as when energy expenditure is increased in relation to energy intake (demonstrated by us and others elsewhere {22,23}). This trajectory component may be of relatively minor significance in training or dieting studies, which usually span a year or less {8}, during which the effects on weight of changing energy balance is likely to be large relative to aging. However, it may be of major significance to long term prospective studies that relate weight change to physical activity.

This theoretical framework is useful for interpreting the other prospective studies of exercise and weight, in which changes in weight between baseline and follow-up are compared to baseline {16-18}; follow-up {19,20}, or concurrent changes in physical activity {17,19,21}. Relationships between weight change and either the baseline or the follow-up exercise will reflect in part the effects of physical activity on age-related weight gain (the trajectory component), as well as any effects of change in activity that are related to either the baseline or follow-up activity (acute component). The third approach treats men and women that do not change their physical activity the same regardless of whether the activity level is high or low, and therefore estimates the cumulative effects of changing energy expenditure (acute component) but not the effect of exercise on age-related weight gain (trajectory component). In contrast, restricting the analyses to those who maintain a consistent exercise dose over time enables us to test whether exercise attenuates the trajectory component directly.

There are obvious limitations to our analyses. We lack data on the energy intake in these runners, which precludes our being able to claim directly that the inverse association between weight gain and exercise was independent of changes in energy intake. The period that these runners were studied, between 1992 and 1994 at baseline and between 2000 and 2001 at follow-up, coincides with national nutritional survey data collected by the National Health and Nutrition Examination Survey (NHANES) {25}. They reported a 4.6% decline in energy intake in men aged 20 to 39 years and less than a 1% increase in men a 40 - 59 years old. These national data suggest energy intake did not increased in men, so it is unlikely that temporal shifts in energy intake could account for age-related weight gain. The NHANES surveys of both 1992-1994 and 2000-2001 show older individuals eat less. Another limitation is that we did not allocate participants at random to a prescribed running distance. Therefore, we cannot distinguish whether exercise caused the attenuation of age-related weight gain, or if individuals who were genetically, behaviorally, or environmentally predisposed to a lower rate of weight gain over time were more successful at sustaining a high levels of vigorous physically activity.

Based on the data presented here and by others, we conclude that maintaining a vigorously active lifestyle diminishes the apparently natural tendency to gain weight with age. Moreover our analyses suggest exercise prevents more extreme weight gain, which may be especially beneficial given the curvilinear relationship between weight, morbidity, and mortality {26}.

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Table 1. Annual average increases in body weight, BMI and waist circumference (±SE) by age and average running distance in 6,119 men and 2,221 women				
	Reported average weekly running distance at baseline and follow-up			
	All	0-24 km/wk	24-48 km/wk	≥48 km/wk
Males				
ΔBody weight (kg per year)				
18-24	1.37±0.12§	1.56±0.17§	0.86±0.28†	0.83±0.22‡
25-34	0.46±0.04§	0.63±0.07§	0.37±0.06§¥	0.26±0.06§#
35-44	0.44±0.02§	0.52±0.03§	0.42±0.03§¥	0.31±0.03§∞
45-54	0.32±0.02§	0.41±0.03§	0.26±0.02§∞	0.23±0.03§∞
55-64	0.17±0.02§	0.14±0.04§	0.21±0.03§	0.13±0.05†
65-74	0.08±0.04*	0.10±0.06	0.06±0.06	0.08±0.09
ΔBMI (kg/m^2 per year)				
18-24	0.42±0.04§	0.48±0.05§	0.28±0.09†	0.27±0.07§
25-34	0.14±0.01§	0.20±0.02§	0.11±0.02§¥	0.08±0.02§#
35-44	0.14±0.01§	0.16±0.01§	0.13±0.01§¥	0.10±0.01§∞
45-54	0.10±0.00§	0.13±0.01§	0.08±0.01§∞	0.07±0.01§∞
55-64	0.06±0.01§	0.06±0.01§	0.07±0.01§	0.04±0.01†
65-74	0.03±0.01*	0.03±0.02	0.02±0.02	0.03±0.03
ΔWaist circumference (cm per year)				
18-24	0.96±0.16§	0.90±0.23§	0.95±0.33†	1.00±0.32†
25-34	0.42±0.05§	0.56±0.08§	0.41±0.07§	0.17±0.08*#
35-44	0.35±0.02§	0.41±0.04§	0.31±0.03§¶	0.29±0.04§
45-54	0.26±0.02§	0.35±0.03§	0.22±0.03§#	0.13±0.04‡∞
55-64	0.27±0.03§	0.29±0.04§	0.28±0.04§	0.15±0.06†
65-74	0.18±0.05§	0.24±0.07‡	0.18±0.07†	-0.18±0.12 ¥
Females				
ΔBody weight (kg per year)				
18-30	0.70±0.12§	0.91±0.20§	0.64±0.17‡	0.39±0.18*
30-40	0.37±0.03§	0.50±0.05§	0.29±0.04§¥	0.21±0.06‡#
40-50	0.31±0.03§	0.42±0.05§	0.23±0.03§#	0.23±0.06§¶
≥50	0.21±0.03§	0.31±0.06§	0.11±0.04*¥	0.15±0.07*
ΔBMI (kg/m^2 per year)				
18-30	0.24±0.04§	0.31±0.07§	0.24±0.07‡	0.13±0.07*
30-40	0.13±0.01§	0.17±0.02§	0.11±0.02§¥	0.08±0.02§¥
40-50	0.12±0.01§	0.16±0.02§	0.08±0.01§#	0.08±0.02§¶
≥50	0.08±0.01§	0.12±0.02§	0.04±0.02†¥	0.06±0.03*
ΔWaist circumference (cm per year)				
18-30	0.91±0.21§	1.01±0.33†	1.00±0.38†	0.64±0.36
30-40	0.33±0.05§	0.47±0.09§	0.16±0.08*¥	0.32±0.11†
40-50	0.40±0.05§	0.48±0.08§	0.36±0.06§	0.28±0.11†
≥50	0.32±0.06§	0.42±0.09§	0.21±0.08†	0.31±0.14*
ΔHip circumference (cm per year)				

18-30	1.10±0.22§	1.54±0.33§	0.32±0.41	1.10±0.38†
30-40	0.33±0.05§	0.40±0.09§	0.32±0.09‡	0.21±0.10*
40-50	0.18±0.05§	0.27±0.07‡	0.17±0.07*	-0.04±0.10¶
≥50	0.25±0.06§	0.38±0.09§	0.14±0.09¶	0.13±0.13

Significance weight increase designated for P<0.05 (*), P<0.01 (†), P<0.001 (‡) and P<0.0001 (§) Weight increase significantly different from the increase at 0-23 km/wk designated for P<0.05 (¶), P<0.01 (¥), P<0.001 (#) and P<0.0001 (∞).

Table 2. Regression slope of annual change in adiposity versus weekly running distance in men and women stratified by age group.

	Body mass (kg/y per km/wk)	BMI (kg/m2 per y per km/wk)	Waist circumference (cm/y per km/wk)
Males			
18-25 years	-0.013±0.006*	-0.004±0.002	-0.005±0.006
25-34 years	-0.009±0.002§	-0.003±0.001§	-0.007±0.002‡
35-44 years	-0.005±0.001§	-0.002±0.000§	-0.004±0.001§
45-54 years	-0.004±0.001§	-0.001±0.000§	-0.004±0.001§
55-64 years	0.000±0.001	0.000±0.000	-0.003±0.001*
65-74 years	0.000±0.000	0.000±0.001	-0.007±0.003†
Age by distance interaction	P<0.0001	P<0.0001	P=0.20
Females			
18-29	-0.006±0.002†	-0.002±0.001*	0.004±0.006
30-39	-0.007±0.001§	-0.002±0.001§	-0.003±0.002
40-49	-0.007±0.001§	-0.002±0.000§	-0.005±0.002*
≥50	-0.003±0.002	-0.001±0.001	-0.003±0.003
Age by distance interaction	P=0.35	P=0.54	P=0.42

Slope significantly different from zero coded as * P<0.05, † P<0.01; ‡ P<0.001, § P<0.0001

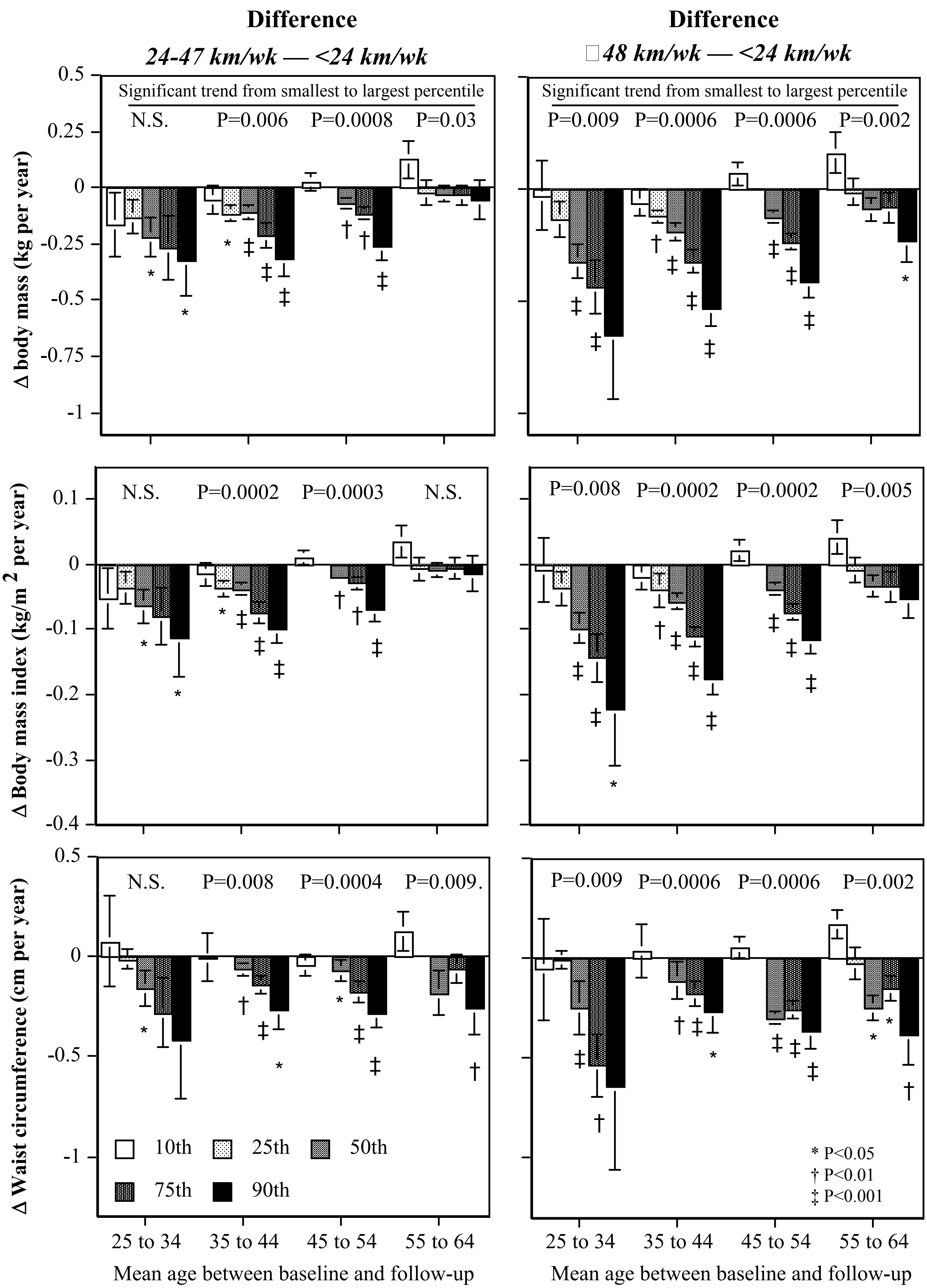
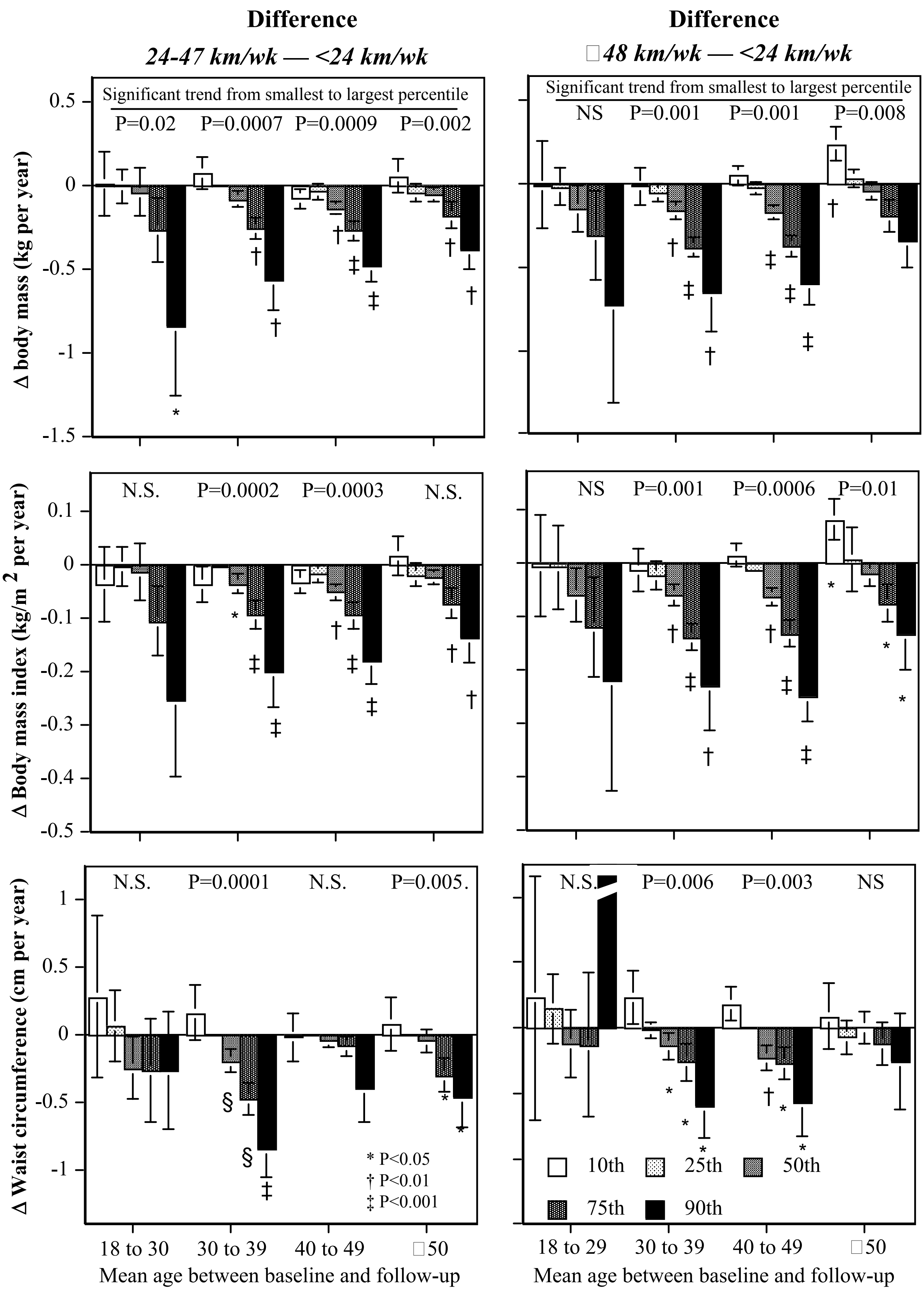

Difference
24-47 km/wk — <24 km/wk
Difference
48 km/wk — <24 km/wk
Significant trend from smallest to largest percentile
N.S.
P=0.006
P=0.0008
P=0.03
P=0.009
P=0.0006
P=0.0006
P=0.002
Δ body mass (kg per year)
N.S.
P=0.0002
P=0.0003
N.S.
P=0.008
P=0.0002
P=0.0002
P=0.005
Δ Body mass index (kg/m 2 per year)
N.S.
P=0.008
P=0.0004
P=0.009.
P=0.009
P=0.0006
P=0.0006
P=0.002
Δ Waist circumference (cm per year)
10th
25th
50th
75th
90th
* P<0.05
† P<0.01
‡ P<0.001
25 to 34
35 to 44
45 to 54
55 to 64
Mean age between baseline and follow-up
Mean age between baseline and follow-up

Figure 1. Difference in the annual changes in body mass (top), BMI (middle), and waist circumference (bottom) between men who less than 24 km/wk and those running 24-47 km/wk (left) and ≥48 km/wk (right). Results are presented by age groups (X-axis) and percentile of weight change (legend). Significance levels for difference greater than zero designated by symbols. Probabilities presented above the bars are for the significance of a linear trend going from the smallest to the highest percentile (percentile effect). Brackets designate ±SE.



Difference
24-47 km/wk — <24 km/wk
Difference
48 km/wk — <24 km/wk
Significant trend from smallest to largest percentile
P=0.02 P=0.0007 P=0.0009 P=0.002
NS P=0.001 P=0.001 P=0.008
Δ body mass (kg per year)
N.S. P=0.0002 P=0.0003 N.S.
NS P=0.001 P=0.0006 P=0.01
Δ Body mass index (kg/m 2 per year)
N.S. P=0.0001 N.S. P=0.005.
N.S. P=0.006 P=0.003 NS
Δ Waist circumference (cm per year)
* P<0.05
† P<0.01
‡ P<0.001
10th 25th 50th
75th 90th
18 to 30 30 to 39 40 to 49 50
18 to 29 30 to 39 40 to 49 50
Mean age between baseline and follow-up
Mean age between baseline and follow-up

Figure 2. Difference in the annual changes in body mass (top), BMI (middle), and waist circumference (bottom) between women who less than 24 km/wk and those running 24-47 km/wk (left) and ≥48 km/wk (right). Results are presented by age groups (X-axis) and percentile of weight change (legend). Significance levels for difference greater than zero designated by symbols. Probabilities presented above the bars are for the significance of a linear trend going from the smallest to the highest percentile (percentile effect). Brackets designate ±SE.