Cross-Sectional Relationships of Exercise and Age to Adiposity in 60,617 Male Runners

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ABSTRACT

WILLIAMS, P. T., and R. R. PATE. Cross-Sectional Relationships of Exercise and Age to Adiposity in 60,617 Male Runners. Med. Sci. Sports Exerc., Vol. 37, No. 8, pp. 1329–1337, 2005. 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%) and waist circumference (91.1%). Results: Between 18 and 55 yr old, the decline in BMI with weekly distance run (slope ± SE) was significantly greater in men 25–55 yr old than in younger men (slope ± SE: −0.036 ± 0.001 vs −0.020 ± 0.002 kg·m−2 per km·wk−1). Declines in waist circumference with distance were also significantly greater in older than younger men (P < 10−6), that is, the slopes decreased progressively from −0.035 ± 0.004 cm per km-wk−1 in 18- to 25-yr-old men to −0.097 ± 0.003 cm per km-wk−1 in 50- to 55-yr-old men). Increases in BMI with age were greater for men who ran under 16 km-wk−1 than for relatively longer distance runners. Waist circumference increased with age at all running distances, but the increase diminished by running further (0.259 ± 0.015 cm-yr−1 if running <8 km-wk−1 and 0.154 ± 0.003 cm-yr−1 for >16 km-wk−1). In men 50–85 yr old, BMI declined −0.038 ± 0.001 kg·m−3 per km·wk−1 run when adjusted for age and declined −0.054 ± 0.003 kg·m−3 (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−1 run when adjusted for age and increased 0.021 ± 0.007 cm per year of age when adjusted for running distance. Conclusions: 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. Key Words: EXERCISE, RUNNING, AGING, VIGOROUS ACTIVITY, BODY MASS INDEX, REGIONAL ADIPOSITY, WAIST CIRCUMFERENCE, POPULATION STUDIES

Physically active men are leaner than sedentary men (7,19). This may be due to self-selection (33), exercise-induced weight loss (34,41,42), or the attenuation of age-related weight gain (9). 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.

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 (6,27,39). The middle-age weight gain is coincident to an increase in intraabdominal fat (4,31). Higher intraabdominal fat is associated with major coronary heart disease (CHD) risk factors, including insulin resistance, dislipoproteinemia, and hypertension (21,23).

Current public health strategies recommend fixed levels of physical activity to prevent weight gain. For example, it has been suggested that unhealthy weight gain can be prevented by increasing total energy expenditure to 170% of resting energy requirements (16,11). This level of activity could be achieved through 60–90 min·d−1 of brisk walking (11), a level of activity that is substantially greater than current physical activity guidelines by government (25,32) and nongovernment organizations (43).

Williams (36) 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. 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 intraabdominal fat unless they annually increased their distance run by 2.24 km (1.39 miles) per week to compensate for the anticipated weight gain during middle age (36).

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 propose to: 1) more precisely define the relationships of age and vigorous exercise to BMI and waist circumference, 2) identify interactions between age and vigorous exercise in their calculated effect on adiposity, and 3) confirm that weight gain is expected to occur at any sustained level of activity.
TABLE 1. Characteristics of male runners (percent or mean ± SD).

<table>
<thead>
<tr>
<th>Kilometers per Week Run</th>
<th>0–15.9</th>
<th>16–31.9</th>
<th>32–47.9</th>
<th>48–63.9</th>
<th>64+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of sample</td>
<td>18.4%</td>
<td>35.3%</td>
<td>25.2%</td>
<td>12.4%</td>
<td>8.6%</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>44.87 ± 11.51</td>
<td>45.58 ± 10.7</td>
<td>44.94 ± 10.55</td>
<td>43.76 ± 10.39</td>
<td>40.76 ± 11.44</td>
</tr>
<tr>
<td>Education (yr)</td>
<td>16.46 ± 2.52</td>
<td>16.5 ± 2.43</td>
<td>16.38 ± 2.49</td>
<td>16.28 ± 2.58</td>
<td>16.06 ± 2.59</td>
</tr>
<tr>
<td>Alcohol (mL·wk⁻¹)</td>
<td>76.24 ± 105.38</td>
<td>83.63 ± 112.96</td>
<td>82.01 ± 115.37</td>
<td>78.47 ± 112.33</td>
<td>70.3 ± 113.36</td>
</tr>
<tr>
<td>Beef (servings per week)</td>
<td>3.33 ± 3.00</td>
<td>3.06 ± 2.76</td>
<td>2.81 ± 2.65</td>
<td>2.61 ± 2.65</td>
<td>2.49 ± 2.7</td>
</tr>
<tr>
<td>Fish (servings per week)</td>
<td>1.49 ± 1.47</td>
<td>1.48 ± 1.4</td>
<td>1.51 ± 1.47</td>
<td>1.54 ± 1.63</td>
<td>1.48 ± 1.49</td>
</tr>
<tr>
<td>Fruit (servings per week)</td>
<td>9.07 ± 8.3</td>
<td>10.12 ± 11.11</td>
<td>11.12 ± 8.77</td>
<td>11.79 ± 9.21</td>
<td>12.38 ± 10.32</td>
</tr>
<tr>
<td>Years run</td>
<td>12.7 ± 8.77</td>
<td>12.04 ± 8.34</td>
<td>12.72 ± 8.16</td>
<td>13.27 ± 7.88</td>
<td>13.92 ± 8.17</td>
</tr>
<tr>
<td>Body mass index (kg·m⁻²)</td>
<td>25.24 ± 3.23</td>
<td>24.51 ± 2.7</td>
<td>23.89 ± 2.56</td>
<td>23.23 ± 2.31</td>
<td>22.47 ± 2.3</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>87.13 ± 7.25</td>
<td>85.65 ± 6.01</td>
<td>84.04 ± 5.62</td>
<td>82.37 ± 5.17</td>
<td>80.42 ± 5.13</td>
</tr>
</tbody>
</table>

METHODS

A two-page questionnaire, distributed nationally at races and to subscribers of the nation’s largest running magazine (Runner’s 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 5 yr, 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 (35). 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 participants signed a statement of informed consent, and the study protocol was approved by the University of California at Berkeley review board.

Body mass index (BMI) was calculated as the weight in kilograms divided by height in meters squared. Height and weight were determined by asking the participant “What is your current height (in inches, without shoes)?” and “What is your current weight (prepregnancy weight if pregnant)?” Self-reported waist circumferences were provided in response to the question “Please provide, to the best of your ability, your body circumference in inches” without further instruction. The relationships between waist circumference and running distance and age are expected to be weakened by different perceptions of where waist circumference lies. However, unless the perceived location varies systematically in relation to running distance or age, this subjectivity is unlikely to affect the relationships reported in the tables and figures.

The data presented in this paper are observational and cross-sectional, so it is not possible to distinguish the causal effects of exercise from effects due to self-selection. Our use of the terminology “increasing weekly distance” in reference to the independent variable and “decreasing BMI” in reference to the dependent variables pertains only to their mathematical functional relationship and should not be interpreted as causal effects.

Statistical analyses. Table 1 presents means ± SD for all variables assessed; all other statistics are expressed as mean ± SE or slopes ± SE. Statistical significance was set at P < 0.01 for two-tailed tests. Men 18–85 yr old were included in the analyses. The relationships of adiposity to age and running distance were examined visually before 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 BMI and waist circumference were then plotted as functions 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 BMI and waist circumference were then plotted as a function of average distance run. We also determined the 10th and 90th percentiles of the BMI distribution for the men stratified by age or by weekly running distance, which were then plotted as a function of age and distance. This was done to confirm prior analyses suggesting that decreases in BMI associated with running distance were greater in relatively overweight men and less in relatively lean men (38) and to assess whether this dependence on the percentile of the BMI percentile distribution also applied to aging.

The 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 amount of vigorous activity.

RESULTS

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, 1016 for reporting that they smoked cigarettes currently, and 525 for following strict vegetarian diets (no meat or dairy products). Of the remaining 62,128 men, 60,617 provided complete information on height and weight so that
BMI could be calculated (97.6%), and 56,611 reported their waist circumferences (91.1%).

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 with those who ran less than 16 km wk$^{-1}$, those who ran over 64 km wk$^{-1}$ had 11% smaller BMI and 8% smaller waist circumferences.

**Associations with running distance in young to middle-aged men.** Figure 1 (top left panel) displays the average BMI (y-axis) for men stratified by age, and the x-axis designates the average weekly 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- to 54-yr-old men. The relationships were principally linear, albeit slightly convex. Table 2 of the appendix shows that longer running distance was almost always associated with significantly lower BMI; that is, the comparisons are mostly significant, with the exception of shorter-distance runners under 35 yr old (see Appendix).

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 $\pm$ SE) was $-0.036 \pm 0.001$ kg m$^{-2}$ per km wk$^{-1}$ for 25- to 55-yr-old men. Within this age range, the declines in BMI per km wk$^{-1}$ run were the same for all ages. However, the age-adjusted decline in BMI in 18- to 25-yr-old men ($-0.020 \pm 0.002$ kg m$^{-2}$ per km wk$^{-1}$) was significantly less than the decline for 25- to 55-yr-old men (difference in slopes $\pm$ SE: $0.015 \pm 0.002$ kg m$^{-2}$ per km wk$^{-1}$, $P < 10^{-9}$). The bottom left 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.

Figure 2 (left panel) examines the relationship of running distance to waist circumferences in men 18–55 yr 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 40–48 km wk$^{-1}$ (consistent with the results for BMI).

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- to 25-yr-old men ($-0.035 \pm 0.004$ cm per km wk$^{-1}$) and 25- to 30-yr-old men ($-0.070 \pm 0.004$ cm per km wk$^{-1}$). After age 30, there were smaller incremental decreases in slope going from men 25–30 yr old to 30–35 yr old (slope $\pm$ SE: $-0.075 \pm 0.003$ cm per km wk$^{-1}$), 35–40 yr old ($-0.083 \pm 0.003$ cm per km wk$^{-1}$), 40–45 yr old ($-0.085 \pm 0.003$ cm per km wk$^{-1}$), 45–50 yr old ($-0.091 \pm 0.003$ cm per km wk$^{-1}$), and 50–55 yr old ($-0.097 \pm 0.003$ cm per km wk$^{-1}$).
The curves for waist circumference versus running distance were slightly convex.

**Associations with age in young to middle-aged men.** BMI rose in association with age at all running distances (Fig. 1, top right panel). The rise was sharpest for men 18–25 and 25–30 yr, and thereafter rose at a diminishing rate until it leveled off at about age 50. For men who ran at least 16 km·wk\(^{-1}\), the shapes of the curves appear to be the same regardless of running distance, that is, 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.

Age-related weight gain appears to have been greater for men who ran under 16 km·wk\(^{-1}\) than over 16 km·wk\(^{-1}\). 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\(^{-1}\) 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.” 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. 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).

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

![Figure 2](http://www.acsm-msse.org)

**Figure 2**—Cross-sectional relationship of waist circumference to age and weekly distance run in men 18–55 yr old (corresponding significance levels are presented on Tables 2 and 3).
(0.219 ± 0.011 cm·yr⁻¹), and least in those averaging over 16 km·wk⁻¹ (0.154 ± 0.003 cm·yr⁻¹). 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). Table 3 (see appendix) shows that differences in mean waist circumference between age groups were significant except for 45- to 50- versus 50- to 55-yr-old men.

**Associations with running distance and age in older men.** Figure 3 displays the association of BMI and waist circumference with running distance and age in men 50–85 yr old. 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 \( \pm SE\) = \(-0.038 \pm 0.001 \text{ kg} \cdot \text{m}^{-2}\) per \text{km} \cdot \text{wk}^{-1}\) run when adjusted for age and declined \(-0.054 \pm 0.003 \text{ kg} \cdot \text{m}^{-2}\) per year of age when adjusted for running distance. Waist circumference declined (slope \( \pm SE\) = \(-0.096 \pm 0.002 \text{ cm} \) per km-wk\(^{-1}\) run when adjusted for age and rose \(0.021 \pm 0.007 \text{ cm}\) per year of age when adjusted for running distance. There was no significant interaction between age and running distance in their effects on BMI \((P = 0.16)\) or waist circumference \((P = 0.25)\).

**DISCUSSION**

The current analyses are unique in their involvement of over 60,000 vigorously active men. They suggest that for men under 50 yr old: 1) even among those most active, BMI and waist circumference increase with age, 2) BMI and waist circumferences decline in association with running distance, and 3) running longer distances may significantly reduce age-related increases in BMI and waist circumference. Our analyses may also characterize more precisely those men most likely to benefit from higher amounts of vigorous exercise. The declines in BMI associated with distance were over two and a half times greater at the 90th percentile of the BMI distribution than at the 10th percentile (suggesting greatest potential benefit for the more overweight (38)). The declines in BMI were greater in 25- to 50-yr-old than 18- to 25-yr-old men (also observed for waist circumference). The large number of observations used in the current analyses has yielded more precise estimates of the relationships between age, exercise, and adiposity than has been previously possible (i.e., smaller standard errors).

Although prior cross-sectional and longitudinal studies have described the association of age with adiposity (6,27,40), none have focused specifically on vigorously active men, except for an earlier paper by Williams (36). He reported that BMI increased at a rate (slope \( \pm SE\) of 0.045 \( \pm 0.006 \text{ kg} \cdot \text{m}^{-2}\) and waist circumference at 0.186 \(\pm 0.014 \text{ cm}\) per year of age regardless of running distance. The enhanced precision provided in the current study suggests 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 47. Application of these relationships to the age distribution of the 4769 men initially studied (36) predicts average increases of 0.035 \(\text{kg} \cdot \text{m}^{-2}\) for BMI and 0.163 \text{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 (36), 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\(^{-1}\) compared with under 8 km-wk\(^{-1}\).

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 (36). 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\(^{-1}\) between 25 and 30 yr old, 2.05 km-wk\(^{-1}\) between 30 and 35 yr old, 1.86 km-wk\(^{-1}\) between 35 and 40 yr old, 1.81 km-wk\(^{-1}\) between 40 and 45 yr old, and 1.69 km-wk\(^{-1}\) between 45 and 50 yr old. Thus, a man running 16 km-wk\(^{-1}\) at age 25 would need to increase his weekly running distance to 64 km-wk\(^{-1}\) by age 50 to maintain his waistline. Although these estimates average about 15% lower than our original calculations (36), 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 (16) and other exercise guidelines (1) that advocate the maintenance of a 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 recently released Institute of Medicine recommendations for preventing unhealthy weight gain (16). There is a manifest need to substantiate these calculations using longitudinal data.

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 yr, remains stable between 50 and 54, and decreases at age 55 and above (14). DiPietro et al. reported that changes in fitness (treadmill test duration) were inversely related to changes in weight during 7.5 yr of follow-up (8). Weight increased with age unless treadmill test duration improved by 1 min annually (0.7% annually) (8). Others have also reported that physical activity attenuates age-related weight gain (12,28,39) and helps prevent age-related weight loss after age 65 (10).

The significance levels of Table 2 suggest that distance run per week was more strongly related to waist circumference than body mass index. The greater effect of distance run on waist circumference than BMI may be a reflection of a preferential reduction in total abdominal and intraabdominal fat that occurs in response to exercise (30). The proportion of glycolytic Type 2b muscle fibers, which may be etiologically involved in the development of obesity (15,20), also increases with age (20). Physical activity has been reported to promote transformations of Type 2b muscle fibers to Type 2a (13), 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 (20).

The men’s curves confirm our recent observation (38) that association between vigorous activity and BMI is strongest (steepest slope) for the heaviest men (e.g., the 90th percentile, Fig. 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⁻¹ 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.

Because diet was not measured in our study, 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 (24) and high carbohydrate (26) 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 (17). 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 (18)) contributed to the observed associations. Cross-sectional observational studies report either no relationship (22) or an inverse relationship (3,19,29) 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 (16).

The apparent inevitable tendency to gain weight with age despite substantial exercise is not an argument against physical activity. Cross-sectional data in male runners suggests that plasma high density lipoprotein cholesterol increases and plasma low-density lipoprotein cholesterol, triglycerides, and fasting glucose decrease incrementally with weekly running distance through at least 64 km·wk⁻¹ (35). Meta-analyses suggest that cardiovascular risk decreases approximately linearly from the lowest to the highest population percentiles of physical activity (37). The current analyses also suggest that the rate of middle-age weight gain is diminished at higher levels of physical activities compared to near sedentary activity levels (Figs. 1 and 2).

There are important limitations to these analyses that we acknowledge. The sample was primarily white, and we collected only minimal data on health and socioeconomic status; therefore, we are unable to provide analyses with respect to the potentially confounding or modifying effects of race, socio-economic status, and health status. We also did not collect data on running terrain, which would impact caloric expenditure per kilometer run and could affect the relationships presented in the figures and tables.

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 (5). 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 (33). 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 is the direct consequence of the activity performed or an artifact of self-selection remains to be determined.

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REFERENCES


**APPENDIX**

The large number of comparisons between age or distance categories required us to develop 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, 25–30, 30–35, 35–40, 40–45, 45–50, and 50–55 yr 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 kilometers per week along the x-axis in Fig. 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 “−−−−−−−−6.” The seven dashes and digits correspond to the significance of the difference in average BMI for men running 0–8 km·wk\(^{-1}\) (represented by...
the row) and men running 8–16 km·wk\(^{-1}\) (represented by the column) for different age groups: nonsignificant for men 18–25, 25–30, 30–35, and 35–40 yr old, \(P < 10^{-4}\) for 40- to 45-yr-old men, \(P < 10^{-6}\) for 45- to 50-yr-old men, and \(P < 10^{-2}\) for 50- to 55-yr-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, 8–16, 16–24, 24–32, 32–40, 40–48, 48–64, and >64 km·wk\(^{-1}\). 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 yr old have significantly different (higher) BMI than men 18–25 yr old at \(P < 10^{-8}\) when running 0–8 km·wk\(^{-1}\), \(P < 10^{-9}\) when running 8–16 km·wk\(^{-1}\), \(P < 10^{-7}\) when running 16–24 km·wk\(^{-1}\), \(P < 10^{-9}\) when running 24–32 km·wk\(^{-1}\), \(P < 10^{-4}\) when running 32–40 km·wk\(^{-1}\), \(P < 10^{-7}\) when running 40–48 and 48–64 km·wk\(^{-1}\), and \(P < 10^{-9}\) when running over 64 km·wk\(^{-1}\).