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Abstract: Introduction/Purpose: To assess in men whether exercise affects the estimated age-related increase in adiposity, and contrariwise, whether age affects the estimated exercise-related decrease in adiposity.
Methods: Cross-sectional analyses of 64,911 male runners who provided data on their body mass index (97.6%), waist (91.1%), hip (47.1%), and chest circumferences (77.9%).
Results: Between 18 to 55 years old, the decline in BMI with weekly distance run (slope±SE) was significantly greater in men 25-55 years old than in younger men (slope±SE :-0.036±0.001 vs -0.020 ±0.002 kg/m2 per km/wk). Declines in waist circumference with distance were also significantly greater in older than younger men (P<10-9), i.e., the slopes decreased progressively from -0.035 ± 0.004 cm per km/wk in 18-25 year old men to -0.097± 0.003 cm per km/wk in 50 - 55 year old men). Increases in BMI with age were greater for men who ran under 16 km/wk than for longer distance runners. Waist circumference increased with age at all running distances, but the increase diminished by running further (0.259±0.015 cm/year if running <8 km/wk and 0.154±0.003 cm/year for >16 km/wk). In men over 50 years old, BMI declined -

0.038±0.001 kg/m2 per km/wk run when adjusted for age and declined -0.054±0.003 kg/m2 (increased 0.021±0.007 cm) per year of age when adjusted for running distance. Their waist circumference declined -0.096±0.002 cm per km/wk run when adjusted for age and increased 0.021±0.007 cm per year of age when adjusted for running distance. Conclusion: These data suggest that age and vigorous exercise interact with each other in affecting men's adiposity, and are consistent with the proposition that vigorous physical activity must increase with age to prevent middle-age weight gain.

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Cross-sectional relationships of exercise and age to adiposity in 60,617 male runners

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Running title: Relationship of exercise and age to adiposity

Abbreviations: BMI: body mass index; km kilometer;

Keywords: Exercise, running, aging, body mass index, regional adiposity, waist circumference, hip circumference, chest circumference.

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Conclusion: These data suggest that age and vigorous exercise interact with each other in affecting men's adiposity, and are consistent with the proposition that vigorous physical activity must increase with age to prevent middle-age weight gain.

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Introduction

1 Physically active men are leaner than sedentary men (13). This may be due to self-selection (23), exercise-induced weight loss (29), or the attenuation of age related weight gain (5). Exercise may improve maintenance of weight loss achieved through energy restriction (2). Previous intervention studies have had limited statistical power to resolve the dose-response relationship between vigorous exercise and body weight, or to characterize interactions with other variables such as age.

2 Younger men are also leaner than their elders. Population studies show that men's body weights increase through late middle age, and then decrease with further aging (19,28). The middle-age weight gain is coincident to an increase in intra-abdominal fat (21). Higher intra-abdominal fat is associated with major coronary heart disease risk factors, including insulin resistance, dislipoproteinemia, and hypertension (22,24).

3 Current public health strategies recommend fixed levels of physical activity level to prevent weight gain. For example, it has been suggested that unhealthy weight gain can be prevented by increasing total physical activity to 170% of resting metabolic rate (10,6). This level of activity could be achieved through 60 to 90 minutes per day of brisk walking (6), a level of activity that is substantially greater than current physical activity guidelines by government (17) and nongovernment organizations (30).

4 Williams has proposed that the long-term prevention of weight gain may require greater amounts of exercise with age, rather than the maintenance of a fixed goal (25). He observed that middle-age weight gain appeared to occur in vigorously active men even if their activity was substantial. He hypothesized that men who maintained a constant weekly running distance

would increase total weight and intra-abdominal fat unless they annually increased their distance run by 2.24 km (1.39 mi) per week to compensate for the anticipated weight gain during middle age.

5 This report seeks to substantiate our preliminary observation in a much larger cross-sectional sample of over 60,000 men, the majority of whom exceed current government physical activity guidelines. Specifically, we purpose to: 1) more precisely define the relationships of age and vigorous exercise to BMI and regional adiposity; 2) identify interactions between age and vigorous exercise in their calculated effect on adiposity; and 3) confirmation that weight gain is calculated to occur at any sustained level of activity. Results for women will appear separately.

Methods

6 A two-page questionnaire, distributed nationally at races and to subscribers of the nation's largest running magazine (Runners' World, Emmaus PA), solicited information on demographics (age, race, education), running history (age when began running at least 12 miles per week, average weekly mileage and number of marathons over the preceding five years, best marathon and 10 km times), weight history (greatest and current weight, weight when started running, least weight as a runner, body circumferences of the chest, waist and hips); diet (vegetarianism and the current weekly intakes of alcohol, red meat, fish, fruit; vitamin C, vitamin E and aspirin), current and past cigarette use, prior history of heart attacks and cancer, and medications for blood pressure, thyroid, cholesterol or diabetes. Running distances were reported in miles run per week, body circumferences in inches, and body weights in pounds. These values were converted to kilometers, centimeters, and kilograms for this report. All participant signed

a statement of informed consent and the study protocol was approved by the institional review board.

7 Body mass index (BMI) was calculated as the weight in kilograms divided by height in meters squared. Self-reported body circumferences of the waist, hip and chest were in response to the question “Please provide, to the best of your ability, your body circumference in inches” without further instruction. The relationships between circumference and running distance or age are expected to be weakened by different perception of where waist, hip and chest circumferences lie. However, unless the perceived location varies systematically in relation to running distance or age, this subjectivity is unlikely to produce the relationships reported in the tables and figures.

8 *Statistical analyses* Table 1 presents means±SD; all other statistics are expressed as mean±SE or slopes±SE. The relationships of adiposity to age and running distance were assessed visually prior to the creation of complex least-squares regression models. The relationships of adiposity to age were assessed by stratifying the data by weekly running distance and then determining the average adiposity within predetermined age intervals. Within each stratum of running distance, average adiposity was then plotted as a function of average age. The relationships of adiposity to weekly running distances were assessed by stratifying the data by age groups and then determining the average adiposity within predetermined distance intervals. Within each age stratum, average adiposity was then plotted as a function of average distance run. These initial graphs were created in order to provide statistically more robust assessments than might be expected from complex regression models alone. The partitioning of men by weekly distance run does not include energy expenditure by other vigorous activities, which may lead to some misclassification when drawing inferences regarding total

vigorous activity. However, running was the primary vigorous intensity activity in these men.

Results

9 Of the 64,911 men who provided complete information on age and weekly running distance, 884 were excluded for thyroid medication use, 358 for using medications for diabetes, 1,016 for reporting that they smoked cigarettes currently, and 525 for following strict vegetarian diets. Of the remaining 62,128 men, 60,617 provided complete information on height and weight so that BMI could be calculated (97.6%), 56,611 reported their waist circumferences (91.1%), and 48,380 reported their chest circumferences (77.9%). Hip circumference was also requested, but only 29,283 (47.1%) of men reported their values.

10 Table 1 provides the characteristics of the sample by weekly running distance. Longer distance runners tended to be somewhat younger, consume less alcohol and red meat, and consume more fish and fruit. They also tended to have run more years than the shorter distance runners. Compared to those who ran less than 16 km/wk, those who ran over 64 km/wk had 11% smaller BMI, 8% smaller waist circumferences, 6% smaller hip circumferences, and 5% smaller chest circumferences.

11 *Associations with running distance in young to middle-aged men* Figure 1 (top right panel) displays the average BMI (Y-axis) for men stratified by age, and the X-axis designates the average distance run. The appendix (Table 2) presents the corresponding significance levels (i.e., differences in average BMI by running distance within each age group). The figure shows that BMI declined in association with running distance in 25-54 years old men. The relationships were principally linear, albeit slightly convex (i.e., upwardly

concave or slightly ∪-shaped). Table 2 of the appendix shows that longer running distance was almost always associated with significantly lower BMI; i.e., the comparisons are mostly significant, with the exception of shorter-distance runners under 35 years old.

12 Linear regression analyses were used to estimate quantitatively the changes in BMI associated with running distance. When adjusted for age, the average linear decline in BMI (slope±SE) was -0.036±0.001 kg/ m^2 per km/wk for 25-55 year old men. Within this age range, the declines in BMI per km/wk run were the same for all ages. However, the age-adjusted decline in BMI in 18-25 years old men (-0.020 ±0.002 kg/ m^2 per km/wk) was significantly less than the decline for 25-55 year old men (difference in slopes±SE: 0.015±0.002 kg/m^2 per km/wk, $P<10^{-9}$). The bottom right panel shows that the effect of running distance on BMI was greater (over two and a half times larger) at the 90th percentile than at the 10th percentile of the sample distribution.

13 Figure 2 (right panels) examines the relationship of running distance to body circumferences in men 18-55 years old and the appendix (Table 2) provides the corresponding significance levels. Differences in mean waist circumference across distance categories were mostly significant except for younger runners who ran less than 40 to 48 km/wk (consistent with the results for BMI). Mean differences in chest and hip circumference tended not to be significantly different under 32 and 40 km/wk, respectively, especially among younger men.

14 Linear regression analyses revealed that the declines in waist circumference were significantly greater in older than younger men ($P<10^{-9}$ for trend). The greatest difference in slope was again between 18-25 year old men (-0.035 ± 0.004 cm per km/wk) and 25-30 year old men (-0.070± 0.004 cm per km/wk). After age 30, there were smaller incremental decreases in slope

going from men 25-30 years old to 30-35 years old (slope±SE: -0.075± 0.003 cm per km/wk), 35-40 years old (-0.083± 0.003 cm per km/wk), 40 to 45 years old (-0.085± 0.003 cm per km/wk), 45 to 50 years old (-0.091± 0.003 cm per km/wk), and 50 to 55 years old (-0.097± 0.003 cm per km/wk). The 18-25 year old men also exhibited significantly smaller declines in hip (-0.032±0.007 cm per km/wk) and chest circumferences (-0.033±0.0075 cm per km/wk) with running distance than men 25-55 years old (-0.0728±0.002 and -0.066±0.002 cm per km/wk, respectively), but within the 25-55 year old age interval the relationship of running distance to waist and hip circumferences did not differ by age (P=0.17 for hip, P=0.43 for chest). The curves for waist circumference versus running distance were slightly convex.

15 *Associations with age in young to middle-aged men* BMI rose in association with age at all running distances (Figure 1, top left panel). The rise was sharpest between 18-25 and 25-30 years, and thereafter rose at a diminishing rate until it leveled off at about age 50. For men who ran at least 16 km/wk, the shapes of the curves appear to be the same regardless of running distance, i.e. the relative differences in BMI at different ages appears to be maintained even though the overall height of the curve is lower at longer distances. The appendix (Table 3) presents the significance levels of the differences between age groups within each category of running distance.

16 Age-related weight gain appears have been be greater for men who ran under 16 km/wk than over 16 km/wk Multiple regression analyses suggested that the increase in BMI per year of age was a mathematical function of age rather than a single slope. Men who ran at least 16 km/wk increased their BMI annually by the function “0.237-0.005*age” . Shorter-distance runners increased their BMI annually by the function “ 0.361-0.008*age kg/ m^2 “. The variable “age” in these expressions shows that the slope decreases with age. Setting these functions to zero and solving for age

shows that the age-related increases in BMI appear to plateau between age 45 and 47 years old. Table 3 shows that differences in average BMI between age groups were less likely to achieve statistical significance after age 35 than before (consistent with the diminishing impact of age from the regression analyses).

17 BMI rose in association with age at both the 10th and 90th percentile of BMI distribution (Figure 1, lower left panel). The rise was only slightly greater at the 90th percentile than at the 10th percentile (on average about 13% larger)

18 Figure 2 (top right) shows that waist circumference rose as men aged regardless of their running level, but that the increase was diminished by nearly half among longer-distance runners. Specifically, the increase was greatest in men who ran under 8 km/wk (0.259±0.015 cm per year), intermediate in those averaging 8-16 km/wk (0.219±0.011 cm per year) and least in those averaging over 16 km/wk (0.154±0.003 cm per year). The relationship of waist circumference with age exhibits some curvature (somewhat concave in the least active runners and becoming more linear with increasing weekly distance). Reported hip circumference also rose with age, assuming a concave form at lower weekly distances, and sinusoidal form at the highest distances. When adjusted for running distance, the average rise in hip circumference was 0.242±0.006 cm per year. Chest circumference rose most sharply from the first (18-25 year old) and second age category (26-30 year old), and rose much less dramatically thereafter. Table 3 (appendix) shows that: 1) differences in mean waist circumference between age groups were significant except for 45-50 vs. 50-55 years old; 2) significant differences in men's hip circumference between age groups largely reflected those of waist circumference except that comparisons between proximal age categories were less likely to be significant; and 3) chest circumferences were

significantly lower in men 18-25 years old than older men, but that after age 25 mean chest circumference did not significantly increase with age.

19 *Associations with running distance and age in older men* Figure 3 displays the association of BMI and waist circumference with age and running distance in men 50 and older. The data were divided into 16 km running intervals (instead of 8 km as used in younger men) because only 30% of the men were over 50. The graphs show declines in both BMI and waist circumference with running distance in all age groups (primarily linear, but slightly convex). The overall heights of the curves relating BMI to running distance decreased with age but were otherwise parallel, whereas waist circumference rose modestly with increasing age. Multiple regression analyses showed that BMI declined (slope±SE) -0.038±0.001 kg/ m^2 per km/wk run when adjusted for age and declined -0.054±0.003 kg/ m^2 per year of age when adjusted for running distance. Waist circumference declined (slope±SE) -0.096 ±0.002 cm per km/wk run when adjusted for age and rose 0.021±0.007 cm per year of age when adjusted for running distance. There were no significant interaction between age and running distance in their effects on BMI (P=0.16) or waist circumference (P=0.25).

Discussion

20 The current analyses are unique in their involvement of over 60,000 vigorously active men. They suggest that for men under 50 years old: 1) even among those most vigorously active, BMI and waist, hip and chest circumferences increase with age; 2) BMI and waist, hip and chest circumferences all decline in association with running distance; and 3) running longer distances significantly reduces age-related increases in BMI and waist circumference. Our analyses also characterizes more precisely those men most likely to benefit from vigorous exercise. The exercise-related

declines in BMI were over two and a half times larger at the 90th percentile than at the 10th percentile of the BMI distribution (confirming the greatest potential benefit for the more overweight (26)), and were greater in 25-50 years old than 18-25 years old men (also observed for body circumferences). The large number of observations used in the current analyses has yielded more precise estimates of the relationships between age, exercise and adiposity then has been previously possible (i.e., smaller standard errors).

21 Although prior cross-sectional and longitudinal studies have described the association of age with adiposity (19,28) none have focused specifically on vigorously active men, except for an earlier paper by Williams (25). He reported that BMI increased at a rate (slope±SE) of 0.045 ±0.006 kg/ m^2 and waist circumference at 0.186 ± 0.014 cm per year of age regardless of running distance. The enhanced precision provided in the current study suggest some refinement of these estimates. Analyses presented here suggest that the expected rise in BMI with aging is curvilinear, initially greater among younger men and diminishing to zero between ages 45 and 48. Application of these relationships to the age distribution of the 4,769 men initially studied (25) predicts average increases of 0.035 kg/ m^2 for BMI and 0.163 cm per year for waist circumference, which are lower than the estimates initially published, albeit within two standard errors. Williams also reported that age-related increases in BMI and waist circumference were the same regardless of weekly distance run, whereas the current analyses suggest that increases in men's BMI and waist circumference with age were reduced by 40% for those who ran over 16 km/wk compared to under 8 km/wk.

22 The cross-sectional relationships described in this report support our initial hypothesis that vigorous physical activity must increase with age to prevent middle-age weight gain. The required increases are greater in younger men and decrease somewhat with age. Our calculations suggest that

to maintain the same waist line from age 25 to age 50 requires that men annually increase their running distances by 2.2 km/wk between 25 and 30 years old, 2.05 km/wk between 30 and 35 years old, 1.86 km/wk between 35 and 40 years old, 1.81 km/wk between 40 and 45 years old, and 1.69 km/wk between 45 and 50 years old. Thus a man running 16 km/wk at age 25 would need to increase his weekly running distance to 65.7 km/wk by age 50 in order to maintain his waistline. Although these estimates average about 15% lower than our original calculations (25), they fully support our hypothesis that the investment in physical activity needs to increase with age to prevent unhealthy weight gain. This is different from the Institute of Medicine (10) and other exercise guidelines (1) that advocate the maintenance of target value that remains constant with age. Although our calculation may be faulted for its derivation from cross-sectional data, this same fault also applies to the the recently released Institute of Medicine recommendations for preventing unhealthy weight gain (10).

23 We have also examined relationships of adiposity to age and running distance in 41,582 women, using the same analytic techniques applied here (unpublished observations). Their results present both consistencies and differences with those of the men. In both men and women, BMI increased with age and declined with distance run. The effect of age on BMI was similar in men and women whereas the effect of exercise was greater in men. Specifically, BMI rose 0.022 ±0.003 and 0.017 ± 0.001 kg/ m^2 per year in women who ran 16-32 and over 32 km/wk, respectively. These slopes are comparable to the corresponding increases of 0.018 and 0.020 kg/ m^2 per km/wk in men of similar ages. However, BMI declined more with exercise in 26-55 year old men (-0.036 ±0.001 kg/ m^2 per km/wk) than in women (-0.023±0.002 kg/ m^2 per km/wk). The shapes of the men and women's curves also differ slightly: 1) the relationship between BMI and running distance became increasing convex with age in women whereas convexity is only

weakly discernible in men; and 2) the relationship between BMI and age was primarily linear in women but concave in men.

24 Although age exhibited very different relationships to waist circumferences in men and women, the effects of exercise on these relationships were similar. In men, getting older was associated with expanding waist lines through age 50 even if they exercised substantially, whereas women who ran as little as 8 km/wk were able to maintain or decreased their waist lines as they aged. In both sexes, running longer distances reduced age-related weight gain. However, higher weekly running distances were associated with smaller *increases* in waist circumferences with age in men (40% less for running at least 16 km/wk compared to under 8 km/wk) and greater *decreases* in waist circumference with age in women. The differences in slope between runners who averaged 0-8 km/wk and 56 km/wk were identical in men and women (i.e., 0.123 cm per year in men and 0.124 cm per year in women).

25 Waist circumference declined significantly with running distance in both sexes, however the curves relating waist circumference to weekly distance run largely coincide across age groups for women whereas in men there is nearly a three-fold difference in slopes between the 50-55 than 18-25 year old men. Again, the relationship of running distance to waist circumference became more nonlinear (convex) with age in women but not men. Hip circumference declined similarly with running distance in men and women (-0.073 cm per year in 25-55 men vs. -0.075 and -0.083 cm per year in 25-35 and 35-50 year old women). However, age-related increases in hip circumference were nearly twice as great in men (0.24 cm per year) than women (0.13 cm per year). Increases in women's chest circumferences were generally linear between ages 18 and 50, whereas men's chest circumferences increased sharply between 18 and 30, and plateaued thereafter. Yet

reductions in chest circumference per km/wk run were about a third larger in men (-0.064 cm per year) as in women (-0.048 cm per year). There was a tendency for the curves relating hip and chest circumferences to weekly distance run to become more convex with age in women than men.

26 The relationship of BMI to age in this highly active cross-sectional sample was consistent with the pattern of weight gain and loss observed prospectively by others in primarily sedentary populations. Men's mean weight is reported to increase with age most rapidly between 19 and 24 and becomes progressively less rapid through 45-49 years, remains stable between 50 and 54, and decreases at age 55 and above (8). DiPietro et al reported that changes in fitness (treadmill test duration) were inversely related to changes in weight during 7.5 years of follow-up. Weight increased with age unless treadmill test duration improved by one minute annually (~0.7% annually) (4). Others have also reported that physical activity attenuates age-related weight gain (20,27,7).

27 The significance levels of table 2 suggest that distance run per week was more strongly related to waist circumference than body mass index. This is an unexpected result given that waist circumference is less accurately reported than either body weight or height, and detailed instructions on where to measure the waist line were not provided. The proportion of glycolytic type 2b muscle fibers, which may be etiologically involved in the development of obesity (9,14), also increases with age (14). Physical activity promotes transformations of type 2b muscle fibers to type 2a, and waist circumference is purported to be more strongly related to the proportion of 2a (negatively correlated) and 2b (positively correlated) muscle fibers than BMI.

28 The men's curves confirm our recent observation that association between vigorous activity and BMI is strongest (steepest slope) for the heaviest men

and women (e.g., the 90th percentile, Figure 1) and becomes progressively weaker with increasing leanness (10th percentile). The difference between the 10th and 90th percentile was much greater for BMI versus km/wk run than BMI versus age, suggesting that the difference in response at the high and low percentiles is a property of the exercise effect rather than an attribute of BMI.

29 Diet was not measured in our study so that we are unable to assess to what extent total caloric intake or nutritional composition may have contributed to our findings. There are reports linking both high fat (16) and high carbohydrate (18) intake to excessive weight cross-sectionally. Table 1 shows that longer distance runners consumed less red meat and more fruit and fish, perhaps indicators of lower fat higher carbohydrate diets. Weight gain has been associated prospectively with lower vegetable intake and higher meat intake (11). We are also unable to comment on whether the distribution of caloric intake during the day (i.e., higher caloric intake in the evening vis-a-vis morning (12)) contributed to the observed associations. Cross-sectional observational studies report either no relationship (23) or an inverse relationship (13) between caloric intake and adiposity. However, the precision provided by diet survey instruments is generally regarded as inadequate for detecting the small differences in energy intake required to achieve the gradual increase in weight over time(10).

30 The primary limitation of this and other cross-sectional observational studies in the difficulty of separating the effects of self-selection from the causal effect of physical activity. Physical activity is reported to show a stronger relationship to weight cross-sectionally than to change in weight measured prospectively (3). The slope may be larger for the cross-sectional data than the longitudinal data because effects due to self selection augment the cross-sectional slope or because measurement error for changes in

activity attenuate the longitudinal slope. In women, weight differences between active and sedentary older women trace back to their weights during young adulthood, suggesting leaner women may choose to run (34). This self-selective effect is unlikely to be restricted to women. Alternatively, measurement error may represent a larger proportion of the variance for estimating change in activity longitudinally, than activity cross-sectionally because measurement error is accumulated twice for the change data but only once for the cross-sectional data. The regression slope will underestimate the true slope by the contribution measurement error to the independent variable (i.e. exercise amount). The extent that the cross-sectional associations reported here are the direct consequence of the activity performed or an artifact of self-selection remains to be determined.

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Table 1. Characteristics of male runners					
	Km per week run				
	0-15.9	16-31.9	32-47.9	48-63.9	64+
Percent of Sample	18.4%	35.3%	25.2%	12.4%	8.6%
Age (years)	44.87 ± 11.61	45.58 ± 10.7	44.94 ± 10.55	43.76 ± 10.39	40.76 ± 11.44
Education (years)	16.46 ± 2.52	16.5 ± 2.43	16.38 ± 2.49	16.28 ± 2.58	16.06 ± 2.59
Alcohol (ml/wk)	76.24 ± 105.38	83.63 ± 112.96	82.01 ± 115.37	78.47 ± 112.33	70.3 ± 113.36
Beef (servings/wk)	3.33 ± 3.01	3.06 ± 2.76	2.81 ± 2.65	2.61 ± 2.65	2.49 ± 2.7
Fish (servings/wk)	1.49 ± 1.47	1.48 ± 1.4	1.51 ± 1.47	1.54 ± 1.63	1.48 ± 1.49
Fruit (servings/wk)	9.07 ± 8.3	10.12 ± 11.11	11.12 ± 8.77	11.79 ± 9.21	12.38 ± 10.32
Years run	12.7 ± 8.77	12.04 ± 8.34	12.72 ± 8.16	13.27 ± 7.88	13.92 ± 8.17
Body mass index (kg/m^2)	25.24 ± 3.23	24.51 ± 2.7	23.89 ± 2.56	23.23 ± 2.31	22.47 ± 2.3
Waist circumference (cm)	87.13 ± 7.25	85.65 ± 6.01	84.04 ± 5.62	82.37 ± 5.17	80.42 ± 5.13
Hip circumference (cm)	95.92 ± 8.78	95.27 ± 7.79	93.87 ± 7.62	92.4 ± 7.28	89.94 ± 7.6
Chest circumference (cm)	104.08 ± 8.39	103.16 ± 7.53	101.99 ± 7.35	100.62 ± 7.42	99.06 ± 7.71

Figure 1. Cross-sectional relationship of body mass index to age and weekly distance run in men 18 to 55 years old (Corresponding significance levels are presented on tables 2 and 3).

Figure 2. Cross-sectional relationship of waist, hip and chest circumference to age and weekly distance run in men 18 to 55 years old (Corresponding significance levels are presented on tables 2 and 3).

Figure 3. Cross-sectional relationship of body mass index (BMI) and waist circumference to age and weekly distance run in men 50 years and older (Corresponding significance levels are presented on tables 2 and 3).

Appendix

The large number of comparisons between age or distance categories required us to develop of a compressed format for presenting the statistical significance of the differences between groups. Table 2 displays the corresponding significance levels for the differences between distance-groups when stratified by age. Each cell in the table contains a string of seven dashes or integers that correspond to the following seven age groups in Figures 1 and 2: 18-25 years, 25-30 years, 30-35 years, 35-40 years, 40-45 years, 45-50 years, and 50-55 years old. The cells compare the average BMI for the distances represented by the row and the distances represented by the column (corresponding to the partitioning by km/wk along the X-axis in Figure 1). Significance levels are coded as nonsignificant ("-" representing $P>0.01$) or by the integer "N" corresponding to $P<10^{-N}$, N=2...9. For example, the second column of the first row of Table 2 contains the entry "----462". The seven dashes and digits correspond to the significance of the difference in average BMI for men running 0-8 km/wk (represented by the row) and men running 8-16 km/wk (represented by the column) for different age groups: nonsignificant for men 18-25, 25-30, 30-35, and 35-40 years old, $P<10^{-4}$ for 40-45 year old men, $P<10^{-6}$ for 45-50 year old men, and $P<10^{-2}$ for 50 to 55 year old men. This compressed format allows the estimation of Bonferroni correction for multiple comparisons ($P<10^{-3}$ required in Table 2 to ensure a simultaneous level of significance of $P<0.05$ for 28 comparisons among distances categories within each age group). Table 3 displays the corresponding significance levels for the differences between age groups when stratified by running distance. The string of eight dashes or integers correspond to the following eight categories of running distance: 0-8 km/wk, 8-16 km/wk, 16-24 km/wk, 24-32 km/wk, 32-40 km/wk, 40-48 km/wk, 48-64 km/wk, and over 64 km/wk. The cells compare the average BMI for the age group represented by the row and the age group represented by the column. For example, the second column of the first row of

Table 3 contains the entry “89794779”, or that men 25-30 years old have significantly different (higher) BMI than men 18-25 years old at $P<10^{-8}$ when running 0-8 km/wk, $P<10^{-9}$ when running 8-16 km/wk, $P<10^{-7}$ when running 16-24 km/wk, $P<10^{-9}$ when running 24-32 km/wk, $P<10^{-4}$ when running 32-40 km/wk, $P<10^{-7}$ when running 40-48 and 48-64 km/wk, and $P<10^{-9}$ when running over 64 km/wk.

Table 2. Significance difference in men's average BMI and body circumferences between age groups.							
	Age groups						
	18-25 y	25-30 y	30-35 y	35-40y	40-45 y	46-50 y	50-55 y
Body mass index (BMI)							
18-25 y		89794779	99998999	99999999	99999999	99999999	99999999
25-30 y	89794779		-22-----	2423-345	34322567	55432789	47342389
30-35 y	99998999	-22-----		---2-2-2	3--2-424	6--4-737	42-4-235
35-40 y	99999999	2423-345	---2-2-2		--------	2----2--	--------
40-45 y	99999999	34322567	3--2-424	--------		--------	--------
45-50 y	99999999	55432789	6--4-737	2----2--	--------		--------
50-55 y	99999999	47342389	42-4-235	--------	--------	--------	
Waist circumference							
18-25 y		5888724-	99999598	99999999	99999999	99999999	99999999
25-30 y	5888724-		-232---4	57993879	99999999	99999999	99999999
30-35 y	99999598	-232---4		32282662	87899999	99999999	99999999
35-40 y	99999999	57993879	32282662		-2333253	79998989	79999998
40-45 y	99999999	99999999	87899999	-2333253		3432-2-3	38762462
45-50 y	99999999	99999999	99999999	79998989	3432-2-3		------3-
50-55 y	99999999	99999999	99999999	79999998	38762462	------3-	
Hip circumference							
18-25 y		43332---	75983544	99999999	99999999	99999999	99999999
25-30 y	43332---		--2--32-	-3663767	38795999	79997999	69999999
30-35 y	75983544	--2--32-		-2-23-23	47265788	99797999	99999999
35-40 y	99999999	-3663767	-2-23-23		-----5--	84362733	56695983
40-45 y	99999999	38795999	47265788	-----5--		3-22----	22643-4-
45-50 y	99999999	79997999	99797999	84362733	3-22----		------2-
50-55 y	99999999	69999999	99999999	56695983	22643-4-	------2-	
Chest circumference							
18-25 y		65992596	97995899	97995999	98996999	99997999	98994999
25-30 y	65992596		--------	2------2	3-----2-	5---22-2	5-------
30-35 y	97995899	--------		------22	------4-	2-----33	2-----2-
35-40 y	97995999	2------2	------22		--------	2-------	--------
40-45 y	98996999	3-----2-	------4-	--------		--------	--------
45-50 y	99997999	5---22-2	2-----33	2-------	--------		----2---
50-55 y	98994999	5-------	2-----2-	--------	--------	----2---	

The 8 character entries within each cell designate the significance of the mean difference between the column and row age groups for men who reported running 0-8 km/wk, 8-16 km/wk, 16-24 km/wk, 24-32 km/wk, 32-40 km/wk, 40-48 km/wk, 48-64 km/wk, and over 64 km per week, respectively. Significance levels are coded "-" P>0.01; "2" P<0.01; "3" P<0.001; "4" P<0.0001; "5" P<0.00001; "6" P<0.000001; "7" P<0.0000001; "8" P<0.00000001; and "9" P<0.000000001.

Table 3. Significance difference in men’s average BMI and body circumferences between running distance group								
	Age							
	0-8 km	8-16 km	16-24 km	24-32 km	32-40 km	40-48 km	48-64 km	≥ 64 km
Body mass index (BMI)								
0-8 km		----462	---8999	-279999	-379999	3799999	6999999	9999999
8-16 km	----462		---4336	-299999	-399999	2999999	5999999	9999999
16-24 km	---8999	---4336		--5-452	-267998	2899999	4999999	9999999
24-32 km	-279999	-299999	--5-452		---3322	-499879	4999999	9999999
32-40 km	-379999	-399999	-267998	---3322		-2632-3	3899999	9999999
40-48 km	3799999	2999999	2899999	-499879	-2632-3		-226882	9999999
48-64 km	6999999	5999999	4999999	4999999	3899999	-226882		4598957
≥ 64 km	9999999	9999999	9999999	9999999	9999999	9999999	4598957	
Waist circumference								
0-8 km		---245-	---6898	-279999	-289999	-699999	5999999	9999999
8-16 km	---245-		-----34	-275899	--79999	-799999	3999999	6999999
16-24 km	---6898	-----34		--63464	--79999	-899999	3999999	8999999
24-32 km	-279999	-275899	--63464		---3335	-399999	3999999	8999999
32-40 km	-289999	--79999	--79999	---3335		-253332	-799999	3999999
40-48 km	-699999	-799999	-899999	-399999	-253332		2247694	5999999
48-64 km	5999999	3999999	3999999	3999999	-799999	2247694		-769959
≥ 64 km	9999999	6999999	8999999	8999999	3999999	5999999	-769959	
Hip circumference								
0-8 km		-----2-	-----5-	----273	----394	-325497	-446999	-899999
8-16 km	-----2-		-------	-------	----343	-3-5465	-336998	-799999
16-24 km	-----5-	-------		-------	--2--42	-348255	-389998	2899999
24-32 km	----273	-------	-------		-----2-	-2-4-32	-346795	3899999
32-40 km	----394	----343	--2--42	-----2-		-3-3---	-3-4442	2989989
40-48 km	-325497	-3-5465	-348255	-2-4-32	-3-3---		----22-	2-64868
48-64 km	-446999	-336998	-389998	-346795	-3-4442	----22-		2-42326
≥ 64 km	-899999	-799999	2899999	3899999	2989989	2-64868	2-42326	
Chest circumference								
0-8 km		-----23	----255	---2398	---5899	--47999	--99999	-399999
8-16 km	-----23		-------	----252	-224768	-365999	2599999	2999999
16-24 km	----255	-------		--2--2-	-223436	-375998	2699999	2999999
24-32 km	---2398	----252	--2--2-		-2--2-3	-322735	2699999	2999999
32-40 km	---5899	-224768	-223436	-2--2-3		-----2-	3-85492	3499999
40-48 km	--47999	-365999	-375998	-322735	-----2-		2-33-3-	2387986
48-64 km	--99999	2599999	2699999	2699999	3-85492	2-33-3-		--2-623
≥ 64 km	-399999	2999999	2999999	2999999	3499999	2387986	--2-623	

The 7 character entries within each cell designate the significance of the mean differen between the column and row running distance groups for men who were 18-25 y, 26-30 y, 31 35 y, 36-40 y, 41-45 y, 46-50 y, and 50-55 y, respectively. Significance levels are cod “-“ P>0.01; “2” P<0.01; “3” P<0.001; “4” P<0.0001; “5” P<0.00001; “6” P<0.000001; “7” P<0.0000001; “8” P<0.00000001; and “9” P<0.000000001.

Figure

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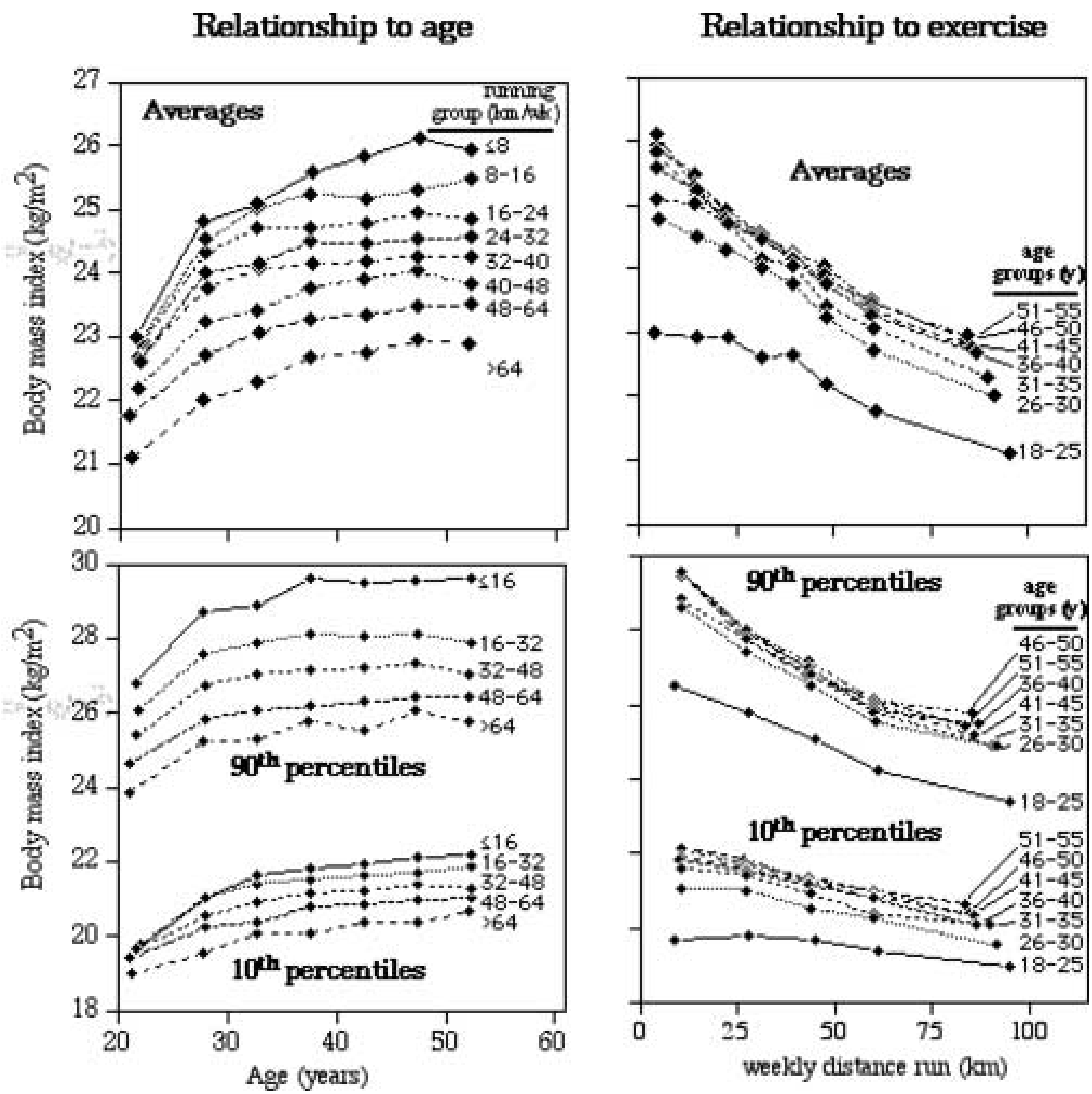

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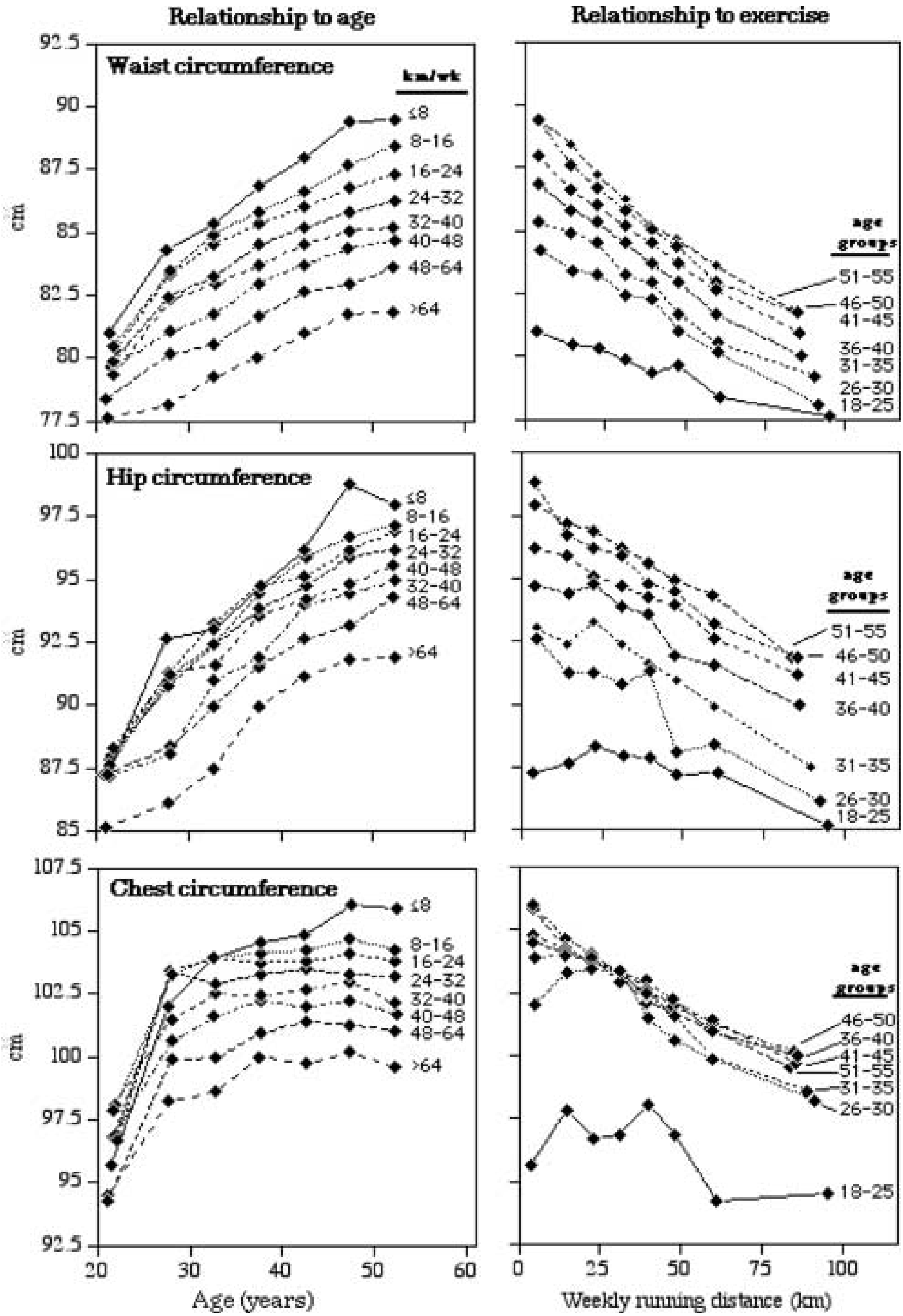

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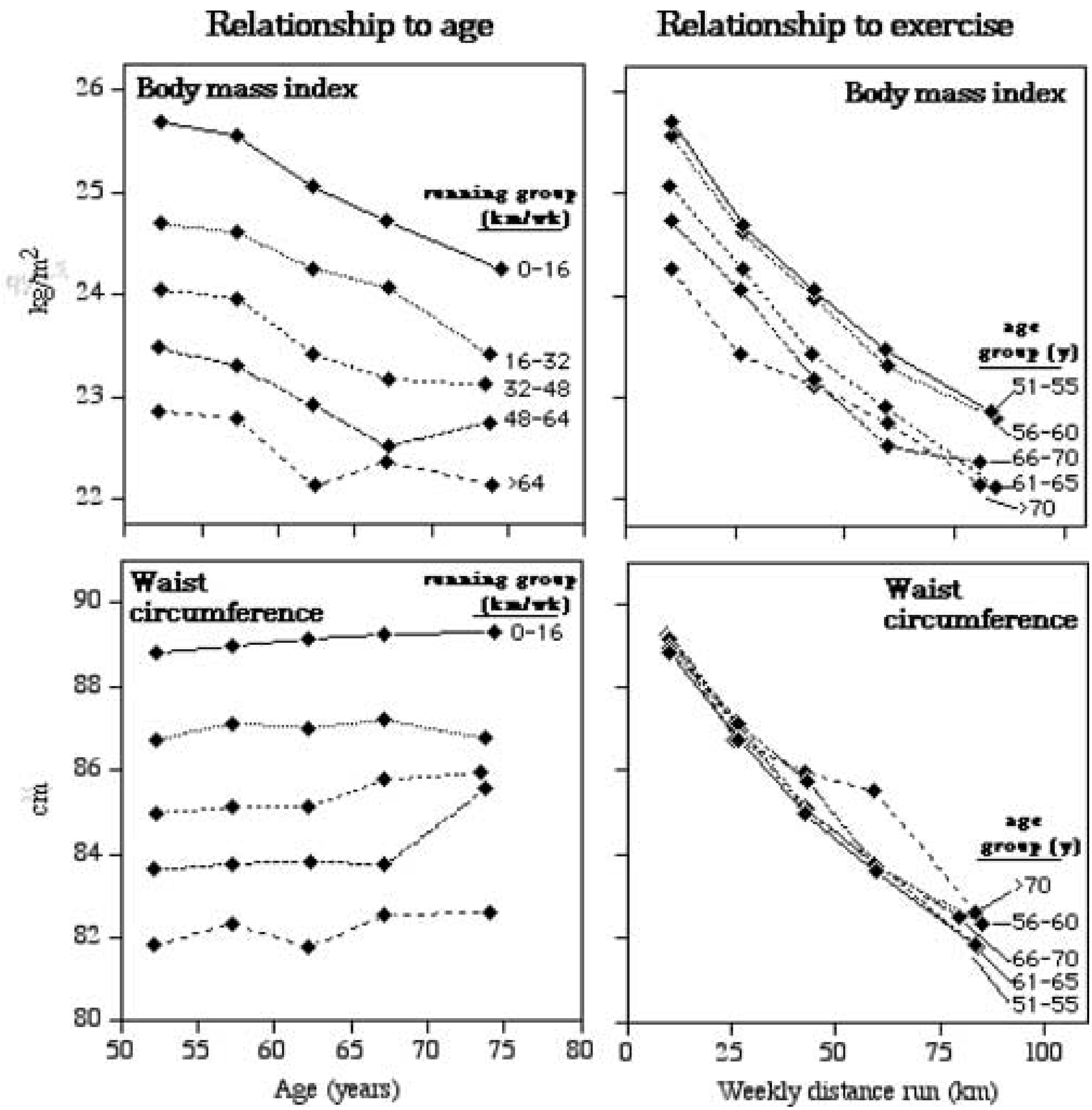

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