Changes in maximal aerobic capacity with age in endurance-trained women: 7-yr follow-up

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Eskurza, Iratxe, Anthony J. Donato, Kerrie L. Moreau, Douglas R. Seals, and Hirofumi Tanaka. Changes in maximal aerobic capacity with age in endurance-trained women: 7-yr follow-up. J Appl Physiol 92: 2303–2308, 2002. —On the basis of cross-sectional data, we previously reported that the absolute, but not the relative (%), rate of decline in maximal oxygen consumption (VO2 max) with age is greater in endurance-trained compared with healthy sedentary women. We tested this hypothesis by using a longitudinal approach. Eight sedentary (63 ± 2 yr at follow-up) and 16 endurance-trained (57 ± 2) women were reevaluated after a mean follow-up period of 7 yr. At baseline, VO2 max was ~70% higher in endurance-trained women (48.1 ± 1.7 vs. 28.1 ± 0.8 ml·kg−1·min−1·yr−1). At follow-up, body mass, fat-free mass, maximal respiratory exchange ratio, and maximal rating of perceived exertion were not different from baseline in either group. The absolute rate of decline in VO2 max was twice as great (P < 0.01) in the endurance-trained (−0.84 ± 0.15 ml·kg−1·min−1·yr−1) vs. sedentary (−0.40 ± 0.12 ml·kg−1·min−1·yr−1) group, but the relative rates of decline were not different (−1.5 ± 0.3 vs. −1.5 ± 0.4% per year). Differences in rates of decline in VO2 max were not related to changes in body mass or maximal heart rate. However, among endurance-trained women, the relative rate of decline in VO2 max was positively related to reductions in training volume (r = 0.63). Consistent with this, the age-related reduction in VO2 max in a subgroup of endurance-trained women who maintained or increased training volume was not different from that of sedentary women. These longitudinal data indicate that the greater decrease in maximal aerobic capacity with advancing age observed in middle-aged and older endurance-trained women in general compared with their sedentary peers is due to declines in habitual exercise in some endurance-trained women. Endurance-trained women who maintain or increase training volume demonstrated age-associated declines in maximal aerobic capacity not different from healthy sedentary women.

maximal oxygen consumption; functional capacity

MAXIMAL AEROBIC CAPACITY is an important indicator of physiological functional capacity and is known to decrease with advancing age (2, 13, 14, 18). The decrease in maximal aerobic capacity with age has a number of physiological and clinical implications as it is associated with increased risks for cardiovascular and all-cause mortality (1) and disability (21), and reductions in cognitive function (20), quality of life (21), and independence (21).

With the number of older adults rapidly increasing, the question of how rates of decline in maximal aerobic capacity with age may differ among populations is of obvious importance. In this context, largely on the basis of cross-sectional data in men, for many years it was suggested that the rate of decline in maximal aerobic capacity with age in endurance exercise-trained adults was only approximately half of that observed in healthy sedentary controls (7, 9, 11). In contrast to this view, on the basis of cross-sectional comparisons, we recently reported that the absolute (ml·kg−1·min−1·yr−1) decrease in maximal oxygen consumption (VO2 max) across subject age actually was greater in endurance-trained compared with healthy sedentary women, although the relative (% per year) decreases were similar (6, 18). However, because of well-recognized limitations associated with cross-sectional study designs (4), these findings need to be confirmed with a longitudinal study.

On the basis of the important influence of habitual physical activity on VO2 max (3, 9, 14) and correlational data from our cross-sectional comparisons (6, 18), we speculated in its previous reports (6, 18) that the greater absolute rate of decline in VO2 max with age in the endurance-trained women in general could be attributable to reductions in training. However, the limited and cross-sectional nature of the available data precluded drawing any definite conclusion on this issue.

Accordingly, in the present investigation, we prospectively tested the hypothesis that the absolute rate of age-related decline in maximal aerobic capacity is greater in endurance-trained than in sedentary women.

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healthy middle-aged and older women. If so, we also sought to determine whether the greater rate of decline in maximal aerobic capacity in endurance-trained women was associated with declines in exercise training. To do so, we retested sedentary and endurance-trained women a mean of 7 yr after originally studying them (5, 16, 17).

METHODS

Subjects. We studied 24 women: 8 sedentary and 16 endurance trained aged 40–78 yr. All subjects were apparently healthy and free of overt cardiovascular diseases, as assessed by medical history questionnaire. Irrespective of training status, women >50 yr of age were further evaluated by physical examination and resting and maximal exercise electrocardiograms. All of the subject were normotensive (<140/90 mmHg), nonobese (body mass index of <30 kg/m2), and nonsmokers. None of the women were taking medications, other than hormone-replacement therapy, that could affect cardiovascular function. Before participation, verbal and written explanations of the nature, purpose, and risks of the study were administered. In turn, subjects gave their written, informed consent to participate in this investigation. This study was reviewed and approved by the Human Research Committee of the University of Colorado at Boulder.

All the subjects were initially tested in years 1993–1994 (5, 16, 17) and subsequently reevaluated in 2000, with a mean follow-up period of 7 yr. At the initial testing, all endurance-trained women had placed in the top 10 for their age group in Bolder Boulder road race (the second largest 10-km road race in the United States). When these women were reevaluated in 2000, they were still actively competing in running road races. None of the sedentary subjects engaged in any type of endurance training during the follow-up period. Their sedentary status was documented by questionnaire as well as VO2max values.

Measurements. VO2max was assessed with on-line computer-assisted open-circuit spirometry during continuous incremental treadmill exercise as described in detail previously (5, 16–18). Gas fractions were analyzed with a Perkin-Elmer MGA-1100 mass spectrometer (Pomona, CA) previously calibrated with standard gases of known concentrations.Expired air volume was measured either with a turbine (VM-2, Interface Associates, Laguna Niguel, CA) or a pneumotachometer (Hans Rudolph, Kansas City, MO). There were no differences between these two systems when ventilation and oxygen uptake were analyzed simultaneously. These machines were calibrated against 3- or 7-liter syringes before and after each session. Heart rates were continuously monitored with an electrocardiogram.

After a 6- to 10-min warm-up period, each subject ran (endurance-trained women) or walked (sedentary women) at a comfortable speed that corresponded to 70–80% of age-predicted maximal heart rate. Treadmill grade was increased 2.5% every 2 min until volitional exhaustion. At the end of each stage, subjects were asked to rate their perception of effort by using a Borg scale (6–20 scale). Each treadmill test lasted between 8 and 12 min. Maximal heart rate was defined as the highest value recorded from electrocardiogram recordings during the test. To ensure that each subject attained VO2max, at least three of the following four criteria were met by each subject: 1) a plateau in oxygen uptake with increasing exercise intensity, 2) a respiration exchange ratio of at least 1.15, 3) an achievement of the age-predicted maximal heart rate (≥ 20 beats/min), and 4) a rating of perceived exertion of at least 18 units (10). The same individualized protocol was used at the baseline and follow-up periods.

Body mass was measured with a physician’s balance scale (Detecto, Webb City, MO) to the nearest 0.1 kg. Body fat percent was estimated from the sum of five-site skinfold measurements with a Lange caliper. Fat-free mass was subsequently calculated as the difference between total body mass and estimated fat mass. Waist circumference was measured at the umbilicus, and hip circumference was determined at the maximum circumference of the buttocks. Measurements of plasma lipid and lipoprotein concentrations were performed by the General Clinical Research Center Core Laboratory at the University of Colorado Health Sciences Center as previously described (16, 17). Arterial blood pressure was measured by a conventional mercury sphygmomanometer after at least 10 min of rest under quiet, comfortable laboratory conditions (16, 17).

Detailed information was obtained from each subject regarding her training records. Endurance-trained women recorded their running intensity, mileage, duration, frequency, and characteristics of training (e.g., long slow distance, interval training) on a daily basis continuously for 2 wk. The same questionnaire was used at the baseline and follow-up periods. Additionally, to minimize the potential influence of seasonal variations in training levels, the reevaluation of the endurance-trained women was conducted at a similar time of the year in their competitive season to that in the initial evaluation. Physical activity levels of the sedentary subjects were estimated by using the Stanford Physical Activity Questionnaire (15).

Statistics. Analysis of variance with repeated measures (group × time) was used to determine differences in the dependent variables in each group before and after the follow-up period. When indicated by a significant F value, a post hoc test using the Newman-Keuls method was performed to identify significant differences among mean values. Univariate correlation and regression analyses were used to determine associations between dependent variables. All data are reported as means ± SE. Statistical significance was set at P < 0.05.

RESULTS

Subject characteristics. Table 1 presents mean values for selected subject characteristics. At baseline, sedentary women had significantly higher body mass, body mass index, body fat, hip circumference, and waist-to-hip ratio compared with endurance-trained women. Height and fat-free mass decreased and body mass index and body fat percentage increased over the follow-up period in both groups (P < 0.05); there were no significant differences in these changes between the two groups. No significant changes were observed in blood pressure and plasma cholesterol and lipid levels in either group. Physical activity levels of the sedentary women did not change (32 ± 1 kcal/day at baseline and 35 ± 1 at follow-up; P = not significant).

VO2max at baseline and during follow-up. At baseline, VO2max was higher (P < 0.01) in endurance-trained compared with sedentary women (Fig. 1). When expressed in absolute terms, the rate of decline in VO2max over the follow-up period was 110% greater (P < 0.05) in endurance-trained (−0.84 ±
0.15 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\)) compared with sedentary (−0.40 ± 0.12 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\)) women. In contrast, the relative rate of decline in \(\text{VO}_{2\text{max}}\) over the same period was not different between endurance-trained (−1.8 ± 0.3% per year) and sedentary (−1.5 ± 0.4% per year) women (\(P = 0.59\)). Age-related declines in maximal heart rate and oxygen pulse also were not different in the two groups (Table 2). In both groups, respiratory exchange ratio and rating of perceived exertion at \(\text{VO}_{2\text{max}}\) were not different at baseline and follow-up, suggesting similar voluntary maximal efforts at the two testing points.

**Correlates of changes in \(\text{VO}_{2\text{max}}\) over the follow-up period.** In the pooled subject population, changes in \(\text{VO}_{2\text{max}}\) were related to corresponding changes in maximal oxygen pulse (\(r = 0.42; P < 0.01\)). Among sedentary women, changes in \(\text{VO}_{2\text{max}}\) were not related to any measure. As illustrated in Fig. 2, among endurance-trained women, changes in \(\text{VO}_{2\text{max}}\) were positively related to decreases in running mileage (\(r = 0.63\)) and more modestly with running (weekly) frequency (\(r = 0.42\) (\(P < 0.01\)) but not with changes in running intensity (\(r = -0.03; P = 0.93\)).

**Subgroup analysis: effects of training volume.** To gain further insight into the role of reductions in training volume with age on the decline in \(\text{VO}_{2\text{max}}\), we divided the endurance-trained women into those who maintained or increased (\(n = 6\)) and those who reduced (\(n = 10\)) their baseline training volume (Table 3). The two subgroups did not differ significantly in baseline levels of \(\text{VO}_{2\text{max}}\). The reduction in \(\text{VO}_{2\text{max}}\) over the follow-up period was significantly greater in the subgroup of endurance-trained women who reduced their training volume (−1.04 ± 0.16 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\)) compared with the other two groups but was not different (\(P = 0.62\)) between the subgroup of endurance-trained women who maintained/increased training volume (−0.52 ± 0.20 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\)) and the sedentary women (Fig. 3). Among the sedentary women and endurance-trained women who maintained/increased their training volume (i.e., groups that exhibited similar rates of reduction in \(\text{VO}_{2\text{max}}\) with age), changes in \(\text{VO}_{2\text{max}}\) were not significantly related to changes in any other variable.
DISCUSSION

For the last decade, our laboratory has been investigating the modulatory influence of regular physical activity on age-related reductions in VO2max in women. As an initial step, we used a meta-analytic approach to address this issue (6) and found that, in marked contrast to the prevailing view in men (7, 9, 11), the absolute rate of decline in VO2max across age was greatest in the most physically active and smallest in the least active women (6). Because of the well-recognized limitations of meta-analysis, we next performed a well-controlled laboratory-based study (18) and obtained findings consistent with those of our prior meta-analysis. However, to provide more definitive insight into the relation between age-related changes in maximal aerobic capacity and habitual exercise status, we conducted the present longitudinal investigation.

The key findings of this new study are as follows. First, in the overall sample of the endurance-trained women in their 50s and 60s, the absolute but not relative rate of decline in VO2max with age was greater than that in healthy sedentary women. Second, endurance-trained women who maintained/increased their training volume demonstrated a rate of decline in VO2max over a 7-yr period that is not different from their sedentary peers. These longitudinal data confirm our previous cross-sectional observations (6, 18) that the decrease in maximal aerobic capacity with advancing age is greater in endurance-trained women in general compared with their sedimentary peers. However, the present results extend importantly our previous findings by demonstrating that the greater decline in VO2max in the overall sample of endurance-trained subjects is due to reductions in training volume in some of the women. Thus, among healthy women aged 34–78 yr, the endurance exercisetrained state is associated only with an accelerated rate of decline in maximal aerobic capacity (compared with sedentary women) when training volume decreases.

During the development of the present manuscript, the results of a longitudinal analysis of age-related reductions in VO2max in endurance-trained women aged 40–73 yr were published (8). They reported age-related rates of decline in VO2max ranging from −0.4 to −0.9 ml·kg−1·min−1·yr−1 in female masters athletes (8). These rates of decline in VO2max are similar to those we obtained in our endurance-trained women and appear to be greater than the rates previously reported in sedentary controls (2, 6), but no sedentary control group was included.

Regarding “physiological” mechanisms, it has been hypothesized that the decline in VO2max with age in trained and untrained adults may be influenced by the corresponding reduction in maximal heart rate (7). However, consistent with our previous cross-sectional results (6, 18, 19), there was no obvious association between reductions in maximal heart rate and habitual exercise status. These findings suggest that other factors, including declines in maximal stroke volume, skeletal muscle oxidative capacity, and/or pulmonary function (e.g., maintenance of arterial oxygen concentrations), may be responsible for explaining group differences in the absolute rate of decline in VO2max with age. Moreover, we wish to emphasize that more than one mechanism may be responsible for population-specific differences in the rate of decline in VO2max with age. The fact that the rates of decline were similar in the sedentary controls and endurance-trained women who maintained/increased training volume suggests the possibility of a common mechanism (or mechanisms), perhaps related to fundamental biological aging processes. On the other hand, the greater rate of decline in VO2max in the endurance-trained women who decreased their training volume is consistent with the superimposition of one or more additional mechanisms.
Table 3. Selected subject characteristics of endurance-trained women: subgroup analyses

<table>
<thead>
<tr>
<th>Variable</th>
<th>Reduced Training Volume</th>
<th>Increased/Maintained Training Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Follow-up</td>
</tr>
<tr>
<td>n</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Age, yr</td>
<td>50 ± 3</td>
<td>56 ± 3</td>
</tr>
<tr>
<td>Height, cm</td>
<td>159 ± 3</td>
<td>159 ± 3</td>
</tr>
<tr>
<td>Body mass, † kg</td>
<td>50.5 ± 1.9</td>
<td>51.0 ± 2.0</td>
</tr>
<tr>
<td>Body fat, %</td>
<td>15 ± 1</td>
<td>18 ± 1*</td>
</tr>
<tr>
<td>Fat-free mass, kg</td>
<td>42.8 ± 1.6</td>
<td>41.9 ± 1.7</td>
</tr>
<tr>
<td>Maximal heart rate, beats/min</td>
<td>168 ± 5</td>
<td>164 ± 5</td>
</tr>
<tr>
<td>Maximal oxygen pulse, ml·kg⁻¹·beat⁻¹</td>
<td>0.296 ± 0.008</td>
<td>0.261 ± 0.012*</td>
</tr>
<tr>
<td>Maximal respiratory exchange ratio</td>
<td>1.16 ± 0.02</td>
<td>1.20 ± 0.03</td>
</tr>
<tr>
<td>Maximal rating of perceived exertion</td>
<td>20 ± 0</td>
<td>20 ± 0</td>
</tr>
<tr>
<td>Running mileage, ‡ km/wk</td>
<td>62 ± 7</td>
<td>42 ± 5*</td>
</tr>
<tr>
<td>Training speed, m/min</td>
<td>189 ± 6</td>
<td>178 ± 5*</td>
</tr>
<tr>
<td>Training frequency, days/wk</td>
<td>5.3 ± 0.4</td>
<td>4.7 ± 0.4*</td>
</tr>
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Values are means ± SE; n, no. of subjects. *P < 0.05 vs. baseline. † P < 0.05 main effect of training volume status.

perhaps linked to processes associated with deconditioning per se. Definitive mechanistic insight into these issues will need to be obtained from future longitudinal studies.

Our series of findings in women (6, 18) differ from the results of our recent meta-analysis in men (22). In the latter investigation, we found that both absolute and relative rates of decline in VO₂max with age were not different between sedentary and endurance-trained men (22). These gender-related differences are in agreement with the previously mentioned cross-sectional study by Ogawa et al. (12). Although they studied distinct groups of young and older men and women, manual construction of a linear regression line with the use of their mean data reveals that the absolute rate of decline in VO₂max was ~50% greater in the endurance-trained compared with the sedentary women, whereas such differences were absent in men (12). It is not clear why there appears to be a sex difference in the age-related reduction in VO₂max between sedentary and endurance-trained healthy adults. Based on the present study’s findings, it is plausible to hypothesize that some endurance-trained women may experience a greater rate of decline in training volume compared with their male counterparts. A well-controlled laboratory-based study would be required to properly test this hypothesis.

In conclusion, the results of the present longitudinal study support our recent cross-sectional findings that, in the overall sample of endurance-trained women, the absolute, but not relative, rate of decline in VO₂max with age was greater in endurance-trained compared with healthy sedentary women. However, our data also indicate that the greater age-associated rate of decline in VO₂max in the overall sample of endurance-trained women appears to be due to those who reduced their training (running) volume. Thus, among healthy women aged 34–78 yr, the endurance exercise-trained state only is associated with an accelerated rate of decline in maximal aerobic capacity (compared with sedentary women) when training volume decreases.

Fig. 3. Absolute rates of decline in VO₂max in endurance-trained women who reduced and who maintained/increased their baseline training volume. Numbers in parentheses indicate baseline VO₂max values ± SE. *P < 0.05 vs. the other two groups.
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