Age-related weight gain, and age-specific weight loss, in 41,582 physically active women studied cross-sectionally

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Short title: Weight gain with age in women runners

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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Objective: To assess in women, whether exercise affects the estimated age-related increase in adiposity, and contrariwise, whether age affects the estimated exercise-related decrease in adiposity.

Subjects and Design: Cross-sectional analyses of 64,911 female runners who provided data on their body mass index (97.6%), waist (91.1%), and chest circumferences (77.9%).

Results: Age affected the relationships between vigorous exercise and adiposity. The decline in BMI per km/wk run was linear in 18-25 year olds (-0.023 ± 0.002 kg/m^2 per km run) and became increasingly nonlinear (convex or upwardly concave) with age. The waist, hip and chest circumferences declined significantly with running distance across all age groups, but the declines were 52-58% greater in older than younger women ($P<10^{-5}$). The relationships between body circumferences and running distance became increasingly convexity (upward concavity) in older women. Conversely, vigorous exercise diminished the apparent increase in adiposity with age. The rise in average BMI with age was greatest in women who ran less than 8 km/week (0.065 ± 0.005 kg/m^2 per y), intermediate of women who ran 8-16 km/wk (0.025 ± 0.004 kg/m^2 per y) or 16-32 km/wk (0.022 ± 0.003 kg/m^2 per y), and least in those who averaged over 32 km/wk (0.017 ± 0.001 kg/m^2 per y). Before age 45, waist circumference rose 0.055 ± 0.026 cm in for those who ran 0-8 km/wk, showed no significant change for those who ran 8-40 km./wk, and declined -0.057 ± 0.012 and -0.069 ± 0.014 cm per year in those who ran 40-56 and over 56 km/wk. The rise in hip and chest circumferences with age were significantly greater in women who ran under eight km/wk than longer distance runners for hip (0.231 ± 0.018 vs 0.136 ± 0.004 cm/year) and chest circumferences (0.137 ± 0.013 vs 0.053 ± 0.003 cm/year).

Conclusions: These cross-sectional associations suggest that in women, age and vigorous exercise interact with each other in affecting adiposity. The extent that these cross-sectional associations are causally related to vigorous exercise or are the consequence of self-selection remains to be determined.

Women generally gain weight as they age {1,2}. Cross-sectional studies show older women are heavier {3}, and longitudinal studies show weight gain over time {4-7}. The gain is generally greater before age 55 than after {8}. Some have proposed that lower physical activity and resting metabolic rate contribute to middle-age weight gain in women {9-11}. The proportion of glycolytic type 2b muscle fibers, which may be an etiologically involved in the development of obesity {12,13}, also increases with age {13}. Increased parity, particularly among less affluent, less educated women, may also contribute {14}. Low social-economic status {15} and smoking cessation also increase women's risk of gaining fat{16}.

Physically active women are leaner than sedentary women {17}. This may be due to self-selection, exercise-induced weight loss, or the attenuation of age related weight gain {18}. The causal relationship between vigorous exercise and weight loss, though logically self-evident, is not strongly supported by intervention trials, particularly in premenopausal women {18-21}, although examples exist {22}. Exercise may improve maintenance of weight loss achieved through energy restriction {23.24}. There is also some evidence that the leanness of physically active older women reflects their leanness during early adulthood (suggesting a component of self-selection) {25}.

This paper examines the contributions of age-related weight gain and vigorous exercise to the relative leanness of physically active women. Although prior cross-sectional and prospective studies have described age-related weight gain in primarily sedentary women, none have specifically focused on women who are vigorously active. Despite their many advantages, past intervention studies have had limited statistical power to resolve the dose-response relationship between vigorous exercise and weight or the influence of other variables such as age. The availability of over 40,000 vigorously active women enables us to examine the complex relationships of adiposity with age and vigorous exercise.

Methods

A two-page questionnaire, distributed nationally at races and to subscribers of the nation's largest running magazine (Runners' World, Emmaus PA), solicited information on demographics (age, race, 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.

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.

The circumference dimensions, rather than their ratios, are reported because waist circumference has been shown to be a better indicator of intra-abdominal fat {26}. Analyses are reported for chest circumference even though it has not been frequently used as a measure of adiposity. However, others have reported chest circumference as a measure of upper body obesity that exhibits relationships to plasma leptin levels that were not apparent for waist or hip measurements {27} and that endurance-oriented physical activity significantly decreases chest diameter {28}. Thoratic fat has also been related to low-density lipoprotein levels {29}. Bra-cup sizes were coded on a five-point scale from 1 (A cup), 2 (B cup), 3 (C cup), 4 (D cup), and 5 (E cup or larger).

Statistical analyses Table 1 presents means±SD; all other values are given 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. We assessed the relationships of adiposity to age 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. We assessed the relationships of adiposity to weekly running distances 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. The partitioning of the data by running distance differed slightly depending upon whether running distance was used as the independent variable (0-8, 8-16, 16-24, 24-32, 32-40, 40-48, 48-64, >64 km) or for stratification (0-8, 8-16, 16-24, 24-32, 32-40, 40-56, >56 km). Fewer strata produced simpler, less complex graphs, while more points within each stratum resolves more clearly the shape of the curves. Similarly, the data were partitioned differently depending upon whether age was used as the independent variable (18-25, 26-30, 31-35, 36-40, 41-45, 46-50, 51-55, 56-60, and >60 years) or for stratification (the curves for women 51-55, 56-60, and >60 years old were similar and were therefore combined).

The large number of comparisons between age or distance categories required the use 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 age-groups when stratified by weekly running distances. Each cell in the table contains a string of seven dashes or integers that correspond to the following seven running distance groups of Figure 1: 0-8 km/wk, 8-16 km/wk, 16-24 km/wk, 24-32 km/wk, 32-40 km/wk, 40-56 km/wk, and •56 km/wk. The cells compare the average BMI for the age group represented by the row and the age group represented by the column (corresponding to the partitioning of age 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 last column of the first row of Table 2 contains the entry “633--2-”. The seven dashes and digits correspond to the significance of the difference in average BMI between 18-24 year old women (represented by the row) and women over 60 (represented by the column) at different running levels: $P<10^{-6}$ for women who ran 0-8 km/wk, $P<10^{-3}$ for women who ran 8-16 km/wk, $P<10^{-3}$ for women who ran 16-24 km/wk, nonsignificant for women who ran 24-32 km/wk and 32-40 km/wk, $P<10^{-2}$ for women who ran 40-56 km/wk, and nonsignificant for women who ran •56 km/wk. This compressed format allows the estimation of Bonferroni correction for multiple comparisons ($P<10^{-3}$ in Table 2 to ensure a simultaneous level of significance of $P<0.05$ for 36 comparisons among age groups within each distance category). Table 3 displays the corresponding significance levels for the differences between running distances when stratified by age. The string of seven dashes or integers corresponds to the following seven age groups: 18-25 y, 26-30 y, 31-35 y, 36-40 y, 41-45 y, 46-50 y, and •50 y. The cells compare the average BMI for the distance represented by the row and the distance represented by the column. For example, the last column of the first row of Table 3 contains the entry “9999999”, or that women running over 64 km/wk have significantly lower average BMI ($P<10^{-9}$) than those that run under 8 km/wk for all seven age groups.

Results

Of the 46,759 women who provided complete information on age and weekly running distance, 2,140 were excluded for thyroid medication use, 134 for using medications for diabetes, 1,022 for reporting that they smoked cigarettes currently, and 913 for following strict vegetarian diets. Of the remaining 42,550 women, 41,961 provided complete height and weight information so that BMI could be calculated (98.6%), 37,258 reported their waist circumferences (87.6%), 37,511 reported hip circumferences (88.2%), 36,572 reported their chest circumferences (86.0%), and 38,298 reported their bra cup sizes (90%).

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 fruit. Compared to those who ran less than 16 km/wk, those who averaged over 64 km/wk had 18% smaller bra cups, 10% lower BMI, 8% lower waist, circumferences, 7% lower hip circumferences, and 4% lower chest circumferences.

BMI versus running distance Figure 1 (top) displays the average BMI (Y-axis) for women stratified by age, and the X axis designates corresponding running distance within the distance group. Table 3 presents the corresponding significance levels (see methods for explanation). Longer weekly running distances were related to lower average BMIs in all seven age strata. The decline was linear in 18-25 year olds (i.e., BMI decreased -0.023±0.002 kg/m^2 per km run). The curves became increasingly more nonlinear with age; specifically they become generally convex (i.e., upwardly concave or slightly U-shaped). To assess this formally, we included a km^2 term to the regression curves fitted to the data within each age stratum. The coefficient for the km^2 term determines the amount of curvature (the coefficient for km^2, multiplied by 2,is also the second derivative). For women 18-25, 26-30, 31-35, 36-40, and >40 years old, the regression coefficients (β±SE) for km^2 (x10^{-4}) were 0.64±0.36, 1.05±0.37, 1.72±0.37, 2.76±0.37, and 4.60±0.30. The increasing magnitude of the km^2 coefficients from the youngest to oldest women confirms numerically the increasing curvature of the regression graphs with age. The positive coefficients for km^2 means that the decline in BMI is greater when running distance is rose at lower distances (e.g., from 10 to 11 km/wk) than at higher distances (e.g., from 50 to 51 km/wk). In Figure 1, the increasing convexity (U-shape ness) with age is shown by the greater decline in average BMI between running 0-8 km/wk and 8-16 km/wk in older women. It is also shown in the smaller average BMI difference between the penultimate (56-64 km/wk) and highest distance categories (•64 km/wk) in older women.

BMI versus age Figure 1 (bottom) displays the average BMI (Y-axis) for women stratified by distance run, and the X axis designates corresponding average age within the age group. Tables 2 present the corresponding significance levels. Average BMI rose as women aged for all running distances. However, the magnitude of the yearly rise was affected by running distance ($P<10^{-9}$), i.e., greatest in women who ran less than 8 km/week (0.065±0.005 kg/m^2 per y), intermediate of women who ran 8-16 (0.025±0.004 kg/m^2 per y) or 16-32 km/wk (0.022±0.003 kg/m^2 per y), and least in those who averaged over 32 km/wk (0.017±0.001 kg/m^2 per y). In women who ran under 8 km/wk, the rise in BMI appeared to accelerate with age after their middle-thirties, whereas at longer distances the age-related rise in BMI was essentially linear. Table 2 suggests that average BMIs were significantly less in women 35 and under vis-a-vis those over 40 years.

Circumferences versus running distance Figure 2 (right) examines the relationship of running distance to body circumferences. In every age category, waist, hip and chest circumferences declined significantly in association with weekly distance run. The declines were significantly greater in older than younger women. This was also demonstrated by stratifying the women by age and within each stratum using least-squares regression to calculate the age-adjusted linear decrease. This approach showed that waist circumference declined -0.056±0.005, -0.063±0.004, -0.074±0.004, -0.083±0.004, -0.090±0.004 and -0.107±0.005 cm/km for women 18-25, 26-30, 31-35, 36-40, 41-50, and over 50 years old, respectively. Hip circumference declined -0.063±0.006, -0.075±0.003, -0.083±0.002 and -0.109±0.005 cm/km for women 18-25, 25-35, 35-50, and over 50 years old, respectively. Chest circumference declined -0.036±0.002, -0.040±0.003, -0.050±0.002, -0.057±0.004, and -0.063±0.004 cm/km for women 18-30, 31-35, 36-45, 46-50, and over 50 years old. Alternatively, combining all of the data into a single regression model that included age, running distance and the interaction between age and distance revealed strongly significant age by distance interactions for waist ($P<10^{-18}$), hip ($P<10^{-5}$), and chest circumferences ($P<10^{-6}$). The calculations suggest that each kilometer run per week by an 18 year old women is expected to be associated with reductions of -0.0487 cm, -0.0674 cm, and -0.0346 cm in waist, hip and chest circumference, respectively. Each additional year of age is estimated to increase the reduction by 3.32% for waist, 1.17% for hip, and 1.85% for chest per kilometer run (i.e, the reduction in waist circumference is estimated to be 66.4% greater for a 48 year old women than in an 18 year old women, or -0.0973 vs. -0.0487 cm per kilometer run).

The graphs of Figure 2 suggest that the relationships between body circumferences versus running distance exhibit increased convexity (upward concavity) as women age. When age, distance run (km), and km^2 were used in the regression curves fitted to each age stratum, the coefficients for km^2 for 18-25, 26-30, 31-35, 36-40, 41-45, 46-50, and >50 years old women ($x10^{-4}$) were 4.1, 6.8, 5.4, 7.4, 9.3, 10.1, and 13.7 for waist circumference, 0.2, 3.7, 5.8, 5.4, 7.3, 6.7, and 10.5 for hip circumference, and 1.3, 2.8, 2.2, 2.8, 5.3, 5.5, and 7.8 for chest circumference. These coefficients were all significant ($P<0.01$) except hip and chest circumference in 18-24 year olds. The progressive increase in the km2 coefficients with age signifies increasing curvature with age.

Circumferences versus age Although waist circumference increased with age in the least active women, especially after age 30, the top right panel of Figure 3 suggest that at longer weekly distances there were no rise in mean waist circumference before age 50, and in fact waist circumferences declined with age in women who ran at least 40 km per week. Table 2 shows that average waist circumferences for the least active women were significantly higher after age 45 than between 18 and 35 years old. Before age 45, linear regression slopes within each distance stratum showed waist circumference rose 0.055 ± 0.026 cm per year in for those who ran 0-8 km/wk, showed no significant change for those who ran 8-40 km/wk, and declined -0.057 ± 0.012 and -0.069 ± 0.014 cm per year in those who ran 40-56 and over 56 km/wk. The interaction between age and running distance was strongly significant under age 45 ($P<10^{-9}$). After age 45 waist circumference rose 0.083 ± 0.013 cm per year of age regardless of running distance.

Hip and chest circumferences increased linearly with age through age 55, and tended to plateau thereafter. The rise prior to 55 years old was significantly greater in women who ran under eight km week than longer distance runners for hip (0.231 ± 0.018 vs 0.136 ± 0.004 cm/year) and chest circumferences (0.137 ± 0.013 vs 0.053 ± 0.003 cm/year). Table 2 suggests that prior to age 40, each 10-year increment in age was associated with a significant rise in hip circumference, but that after 45 hip circumferences were relatively stable at all running distances. Chest circumference exhibited a weaker but similar pattern as hip circumference.

Bra cup size versus age and running distance Figure 3 (lower panel) shows that bra cup sizes declined in association with running distance regardless of age. The upper panel of Figure 3 shows that the relationship of cup size to age was similar for all distance categories: i.e., they mostly showed an initial rise through the third decade, a decline during the fourth decade, and rose again starting in the fifth decade. Regression analyses suggest that when adjusted for weekly running distance, bra cups rose 0.020± 0.005 per year for 18-26 year old women, declined -0.011± 0.001 per year for 27-42 year old women (-0.009± 0.001 when adjusted for parity), and rose 0.011± 0.001 per year for women over 42 years old (-0.007± 0.002 when adjusted for menstrual status). When adjusted for age, bra cup size declined by -0.006±0.001 sizes per kilometer run.

Parity and menstrual status versus age and running distance When adjusted for age and distance run, menstrual status was unrelated to BMI and circumferences of the waist, hip and chest. However, women who were currently menstruating reported having smaller bra cup (-0.057±0.012 sizes) than nonmenstruating women. Women who reported having had two or more children had slightly higher BMI (0.028±0.008, P=0.006) and waist circumferences (0.117±0.03, P=0.0002), and smaller bra cups (-0.011±0.004, P=0.005) than women having fewer children when adjusted for age and running distance.

Discussion

The analyses presented in this report are unique in their involvement of over 40,000 vigorously active women. The large sample size provides precise estimates of means, percentiles and regression coefficients that permit the resolution of the detailed relationships between age, adiposity and vigorous exercise. This permits the creation of graphs from the stratification of the data by age and by distance run, so that the nature of the relationship may be assessed visually prior to the creation of complex regression models. This is important because least squares regression (particularly polynomial regression models) may yield complex solutions that are misleading due to outliers or incorrect model specifications. The least-squares minimization can yield numerical solutions that are not visually obvious. We believe that the nonlinearities and interactions revealed by our application of robust graphical techniques to a large size sample are likely to reflect the true relationships rather than effects due to outliers or modeling errors.

Another strength of these data is the availability of self-reported regional adiposity measurements. Measurement error in the dependent variable (including those due to rounding) will affect the precision of the regression coefficients but should not bias them. Thus even though self-reported waist, hip and chest measurements are less accurate than total weight, the large sample size will yield numerically precise estimates of the expected circumference for a given running distance or age. The distribution of body fat may provide a more accurate assessment of the health consequence of adiposity {30,31} and the benefits of vigorous exercise than total weight. Others report significant reductions in hip circumference in women who lose weight by dieting, although the implications of this reduction on health are unclear (smaller hip circumference is associated with a greater risk type 2 diabetes {32} and poorer glucose tolerance {33}, but lower breast cancer risk {34}). Physical activity promotes transformations of type 2b muscle fibers to type 2a{35}, and waist circumference is purported to be more strongly related to the proportion of 2a (discordant) and 2b (concordant) muscle fibers than BMI {13}. This may account in part for the significant decrease waist circumference but not total weight several studies of premenopausal overweight women who take up walking for exercise {36,37}.

Despite the large number of studies that report anthropomorphic data in women, and evidence suggesting cup size improves the prediction of women's body density {38}, there is a paucity of research on breast size in relation to weight loss, exercise, or health. This may be because total breast volume is reported to be only moderately correlated with total percent body fat (r =0 .40), and breast weight on average account for a small percentage total fat weight (3.5%) and no more than 12 percent of the estimated quantities of sex-specific fat {39}. Yet, the percentage change in women's regional adiposity measurements was over two-fold larger for bra cup (18%) than for waist (8%), hip (7%) or chest (4%) circumferences. The metabolic characteristics of breast fat show similarities and differences to both abdominal and gluteofemoral fat depots. In premenopausal women, mammary and abdominal adipocytes have lower lipoprotein lipase activity and higher lipolytic responsiveness and sensitivity than femoral adipocytes {40}. These differences in lipoprotein lipase and lipolysis diminish after menopause {40}. The mRNA and protein expression of resistin, a hormone that may play a role linking obesity with type 2 diabetes, is lower in thigh and breast adipocytes than abdominal fat {41}.

Our analyses show that the relationships between age, physical activity, and adiposity are indeed complex, i.e. they are nonlinear and are not simple additive effects. The decline in BMI per km/wk run was linear in 18-25 year olds and became increasingly more nonlinear (convex or upwardly concave) with age. In every age category, the waist, hip and chest circumferences declined significantly with running distance, but the declines were 52-58% greater in older than younger women ($P<10^{-5}$). The relationships between circumferences and running distance exhibited increased convexity (upward concavity) as women aged. Although convexity represented significant departures from linearity, often these departures were minor and the description of the relationships in terms of their linear approximations were mostly correct. Nevertheless, they highlight interesting differences at the extremes of the age range, such as a greater potential effect of small amounts of activity on BMI in older vis-a-vis younger women, or effects due to self-selection that are age dependent. This might account in part for the suggestion that weight loss by exercise is more successful in postmenopausal than premenopausal women {19,22}.

The dramatic reductions in adiposity with physical activity reported here are much larger than those reported in other population-based samples. One analyses of studies that used doubly-labeled water to measure physical activity in primarily sedentary women under 50 y old concluded that activity was related to body fat in males but not females {3,43}. Some training studies report that the same exercise challenge is less likely to cause weight loss in women than men, possible due to their greater tendency for women to compensate for energy expenditure through increased energy intake {43,44}.

It also has been suggested that training may produce less weight loss in women than men because abdominal fat (generally higher in males) is more responsive to exercise than gluteofemoral fat (generally higher in females) {45}. However, this distinction is inconsistent with the strong inverse relationships displayed in Figure 2 between running distance and hip circumferences. Other reports demonstrate strong relationships between women's adiposity and their physical activity {46}, suggest that leisure-time physical activity is more strongly related to adiposity in women but not men {47-49}, or that the gender difference depends upon whether the activity is of moderate (greater effect in women) or vigorous intensity (greater effect in men) {50}.

We observed that BMI, hip and chest circumference all increased through the middle fifties and tended to plateau thereafter, which is consistent with other published reports {8,51}. Vigorous exercise also affected the relationship between adiposity and age. The rise in average BMI, hip and chest circumferences with age were all greater for women who averaged less than 8 km/week than for longer distance runners. Before age 45, waist circumference increased with age for those who ran 0-8 km/wk, showed no significant change with age for those who ran 8-40 km./wk, and decreased in those who ran over 40 km/wk. Others have also reported the physical activity may attenuate age-related weight gain and {14,48,50} and weight gain following smoking cessation {52}. One study of Americans showed that consistently inactive women were seven-fold more likely to gain over 10 kg during 10 years of follow-up as active women {48}. A Finnish cohort found that women who rarely engaged in leisure-time physical activity were nearly twice as likely to gain 5 kg in 5 y as were those who frequently engaged in such activity {14}. Women who increase their activity show smaller increases in BMI over time {5}. Kahn et al. reported that walking 4 or more hours per week was associated with decreases in BMI during ten-years of follow-up {53}. Haapanen et al reported that light to moderately active women gained more weight than vigorously active women {8}. Vigorous activity, but not total activity, was reported to be protective against weight gain in the Nurses Health Study II{24}. Women who exercised vigorously for 5 or more hours per week gained about 0.5 kg less than inactive women, while every 10 hours spent sitting was associated with an 0.11 kg weight gain during 6 years of follow-up {24}.

Women runners who had borne two or more children had higher BMI and larger waist circumferences than women with fewer children. This is consistent with findings from the National Health and Nutrition Survey's Epidemiological Follow-up Survey of white women, which found that childbearing was associated with a weight gain of 1.7 kg in 25 to 45 year old women who were followed for 10 years {54}. Ten year follow-up of 25-44 year old white women from the First National Health and Nutrition Examination Survey (NHANES I) found that compared to women with no change in parity, those who increased parity by one child, or two or more children, increased their weight by 0.5 and 3.2 kg respectively {7}. However, substantial parity-associated weight-gain was less likely for married, employed women of higher educational attainment {7}, which probably characterizes our sample of women runners. Physical activity is not thought to affect gestational weight gain {55} but may reduce postpartum weight retention six to twelve months postpartum {56}. We also found no significant effect of menstrual status on adiposity, other than bra cup size, which is consistent with other studies showing that the trajectory of age-related increases in weight were not affected by menopause or hormone replacement {46.57-60}.

Prior observational studies of physical activity and adiposity have been criticized for the low prevalence of higher intensity physical activity, the measurement error associated with low-intensity activity, and the inappropriate time frame of the assessment {17.61}. The women studied here nearly all engaged in running, which is a well-quantified activity that is generally sustained by a regular regimen over many years. Our survey data lack reliable data on changes in energy intake that could theoretically account for results reported here. However, it is now recognized that even extensive diet records are unable to provide the precision required to detect the minute variations in daily energy intake that culminate in weight gain over years {62}. Such estimates require doubly labeled water for estimating energy expenditure, which is not practical for large cohorts. This report has also focused only on the changes in weight as summarized by the statistical mean and regression coefficients, deferring to a later report how these relationships may change for different percentiles of the weight distribution {63}. We also caution that the relationship between BMI and exercise may change with age because BMI may reflect lean and fat body mass differently in younger and older women. Specifically, data collected as part of the National Health and Nutrition Examination Survey (NHANES I and II) showed that BMI correlated more strongly with body fat in younger than older women and more strongly with muscle mass in older than younger women {64}. BMI also doesn't reflect the relative proportions of lean to fat body mass, which has been shown in older individuals to influence physical performance {65}.

The primary limitation of this and other cross-sectional observational studies is 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 {66}. Weight differences between active and sedentary older women trace back to their weights during young adulthood {25}. The extent that the cross-sectional associations we observed are causally related to vigorous exercise or are the consequence of self-selection remains to be determined.

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Figure 1. Relationship of age and reported distance run to body mass index and bra cup size in women runners.

Figure 2. Relationship of age and reported distance run to waist, hip and chest circumferences in women runners.

Table 1. Characteristics of female runners					
	Km per week run				
	0-15.9	16-31.9	32-47.9	48-63.9	64+
Age (years)	38.8 ±10.9	39.1 ±10.1	38.6 ±9.7	37.5 ±9.8	35.7 ±10.0
Education (years)	16.0±2.4	16.1 ±2.3	16.1 ±2.3	16.0 ±2.3	15.9 ±2.3
Alcohol (ml/wk)	46.2±70.0	50.3 (71.5	51.4 (72.	49.3 (71.7	43.0 (71.2
Beef (servings/wk)	2.2±2.4	2.0±2.2	1.7±2.0	1.5±2.1	1.4±1.9
Fish (servings/wk)	1.2±1.3	1.2±1.3	1.2±1.3	1.3±1.5	1.3±1.5
Fruit (servings/wk)	9.3±9.6	10.1±7.1	10.8±7.4	11.3±10.3	11.9 ±8.7
Years run	9.0±7.0	8.0±6.6	9.3±6.6	10.0±6.5	11.0±6.5
Body mass index (kg/m^2)	22.7±3.5	21.9±2.6	21.4±2.3	20.9±2.2	20.5±2.0
Waist circumference (cm)	72.6±8.5	70.5±6.8	69.0±6.1	68.0±5.7	67.0±5.9
Hip circumference (cm)	94.1±8.4	92.6±7.0	91.1±6.5	89.8±6.0	87.9±6.4
Chest circumference (cm)	89.9±6.1	88.9±5.1	88.1±4.9	87.3±4.7	86.6±4.5
Bra cup (5 pt scale)	2.2±0.9	2.1±0.8	2.0±0.8	1.9±0.8	1.8±0.8
Mean±SD					

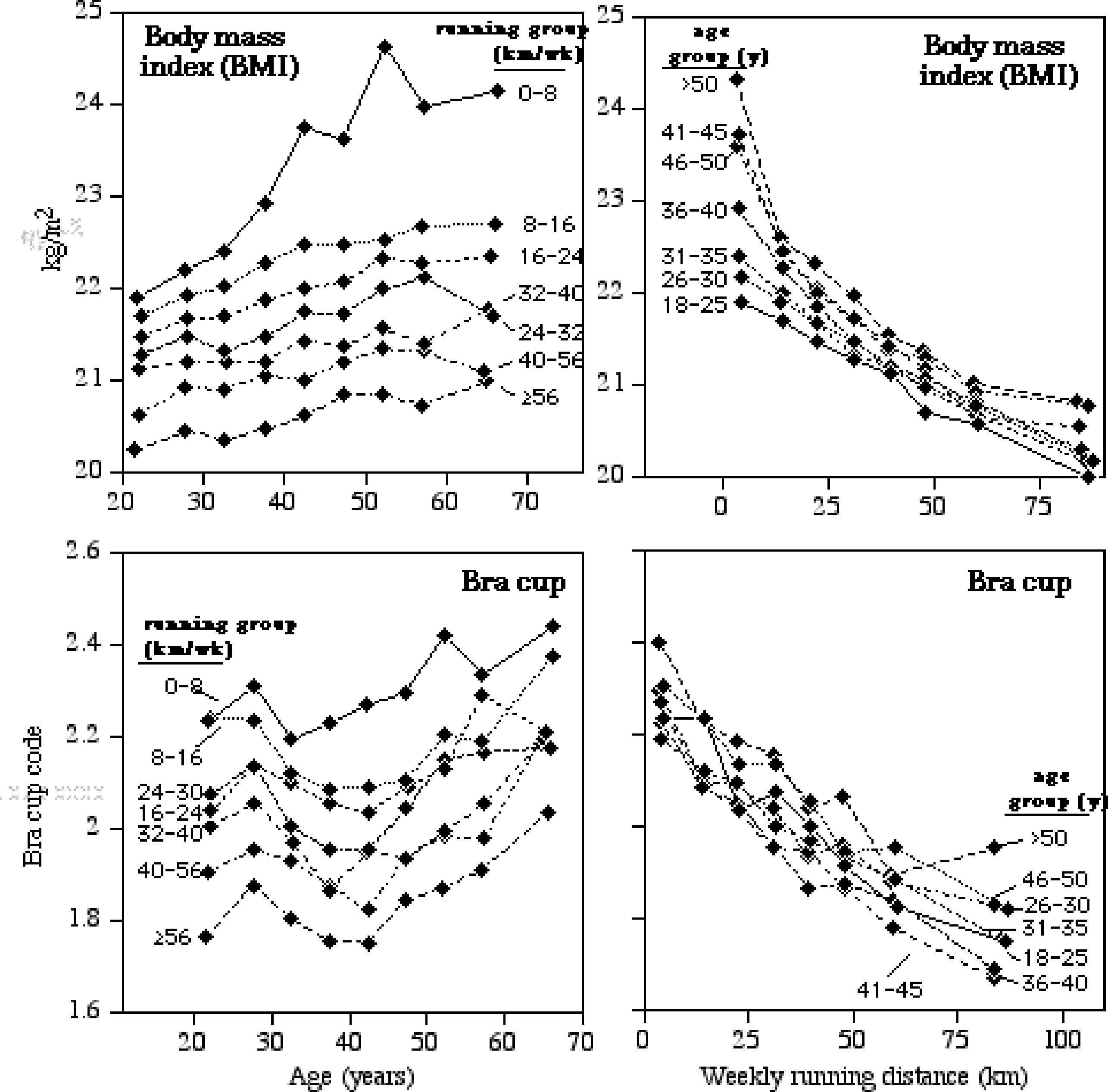
Table 2. Significance difference in women's average BMI, body circumferences, and bra cup sizes between age groups.									
	Age groups								
	18-25 y	26--30 y	30-35 y	36-40 y	41-45 y	46-50 y	51-55 y	56-60 y	≥60 y
Body mass index (BMI)									
18-24 y		-------	-------	532--2-	9643-4-	9543-42	9574-33	6444-3-	633--2-
25-29 y	-------		-------	32-----	942----	933----	9353---	5223---	522----
30-34 y	-------	-------		2------	9325---	7234-2-	9265--2	4224---	422----
35-39 y	532--2-	32-----	2------		3--2---	2------	6-33---	2--3---	2------
40-44 y	9643-4-	942----	9325---	3--2---		-------	2-2---2	-------	-------
45-49 y	9543-42	933----	7234-2-	2------	-------		2------	-------	-------
50-54 y	9574-33	9353---	9265--2	6-33---	2-2---2	2------		-------	-------
55-59 y	6444-3-	5223---	4224---	2--3---	-------	-------	-------		-------
≥60 y	633--2-	522----	422----	2------	-------	-------	-------	-------	
Waist circumference									
18-24 y		-------	------3	------4	------6	2-----4	4-----2	2------	2------
25-29 y	-------		-------	------2	------3	2------	4-2----	2-2----	2-3-2--
30-34 y	------3	-------		-------	-------	2------	5-2----	2-2----	223-2--
35-39 y	------4	------2	-------		-------	-------	3-2----	-------	--3-22-
40-44 y	------6	------3	-------	-------		-------	2------	-------	--3-22-
45-49 y	2-----4	2------	2------	-------	-------		-------	-------	-22-2--
50-54 y	4-----2	4-2----	5-2----	3-2----	2------	-------		-------	----2--
55-59 y	2------	2-2----	2-2----	-------	-------	-------	-------		-------
≥60 y	2------	2-3-2--	223-2--	--3-22-	--3-22-	-22-2--	----2--	-------	
Hip circumference									
18-24 y		36--33-	583-572	8975794	9999995	9999999	9999999	9999992	9999997
25-29 y	36--33-		--2----	237223-	7699582	9598985	9999798	999849-	5596554
30-34 y	583-572	--2----		-323---	4759442	7599755	9999568	799826-	4466444
35-39 y	8975794	237223-	-323---		2--42--	4-43522	7275335	5474-4-	2-33222
40-44 y	9999995	7699582	4759442	2--42--		-------	3-4---4	225--2-	--2---2
45-49 y	9999999	9598985	7599755	4-43522	-------		-------	-22----	-------
50-54 y	9999999	9999798	9999568	7275335	3-4---4	-------		-------	-------
55-59 y	9999992	999849-	799826-	5474-4-	225--2-	-22----	-------		-------
≥60 y	9999997	5596554	4466444	2-33222	--2---2	-------	-------	-------	
Chest circumference									
18-24 y		-2---2-	23---23	6624262	9847373	9936243	9557354	554222-	442--3-
25-29 y	-2---2-		-------	4232---	8354---	8443---	9265-22	324----	322----
30-34 y	23---23	-------		-------	53-3-2-	54-2---	8-34-2-	222----	22-----
35-39 y	6624262	4232---	-------		-------	-------	4-22---	--2----	-------
40-44 y	9847373	8354---	53-3-2-	-------		-------	2------	-------	-------
45-49 y	9936243	8443---	54-2---	-------	-------		-------	-------	-------
50-54 y	9557354	9265-22	8-34-2-	4-22---	2------	-------		-------	-------
55-59 y	554222-	324----	222----	--2----	-------	-------	-------		-------
≥60 y	442--3-	322----	22-----	-------	-------	-------	-------	-------	
Bra cup size (A=1; B=2; C=3; D=4; E=5; F=6)									
18-24 y		------2	-------	-2-22--	-2-2---	-------	-------	--3----	-----2-
25-29 y	------2		-2-3---	-3-65-2	-326--4	-2-----	-------	-------	-----2-
30-34 y	-------	-2-3---		----2--	------2	-------	3--3---	--2----	22---2-

35-39 y	-2-22--	-3-65-2	----2--		-------	-------	2--5-2-	--32---	-3-223-
40-44 y	-2-2---	-326--4	------2	-------		-------	---5-2-	--42---	-3-2-3-
45-49 y	-------	-2-----	-------	-------	-------		-------	--2----	-2---2-
50-54 y	-------	-------	3--3---	2--5-2-	---5-2-	-------		-------	-------
55-59 y	--3----	-------	--2----	--32---	--42---	--2----	-------		-------
≥60 y	-----2-	-----2-	22---2-	-3-223-	-3-2-3-	-2---2-	-------	-------	

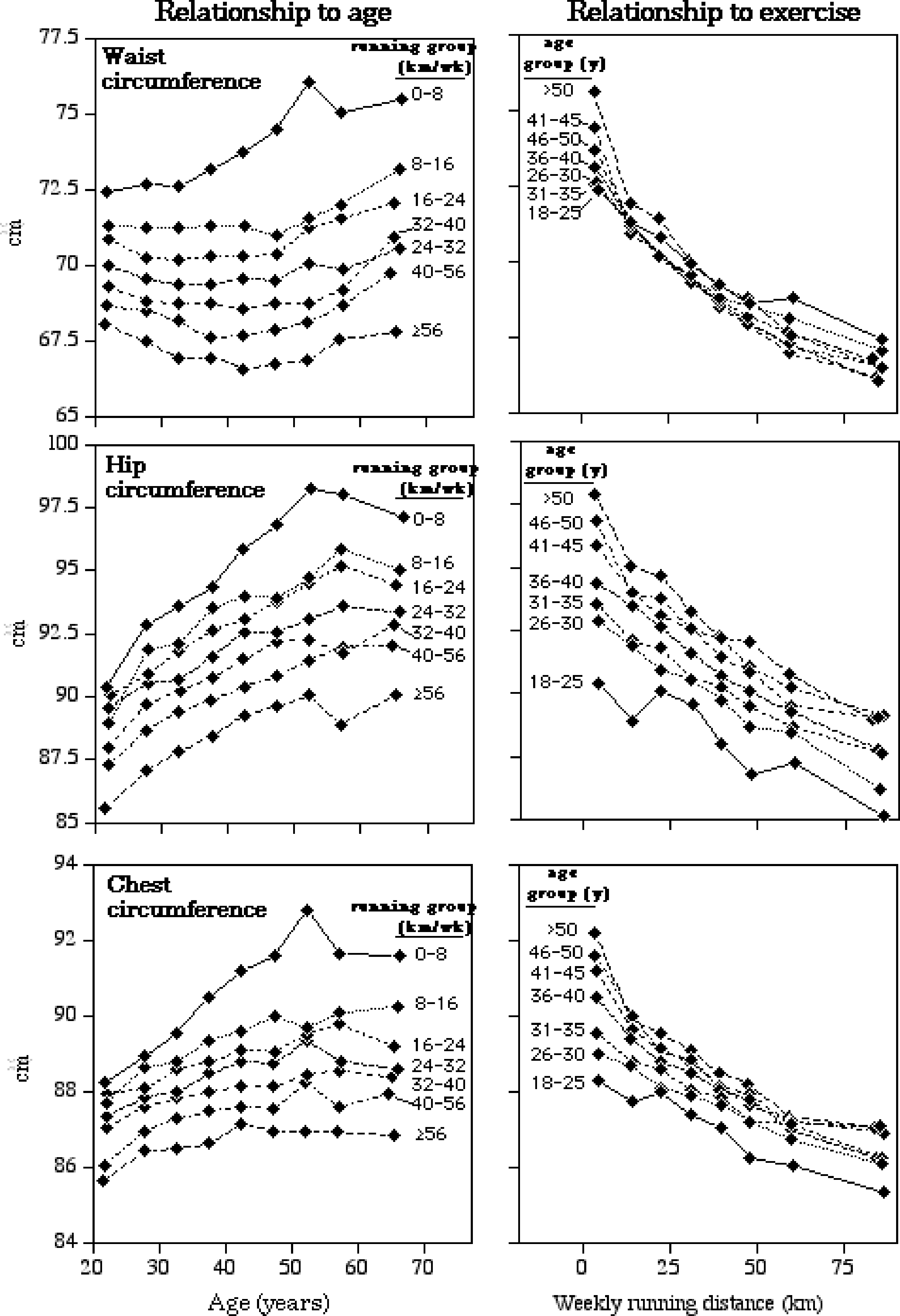
The 7 character entries within each cell designate the significance of the mean difference between the column and row age groups for women who reported running 0-8 km/wk, 8-16 km/wk, 16-24 km/wk, 24-32 km/wk, 32-40 km/wk, 40-56 km/wk, and over 56 km per week, respectively. Significance levels are coded "-" $P>0.01$; "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 women's average BMI, body circumferences, and bra cup sizes between running distance groups.								
	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		---3969	-359999	2599999	3999999	9999999	9999999	9999999
8-16 km	---3969		--2342-	2399965	3799999	9999999	9999999	9999999
16-24 km	-359999	--2342-		--44222	-459688	6899979	9999999	9999999
24-32 km	2599999	2399965	--44222		---2222	4434724	6999999	9999977
32-40 km	3999999	3799999	-459688	---2222		2------	3364923	9999923
40-48 km	9999999	9999999	6899979	4434724	2------		--2-6--	699952-
48-64 km	9999999	9999999	9999999	6999999	3364923	--2-6--		4544---
≥ 64 km	9999999	9999999	9999999	9999977	9999923	699952-	4544---	
Waist circumference								
0-8 km		-234689	2799999	4999999	7999999	9999999	9999999	9999999
8-16 km	-234689		-2332--	2599736	4999979	8999999	7999999	9999999
16-24 km	2799999	-2332--		--23224	3468959	6699999	5999999	9999999
24-32 km	4999999	2599736	--23224		---23--	2236742	2489999	6999968
32-40 km	7999999	4999979	3468959	---23--		-------	--36643	3589934
40-48 km	9999999	8999999	6699999	2236742	-------		----2-2	-3575-3
48-64 km	9999999	7999999	5999999	2489999	--36643	----2-2		2223---
≥ 64 km	9999999	9999999	9999999	6999968	3589934	-3575-3	2223---	
Hip circumference								
0-8 km		--2-478	-444999	-599999	3999999	6999999	5999999	9999999
8-16 km	--2-478		---22--	-249647	-569959	3999999	2999999	8999999
16-24 km	-444999	---22--		--34-55	3259869	7799999	5899999	9999999
24-32 km	-599999	-249647	--34-55		2--34-2	5537953	4689999	9999999
32-40 km	3999999	-569959	3259869	2--34-2		-----3-	-256984	5999999
40-48 km	6999999	3999999	7799999	5537953	-----3-		---25-2	2649548
48-64 km	5999999	2999999	5899999	4689999	-256984	---25-2		3524--3
≥ 64 km	9999999	8999999	9999999	9999999	5999999	2649548	3524--3	
Chest circumference								
0-8 km		---2637	-237999	-369999	2489999	6699999	7999999	9999999
8-16 km	---2637		---2-2-	-234342	-347985	4599996	5999999	9999998
16-24 km	-237999	---2-2-		--2----	--33533	5285764	7699999	9999987
24-32 km	-369999	-234342	--2----		----2--	2-32442	4439977	9989865
32-40 km	2489999	-347985	--33533	----2--		--2----	2225423	6578332
40-48 km	6699999	4599996	5285764	2-32442	--2----		---33--	23262--
48-64 km	7999999	5999999	7699999	4439977	2225423	---33--		--2----
≥ 64 km	9999999	9999998	9999987	9989865	6578332	23262--	--2----	
Bra cup size (A=1; B=2; C=3; D=4; E=5; F=6)								
0-8 km		---2333	33-4635	2349956	3669999	7979978	9999999	9999998
8-16 km	---2333		3------	2-233--	3437334	7956722	9978949	9999943
16-24 km	33-4635	3------		--22---	--37-32	-5455--	4478948	7899942
24-32 km	2349956	2-233--	--22---		---2---	25-----	5423537	8878822
32-40 km	3669999	3437334	--37-32	---2---		-------	2---4-2	54537--
40-48 km	7979978	7956722	-5455--	25-----	-------		------2	2-333--
48-64 km	9999999	9978949	4478948	5423537	2---4-2	------2		--22---
≥ 64 km	9999998	9999943	7899942	8878822	54537--	2-333--	--22---	

The 7 character entries within each cell designate the significance of the mean difference between the column and row age groups for women who were 18-25 y, 26-30 y, 31-35 y, 36-40 y, 41-45 y, 46-50 y, and over 50 years old, 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.



Body mass index (BMI)
running group (km/wk)
0-8
8-16
16-24
32-40
24-32
40-56
≥56
kg/m2
Age (years)
age group (y)
>50
41-45
46-50
36-40
31-35
26-30
18-25
Bra cup
Bra cup code
24-30
Weekly running distance (km)



Relationship to age
Relationship to exercise
Waist circumference
running group (km/wk)
0-8
8-16
16-24
32-40
24-32
40-56
≥56
age group (y)
>50
41-45
46-50
36-40
26-30
31-35
18-25
Hip circumference
running group (km/wk)
0-8
8-16
16-24
24-32
32-40
40-56
≥56
age group (y)
>50
46-50
41-45
36-40
31-35
26-30
18-25
Chest circumference
running group (km/wk)
0-8
8-16
16-24
24-32
32-40
40-56
≥56
age group (y)
>50
46-50
41-45
36-40
31-35
26-30
18-25
cm
cm
cm
77.5
75
72.5
70
67.5
65
100
97.5
95
92.5
90
87.5
85
94
92
90
88
86
84
20
30
40
50
60
70
0
25
50
75
Age (years)
Weekly running distance (km)