HIGHLIGHTED TOPIC | Physiology of Aging

Longitudinal changes in aerobic power in older men and women

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1 Canadian Centre for Activity and Aging, 2 School of Kinesiology, and 3 Faculty of Medicine and Dentistry, University of Western Ontario, London, Ontario N6G 2M3; 4 School of Nutrition and Dietetics, Acadia University, Wolfville, Nova Scotia, Canada B4P 2R6

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Stathokostas, Liza, Shanthi Jacob-Johnson, Robert J. Petrella, and Donald H. Paterson. Longitudinal changes in aerobic power in older men and women. J Appl Physiol 97: 784–789, 2004. First published March 26, 2004; 10.1152/japplphysiol.00447.2003.—The purpose of this study was to describe the longitudinal (10 yr) decline in aerobic power [maximal O2 uptake (VO2 max)] and anaerobic threshold [ventilatory threshold (TVel)] of older adults living independently in the community. Ten years after initial testing, 62 subjects (34 men, mean age 73.5 ± 6.4 yr; 28 women, 72.1 ± 5.3 yr) achieved VO2 max criteria during treadmill walking tests to the limit of tolerance in the community. Ten years after initial testing, 62 subjects (34 men, mean age 73.5 ± 6.4 yr; 28 women, 72.1 ± 5.3 yr) achieved VO2 max criteria during treadmill walking tests to the limit of tolerance, with TVel determined in a subset of 45. VO2 max in men showed a rate of decline of −0.43 mlkg−1min−1yr−1, and the decline in VO2 max was consequent to a lowered maximal heart rate with no change in the maximum O2 pulse. The women showed a slower rate of decline of VO2 max of −0.19 mlkg−1min−1yr−1 (P < 0.05), again with a lowered HRmax and unchanged O2 pulse. In this sample, lean body mass was not changed over the 10-yr period. Changes in VO2 max were not significantly related to physical activity scores. TVel showed a nonsignificant decline in both men and women. Groupings of young-old (65–72 yr at follow-up) vs. old-old (73–90 yr at follow-up) were examined. In men, there were no differences in the rate of VO2 max decline. The young-old women showed a significant decline in VO2 max, whereas old-old women, initially at a VO2 max of 19.4 ± 3.1 mlkg−1min−1, showed no loss in VO2 max. The longitudinal data, vs. cross-sectional analysis, showed a greater decline for men but similar estimates of the rates of change in women. Thus the 10-yr longitudinal study of the cohort of community-dwelling older adults who remained healthy, ambulatory, and independent showed a 14% decline in VO2 max in men, and a smaller decline of 7% in women, with the oldest women showing little change over the 10-yr period.

aerobic fitness; treadmill testing; maximal oxygen uptake; aging; oxygen pulse; physical activity

AEROBIC FITNESS IN THE OLDER POPULATION is related to health status (18), all-cause mortality (30), and functional capacity (19, 28, 32). Earlier, our laboratory reported the aerobic fitness [maximal O2 uptake (VO2 max) and submaximal aerobic power (ventilatory threshold; TVel)] in a relatively large sample of both men and women, aged 55–85 yr, living independently in the community (9, 31). The opportunity arose to retest these individuals in a 10-year follow-up. By natural selection, this sample represents those who remained healthy, ambulatory, living independently, and capable of performing a treadmill test (“successful aging”). Thus the purposes of this study were 1) to examine the longitudinal change in maximal (VO2 max) and submaximal (TVel) aerobic power of older adults and to compare the changes in men and women, 2) to compare the 10-yr changes in VO2 max in young-old (initially 55–62 yr) and old-old (initially 63–80 yr), and 3) to compare the change in VO2 max from the longitudinal vs. the cross-sectional data (in the sample drawn from the same population).

The majority of studies of the differences in aerobic fitness measures with age, or “age-related changes,” have been cross-sectional in design. Ideally, longitudinal studies are needed to observe the effects of age. A few longitudinal reports of aerobic fitness with age of older adults have described the rate of decline in “specialized” groups of masters athletes or endurance-trained subjects (15, 25, 26, 35). This information may not be generalizable to the “normal” healthy older population, and the existing data (4, 12, 21, 22, 35) in this regard give an inconsistent representation of the longitudinal rate of decline with age in the older population.

Aging itself is not uniform, either within an individual or between individuals, and it may affect different systems at different onset times and rates (33). Cross-sectional studies do not capture these individual changes, whereas longitudinal data are particularly advantageous in this regard. For example, as opposed to the customary gain in fat mass during middle-age and the importance of changes in body composition to the age-related aerobic fitness (21, 22), older age is often associated with a significant loss of lean body mass (19, 31). Also, exercise behaviors influence the age-related decline in aerobic fitness (21, 22), and across older ages in those remaining ambulatory and independent, it appears that cardiorespiratory fitness declines toward a minimum compatible with daily living (31). These factors might also relate to whether men and women show similar declines in their aerobic fitness in older age. The data of the present study also provided information to assess whether this older age group demonstrates a uniform change or whether there is an age period of maintenance or of accelerated loss. Thus we compared the rates of decline in a young-old group at follow-up of mean age 65–72 yr with the old-old group aged 73–90 yr (i.e., young-old vs. old-old).

METHODS

Subjects

The original cohort included 441 men and women aged 55–85 yr from a random sample from the city of London, Ontario (1987, Submitted 1 May 2003; accepted in final form 24 March 2004.

AERobic Fitness in the older population is related to health status (18), all-cause mortality (30), and functional capacity (19, 28, 32). Earlier, our laboratory reported the aerobic fitness [maximal O2 uptake (VO2 max) and submaximal aerobic power (ventilatory threshold; TVel)] in a relatively large sample of both men and women, aged 55–85 yr, living independently in the community (9, 31). The opportunity arose to retest these individuals in a 10-year follow-up. By natural selection, this sample represents those who remained healthy, ambulatory, living independently, and capable of performing a treadmill test (“successful aging”). Thus the purposes of this study were 1) to examine the longitudinal change in maximal (VO2 max) and submaximal (TVel) aerobic power of older adults and to compare the changes in men and women, 2) to compare the 10-yr changes in VO2 max in young-old (initially 55–62 yr) and old-old (initially 63–80 yr), and 3) to compare the change in VO2 max from the longitudinal vs. the cross-sectional data (in the sample drawn from the same population).

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METHODS

Subjects

The original cohort included 441 men and women aged 55–85 yr from a random sample from the city of London, Ontario (1987,
population 280,000) as described by Koval et al. (27). From this
group, 298 subjects achieved V\textsubscript{O2,max} criteria on a fatigue-limited
treadmill walking test (31). Follow-up subjects were recruited from
these 298 by letter, followed with a telephone call.

In the present 10-yr follow-up, 205 of the original 298 subjects who
participated in treadmill testing were recruited for retesting (i.e., 69%-
recruitment rate). Reasons for no follow-up included death, loss of
independence, refusal, and no contact. All of the experimental proce-
dures were fully explained (in written and verbal format), and each
participant signed an informed consent approved by The Review
Board for Research Using Human Subjects at the University of
Western Ontario. Inclusion criteria for treadmill retesting were on
the basis of assessment by the study physician of the physical and
cognitive abilities to walk on a motor-driven treadmill. Exclusion
criteria for the present study were adopted from the initial testing
and consisted of the following: cardiovascular disease (i.e., unstable
angina or uncontrolled severe hypertension), blindness, orthopedic dis-
abilities with inability to walk or confinement to a wheelchair, and
the lack of mental and cognitive abilities to understand and execute the
activities. Ninety subjects were excluded for medical reasons, health
symptoms or signs identified early in the test, a general inability to
accommodate to walking on a treadmill due to discomfort or poor
balance, or inability to accommodate to the breathing apparatus
(mouthpiece). Thus, in the 10-yr follow-up, 115 subjects now aged
65–96 yr maintained an independent lifestyle and were able to
exercise on the treadmill.

Measurements and Testing Procedures

Testing procedures and measurements were carried out as closely
as possible to the original study. Anthropometric measurements in-
cluded height, body mass, and four skinfold thicknesses (triceps,
biceps, subscapular, and suprailiac) taken with Harpenden calipers on
the subject’s right side. Body density was estimated from the loga-
rithm of the sum of four skinfold measurements (14), and percent
body fat was estimated by using Siri’s (37) equation.

Physical activity was assessed by the Minnesota Leisure-Time
Activity (LTPA) questionnaire (40). For the present data in older
adults, the intensity codes (metabolic rate scores) for different activ-
ities, developed for middle-aged subjects, were reduced (proportional
to the age-related slowing of self-paced walking) to acknowledge that
older subjects would pursue these activities at a slower absolute pace.

The determination of V\textsubscript{O2,max} and associated cardiorespiratory
variables was carried out using a treadmill test. Treadmill speed was
set at 45.5 m/min (1.7 miles/h), and grade was held at 0% for the
first 4 min of walking. This was followed by a grade or velocity increase
or combination of velocity and grade increases in specific small
increments to elicit a ramplike test. At the end of the test, the subjects
walked on the treadmill for 2 min at 0% grade percent and a speed
of 45.5 m/min for recovery. The protocol was designed to elicit O\textsubscript{2}
demand increases each minute, ranging from 1 to 3 ml·kg\textsuperscript{-1}·min\textsuperscript{-1},
and the protocol for each subject was selected to result in a test of
8–12 min. The study physician monitored electrocardiogram, blood
pressure, and symptoms (e.g., chest pain, severe shortness of breath)
throughout the treadmill tests.

Data Collection and Analyses

During the test, subjects breathed through a mouthpiece, and
inspired and expired gas flows were measured using a low-dead-space
(90 ml) bidirectional turbine (model VMM 110, Alpha Technologies)
calibrated before each test using a syringe of known volume (0.990
liter). Respired gases were sampled continuously (1 ml/s) at the mouth
and analyzed for fractional concentrations of O\textsubscript{2}, CO\textsubscript{2}, and N\textsubscript{2} using a
mass spectrometer (model MGA-1100, Perkin Elmer) calibrated
daily against precision-analyzed gas mixtures. Changes in gas con-
centrations were aligned with gas volumes by measuring the time
delay for a square-wave bolus of gas passing the turbine to the
resulting changes in fractional gas concentrations as measured by the
mass spectrometer. Breath-by-breath alveolar gas exchange data were
calculated by using the algorithms of Beaver et al. (6), and data for
V\textsubscript{O2,max} and T\textsubscript{V\textsubscript{E}} were expressed as the 15-s average. Heart rate was
recorded continuously by a 12-lead electrocardiograph, and blood
pressure was recorded with manual sphygmomanometry. Maximal O\textsubscript{2}
pulse was calculated from the V\textsubscript{O2,max} and maximal heart rate (HR-
max) measurements. V\textsubscript{O2,max} and T\textsubscript{V\textsubscript{E}} criteria were replicated from the initial testing. V\textsubscript{O2,max} was considered to have been attained if the following criteria
were reached: 1) a feeling of fatigue, and a 15-s plateau in O\textsubscript{2} uptake concurrent with an increase in power output, wherein the O\textsubscript{2} uptake increase over a 15-s period was less than one-half of the V\textsubscript{O2} increase
per work rate increase during the submaximal period of the test; or 2) a
respiratory exchange ratio >1.0 and a heart rate within 5 beats/min
of the age-specific H\textsubscript{Rmax} (220 beats/min – age). T\textsubscript{V\textsubscript{E}} was determined by
visual inspection of data using the criteria outlined by Davis et al.
(11) of a systematic increase in expired ventilation/O\textsubscript{2} uptake (or
t-end tidal P\textsubscript{O2}) with no concomitant rise in expired ventilation/CO\textsubscript{2}
production or a decrease in end-tidal P\textsubscript{CO2}. Two independent inves-
tigators determined T\textsubscript{V\textsubscript{E}, with discrepancies resolved by conference.

Statistical Analyses

Data analyses were performed with the Statistical Package for the
Social Sciences version 11.0. Data collected during initial and follow-
up testing were used to determine longitudinal changes in anthropo-
metric, physical activity, and cardiorespiratory variables. Descrip-
tive data are expressed as means ± SD. To compare the follow-up
sample with the original random sample, the follow-up subset of men
and women was removed from the original sample. Comparisons were
made by independent t-tests, with Levene’s test used to assess equality
of variances. Comparisons of original and follow-up data of study
variables were performed by using a two-way (initial-10 yr, gender)
repeated-measures analysis of variance. Analysis of covariance was
used to assess the change in V\textsubscript{O2,max} over time, adjusted for changes
in physical activity scores or lean body mass. Additionally, the
longitudinal sample was divided into two age groupings (young-old,
at follow-up aged 65–72 yr; old-old, aged 73–90 yr) to observe
whether the rates of decline differed. Within- and between-group
differences were assessed by analysis of variance within each sex. The
difference between follow-up and initial values for study variables
was used to express absolute and percent longitudinal changes. Sig-
nificance level was set at P < 0.05.

RESULTS

Subject Participation

Table 1 describes subject participation in the longitudinal
follow-up of performance and health-related tests. Average
time between tests was 10.1 ± 0.4 yr. In 81 of the 115 subjects,
the reason given for stopping the treadmill test was fatigue, and
62 (34 men, 28 women) of these subjects attained V\textsubscript{O2,max}

<table>
<thead>
<tr>
<th>Category</th>
<th>Total</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participated in treadmill testing</td>
<td>115</td>
<td>55</td>
<td>60</td>
</tr>
<tr>
<td>Completed fatigue-limited treadmill test</td>
<td>81</td>
<td>42</td>
<td>39</td>
</tr>
<tr>
<td>Achieved V\textsubscript{O2,max} criteria</td>
<td>62</td>
<td>34</td>
<td>28</td>
</tr>
<tr>
<td>T\textsubscript{V\textsubscript{E}} and V\textsubscript{O2,max} measured</td>
<td>45</td>
<td>22</td>
<td>23</td>
</tr>
</tbody>
</table>

V\textsubscript{O2,max}, maximal oxygen uptake (aerobic power); T\textsubscript{V\textsubscript{E}, ventilatory threshold
(submaximal aerobic power).
criteria. TVe was obtained for 45 subjects (22 men and 23 women).

The subsets of 34 men and 28 women were removed from, and then compared with, the original larger sample for their representativeness. On the basis of the initial data, those who remained in the longitudinal sample of men were on the initial tests significantly older (73.5 ± 6.4 vs. 69.9 ± 8.1 yr), had a greater sum of four skinfolds (56.8 ± 15.3 vs. 47.5 ± 20.0 mm; P = 0.016), and had significantly greater percent body fat (27.8 ± 4.5 vs. 24.3 ± 4.0%). There were no differences in VO2max. The longitudinal female subset had a greater initial VO2max (1.39 ± 0.27 vs. 1.16 ± 0.23 l/min) and body mass-adjusted VO2max (22.1 ± 4.6 vs. 18.5 ± 3.5 ml·kg⁻¹·min⁻¹; P = 0.026), with a similar percent body fat (36.2 ± 4.5 vs. 35.7 ± 4.4%) compared with the original sample. There was no difference in men or women for baseline activity scores of the follow-up [416 metabolic equivalents (MET)-min⁻¹·day⁻¹] vs. original sample (414 MET·min⁻¹·day⁻¹).

The male and female samples in the 10-yr follow-up (comparison in Tables 2 and 3) did not differ significantly in age. Men were taller with a greater body mass and body mass index (P = 0.023) than the women, whereas the women had a greater sum of skinfolds and percent body fat. Five women (of 28) in the follow-up sample were receiving hormone replacement therapy compared with 15 (of 146) women in the original sample.

Table 3. Comparison of anthropometric and physical activity data for longitudinal sample of women

<table>
<thead>
<tr>
<th>Variable</th>
<th>Original</th>
<th>Follow-up</th>
<th>Mean Change</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yr</td>
<td>62.0±5.2</td>
<td>72.1±5.3</td>
<td>10.1±0.2</td>
<td>0.000</td>
</tr>
<tr>
<td>Height, cm</td>
<td>160.0±6.2</td>
<td>158.3±5.9</td>
<td>−1.7±7.1</td>
<td>0.206</td>
</tr>
<tr>
<td>Mass, kg</td>
<td>64.3±7.5</td>
<td>66.6±8.7</td>
<td>2.3±6.4</td>
<td>0.073</td>
</tr>
<tr>
<td>BMI</td>
<td>25.2±3.1</td>
<td>25.2±3.1</td>
<td>0.0±3.5</td>
<td>1.000</td>
</tr>
<tr>
<td>Skinfold, mm</td>
<td>64.2±19.2</td>
<td>78.1±23.7</td>
<td>13.9±25.4</td>
<td>0.010</td>
</tr>
<tr>
<td>Body fat, %</td>
<td>36.2±4.5</td>
<td>38.5±5.1</td>
<td>2.3±5.3</td>
<td>0.023</td>
</tr>
<tr>
<td>Fat-free mass, kg</td>
<td>41.5±5.5</td>
<td>40.7±3.7</td>
<td>−0.8±4.5</td>
<td>0.401</td>
</tr>
<tr>
<td>Leisure time</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>physical activity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MET·min⁻¹·day⁻¹</td>
<td>405±247</td>
<td>561±286</td>
<td>156.8±428.1</td>
<td>0.063</td>
</tr>
</tbody>
</table>

Values are means ± SD for n = 28 subjects.

Table 4. Comparison of cardiorespiratory fitness data for longitudinal sample of men

<table>
<thead>
<tr>
<th>Variable</th>
<th>Original</th>
<th>Follow-up</th>
<th>Mean Change</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2max, l/min</td>
<td>2.11±0.39</td>
<td>1.76±0.44</td>
<td>−0.35±0.48</td>
<td>0.000</td>
</tr>
<tr>
<td>m/Min⁻¹·kg⁻¹</td>
<td>26.3±5.4</td>
<td>22.0±5.3</td>
<td>−4.3±6.0</td>
<td>0.000</td>
</tr>
<tr>
<td>TVE</td>
<td>1.67±0.38</td>
<td>1.37±0.39</td>
<td>−0.30±0.46</td>
<td>0.004</td>
</tr>
<tr>
<td>m/Min⁻¹·kg⁻¹</td>
<td>20.6±4.2</td>
<td>19.4±4.5</td>
<td>−1.4±5.7</td>
<td>0.270</td>
</tr>
<tr>
<td>HRmax, beats/min</td>
<td>164.0±15.2</td>
<td>140.0±15.4</td>
<td>−24.0±14.7</td>
<td>0.000</td>
</tr>
<tr>
<td>O2 pulse, ml/beat</td>
<td>13.2±2.2</td>
<td>13.0±2.9</td>
<td>−0.2±2.7</td>
<td>0.740</td>
</tr>
</tbody>
</table>

Values are means ± SD for n = 34 subjects. However, TVE was measured with n = 22, and 5 men were excluded from maximal heart rate (HRmax) data because of use of β-blocker medication.

Age-related Longitudinal Changes

Body composition. In both men (P = 0.042) and women (P = 0.010), the increase in sum of four skinfolds was significant, and in women the increase in estimated percent body fat was also significant (P = 0.023). Nevertheless, there was no significant age-related change over the 10 yr in mean body mass or calculated fat-free mass for either men or women (Tables 2 and 3).

Total LTPA. LTPA scores showed a significant increase over the 10-yr period (416 ± 216 to 584 ± 271 MET·min⁻¹·day⁻¹; P = 0.001). The increase in activity levels was significant in men (P = 0.005) and approached significance in women (P = 0.063) (Tables 2 and 3). Men vs. women were not different on baseline or 10-yr activity scores.

VO2max. From the fatigue-limited treadmill test, HRmax averaged 95% of age-predicted maximum, and the mean respiratory exchange ratio was 1.09. The men showed a significant age-related decline in VO2max (l/min) (Table 4), representing a decline of 0.035 l·min⁻¹·yr⁻¹. The change in VO2max in the women (Table 5) was not significant (−0.006 l·min⁻¹·yr⁻¹) over the 10-yr period. In both men and women, there was a significant decrease in body mass-adjusted VO2max. Calculated from the initial and follow-up means (Tables 4 and 5), the men showed a decrease of 0.43 ml·kg⁻¹·min⁻¹·yr⁻¹ (P < 0.001) and the women 0.19 ml·kg⁻¹·min⁻¹·yr⁻¹ (P = 0.010), corresponding to declines of 14.7 ± 21.1 and 7.0 ± 15.5% over the decade for men and women, respectively. The rate of decline in men compared with women was not statistically different (P = 0.064). The initial VO2max of men was significantly higher than that of the women, with the rates of decline predicting a similar VO2max in men and women at −80

Table 5. Comparison of cardiorespiratory fitness data for longitudinal sample of women

<table>
<thead>
<tr>
<th>Variable</th>
<th>Initial</th>
<th>Follow-up</th>
<th>Mean Change</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2max, l/min</td>
<td>1.39±0.27</td>
<td>1.33±0.22</td>
<td>−0.06±0.20</td>
<td>0.116</td>
</tr>
<tr>
<td>m/Min⁻¹·kg⁻¹</td>
<td>22.1±4.6</td>
<td>20.2±3.7</td>
<td>−1.9±3.6</td>
<td>0.010</td>
</tr>
<tr>
<td>TVE</td>
<td>1.11±0.26</td>
<td>1.11±0.19</td>
<td>0.00±0.23</td>
<td>0.835</td>
</tr>
<tr>
<td>m/Min⁻¹·kg⁻¹</td>
<td>17.8±4.1</td>
<td>16.7±2.9</td>
<td>−1.1±3.6</td>
<td>0.261</td>
</tr>
<tr>
<td>HRmax, beats/min</td>
<td>165.2±13.6</td>
<td>141.3±17.8</td>
<td>−23.9±19.3</td>
<td>0.000</td>
</tr>
<tr>
<td>O2 pulse, ml/beat</td>
<td>10.0±2.2</td>
<td>9.0±1.4</td>
<td>1.1±1.7</td>
<td>0.108</td>
</tr>
</tbody>
</table>

Values are means ± SD for n = 28 subjects. However, TVE was measured with n = 23.
yr of age. In the baseline data, total physical activity was not significantly correlated with \( \dot{V}O_2 \text{max} \), nor was there a significant correlation with the quantity of activity characterized as heavy intensity. The significant change in \( \dot{V}O_2 \text{max} \) over the 10-yr period remained significant after accounting for the change in LTPA as a covariate. In fact, the change in \( \dot{V}O_2 \text{max} \) was not significantly affected by the change in LTPA score (\( P = 0.232 \)). This also was the case using the “heavy” activities score to represent activity values. From regression analysis of the change in \( \dot{V}O_2 \text{max} \) with the change in LTPA, the \( R^2 \) was 0.024; that is, only 2.4% of the variance in the change in \( \dot{V}O_2 \text{max} \) was accounted for by the variance in the change in physical activity levels.

Whereas the mean \( \dot{V}O_2 \text{max} \) decreased, this was not an exclusive trend. Figure 1, A and B, shows the individual variability, and notably six men and seven women demonstrated increases in body mass-adjusted \( \dot{V}O_2 \text{max} \) over the 10-yr period. In both the initial and follow-up testing, these 13 subjects were fatigue limited and reached their age-predicted \( HR_{\text{max}} \) values (initial, 157 beats/min; follow-up, 145 beats/min), indicating valid results. Of the 13 subjects who demonstrated an increase in \( \dot{V}O_2 \text{max} \), 10 reported having taken up an exercise training program, and the 13 subjects as a group demonstrated a significant increase in participation of structured exercise as reported in the LTPA (initial, 49.9 ± 98.9 METS·min\(^{-1}\)·day\(^{-1}\) vs. follow-up, 53.5 ± 54.7 METS·min\(^{-1}\)·day\(^{-1}\); \( P = 0.04 \).

\( HR_{\text{max}} \). \( HR_{\text{max}} \) decreased significantly over the 10-yr period by a mean of 2.4 beats/yr in both men and women (Tables 4 and 5). (Five men were on \( \beta \)-blocker medication, and their data were removed from these heart rate analyses.) The calculated maximal \( O_2 \) pulse was unchanged over the 10-yr period for men (13.2 ± 2.2 to 13.0 ± 2.9 ml/beat) and women (8.4 ± 1.5 to 9.5 ± 1.8 ml/beat) (Tables 4 and 5). The \( HR_{\text{max}} \) showed no difference in men compared with women, either initially or at follow-up; however, the \( O_2 \) pulse (both initial and follow-up) was significantly higher in the men compared with women.

\( TV_o \). \( TV_o \) (l/min) was significantly reduced in the men after the 10-yr period, but it was not significantly changed for the women (Tables 4 and 5). Body mass-adjusted \( TV_o \) was not significantly changed for either men or women. Calculated from the initial and follow-up means (Tables 4 and 5), non-

\( TVE. \)
significant declines of 0.13 and 0.09 ml·kg⁻¹·min⁻¹·yr⁻¹ in TVE were observed for men and women, respectively. The TVE as a percentage of VO₂max was not significantly changed with age in either men (VO₂max was not significantly changed with age in either men (80.2 ± 20.6 to 80.5 ± 11.5%) or women (79.8 ± 12.3 to 83.6 ± 6.7%). The individual variability of the changes in TVE is depicted in Fig. 2, A and B.

Age-Related Longitudinal Changes Comparing Age Groups

In the men, only the old-old group showed a significant increase in skinfolds and loss of fat-free mass (~1.9 kg). There was no difference in the rate of decline of VO₂max comparing the young-old group (~4.2 ml·kg⁻¹·min⁻¹) vs. the old-old group (~4.4 ml·kg⁻¹·min⁻¹) (Fig. 3A). The reductions in HRmax were different (young-old: 19.1 beats/min; old-old: 30.0 beats/min; P < 0.001). The change in TVE was not different for the young-old group (0.1 ml·kg⁻¹·min⁻¹) vs. the old-old group (~1.7 ml·kg⁻¹·min⁻¹). The women showed no between-age-group differences in the change in body composition. The VO₂max decline was significant in the young-old group (~3.1 ml·kg⁻¹·min⁻¹) but not in the old-old group (~0.2 ml·kg⁻¹·min⁻¹) (Fig. 3B), and thus there was a significant difference (P = 0.029) in the rates of decline between groups. Both age groups showed a similar reduction in HRmax (24 beats/min). The change in TVE was not different for the young-old group (~1.9 ml·kg⁻¹·min⁻¹) vs. the old-old group (0.30 ml·kg⁻¹·min⁻¹).

Comparison of Longitudinal Changes With Cross-Sectional Data

In men, the aerobic fitness variables in general showed a greater decline with age from the longitudinal data vs. the cross-sectional analysis of the initial data in the same individuals. Specifically, the VO₂max decline was ~0.43 ml·kg⁻¹·min⁻¹·yr⁻¹ compared with ~0.25 ml·kg⁻¹·min⁻¹·yr⁻¹ from the cross-sectional analysis of initial data in the same group (Table 6). In women, the longitudinal and cross-sectional data in general yielded more similar rates of change, with VO₂max declines of ~0.19 and ~0.17 ml·kg⁻¹·min⁻¹·yr⁻¹, respectively (Table 6). Anthropometric data did not show consistent differences in the longitudinal vs. cross-sectional analyses.

DISCUSSION

This longitudinal study examined the relationship between age and aerobic parameters in a sample of independently living older men and women. Past investigations have been either cross-sectional, including large age ranges, or longitudinal but not representative of the general aging population. The present study is unique in the report of the decline of VO₂max for male sub-jects divided by age groups (initially 55–86 yr, mean age 72.8 yr) of both men and women over a 10-yr period.

In longitudinal studies, the validity of the data can be compromised, especially when the time between testing intervals is long. In the present study, this issue was minimized by the use of the same exercise test protocol and laboratory equipment setup for both test sessions. Continuous use of the laboratory setup throughout the 10-yr period gave consistent measures of O₂ for given cycle work rates. Furthermore, during the time frame of this study, the laboratory achieved the Canadian Society for Exercise Physiology (CSEP) accreditation for cardiorespiratory testing, with measured VO₂max on athletes tested in the different laboratories within 5% of the.

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mean standard of other accredited laboratories. Possible error in measurement techniques is acknowledged for the body composition measurements because the study investigators differed for the original and follow-up test sessions. This source of error was minimized by using investigators who were all trained and accredited by CSEP as Certified Fitness Consultants and by the use of carefully documented study protocols. Comparatively, this source of error would be minimal in light of an inherent 20% error in the use of skinfold measurement to determine fat-free mass in older adults (29).

In a descriptive study of the normal population, there also exists the problem of obtaining a representative sample. The original sample, as described by Paterson et al. (31), represented those from a random sample of the healthy older population able to complete a fatigue-limited exercise test. The characteristics of the follow-up sample in this age group are influenced by selective “survivorship” and morbidity, and thus this study necessarily describes the changes over time in those who remained ambulatory and independent (i.e., “successful,” healthy aging). Nevertheless, the initial characteristics of those available for the follow-up were similar to the original sample with only some exceptions. The returning sample of men and women both actually had a greater percent body fat, and the women, but not the men, had a significantly greater \( \dot{V}O_2 \) max (ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\); \( P = 0.03 \)). Thus the longitudinal sample of men was not overrepresented by leaner and fitter men (as one might have expected), although the female sample may be biased with the fitter subgroup able to participate in the follow-up. Compared with the samples studied by other groups (as detailed in Tables 7 and 8), the \( \dot{V}O_2 \) max of the men and women of the present study was similar, or somewhat lower, although the age comparisons are not exact. Mean \( \dot{V}O_2 \) max of

Table 6. Comparison of cross-sectional differences across age vs. longitudinal rates of change per year for the same sample of men and women

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cross-sectional</th>
<th>Longitudinal</th>
<th>Cross-sectional</th>
<th>Longitudinal</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \dot{V}O_2 ) max, l·min(^{-1})·yr(^{-1})</td>
<td>-0.026</td>
<td>-0.035</td>
<td>-0.013</td>
<td>-0.006</td>
</tr>
<tr>
<td>Body mass, kg/yr</td>
<td>0.30</td>
<td>0.04</td>
<td>0.13</td>
<td>0.23</td>
</tr>
<tr>
<td>( \dot{V}O_2 ) max, ml·kg(^{-1})·min(^{-1})·yr(^{-1})</td>
<td>-0.25</td>
<td>-0.43</td>
<td>-0.17</td>
<td>-0.19</td>
</tr>
<tr>
<td>( T_{\dot{V}O_2} ), l·min(^{-1})·yr(^{-1})</td>
<td>-0.015</td>
<td>-0.030</td>
<td>-0.007</td>
<td>0.000</td>
</tr>
<tr>
<td>( T_{\dot{V}O_2} ), ml·kg(^{-1})·min(^{-1})·yr(^{-1})</td>
<td>-0.02</td>
<td>-0.14</td>
<td>-0.08</td>
<td>-0.11</td>
</tr>
<tr>
<td>HR, beat·min(^{-1})·yr(^{-1})</td>
<td>-0.68</td>
<td>-2.40</td>
<td>-1.49</td>
<td>-2.39</td>
</tr>
<tr>
<td>O(_2) pulse, ml/beat</td>
<td>-0.14</td>
<td>-0.02</td>
<td>0.00</td>
<td>0.11</td>
</tr>
<tr>
<td>BMI, per year</td>
<td>0.17</td>
<td>0.09</td>
<td>0.06</td>
<td>0.00</td>
</tr>
<tr>
<td>Skinfolds, mm/yr</td>
<td>0.48</td>
<td>0.58</td>
<td>1.30</td>
<td>1.39</td>
</tr>
<tr>
<td>Body fat, %/yr</td>
<td>0.10</td>
<td>0.17</td>
<td>0.28</td>
<td>0.23</td>
</tr>
<tr>
<td>Fat-free mass, kg/yr</td>
<td>-0.03</td>
<td>-0.01</td>
<td>-0.18</td>
<td>-0.08</td>
</tr>
</tbody>
</table>

\( n \), No. of subjects

Table 7. Rate of decline in \( \dot{V}O_2 \) max with age as reported for men in cross-sectional and longitudinal studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Population</th>
<th>( n )</th>
<th>Age, yr</th>
<th>Test Mode</th>
<th>Rate of Decline, ml·kg(^{-1})·min(^{-1})·yr(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross-sectional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Åstrand et al. (2)</td>
<td>Moderately active</td>
<td>81</td>
<td>50–64</td>
<td>Cycle</td>
<td>0.52</td>
</tr>
<tr>
<td>Dehn and Bruce (12)</td>
<td>Healthy</td>
<td>86</td>
<td>52.2 (40–72)</td>
<td>Treadmill</td>
<td>0.28</td>
</tr>
<tr>
<td>Jones et al. (24)</td>
<td>General population</td>
<td>50</td>
<td>15–71</td>
<td>Cycle</td>
<td>0.44</td>
</tr>
<tr>
<td>Posner et al. (34)</td>
<td>Healthy</td>
<td>68</td>
<td>20–89</td>
<td>Cycle</td>
<td>0.44</td>
</tr>
<tr>
<td>Fleg and Lakatta (17)</td>
<td>Subset of BLSA</td>
<td>83</td>
<td>54.2±14.9</td>
<td>Treadmill</td>
<td>0.39</td>
</tr>
<tr>
<td>Babcock et al. (5)</td>
<td>Healthy</td>
<td>79</td>
<td>30–84</td>
<td>Cycle</td>
<td>0.28</td>
</tr>
<tr>
<td>Toth et al. (42)</td>
<td>Healthy</td>
<td>378</td>
<td>44±20</td>
<td>Treadmill</td>
<td>0.42</td>
</tr>
<tr>
<td>Jackson et al. (21)</td>
<td>Healthy NASA employees</td>
<td>1,499</td>
<td>45.9±7.7</td>
<td>Treadmill</td>
<td>0.46</td>
</tr>
<tr>
<td>Paterson et al. (31)</td>
<td>Random sample</td>
<td>152</td>
<td>70.0±8.1</td>
<td>Treadmill</td>
<td>0.31</td>
</tr>
<tr>
<td>Talbot et al. (38)</td>
<td>General population</td>
<td>619</td>
<td>52.1±16.7</td>
<td>Treadmill</td>
<td>0.33</td>
</tr>
<tr>
<td>Longitudinal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dehn and Bruce (12)</td>
<td>Healthy</td>
<td>40</td>
<td>40–72</td>
<td>Treadmill</td>
<td>0.94</td>
</tr>
<tr>
<td>Åstrand et al. (4)</td>
<td>Former physical education students</td>
<td>35</td>
<td>42.9 (41–46)</td>
<td>Cycle</td>
<td>0.44</td>
</tr>
<tr>
<td>Rogers et al. (35)</td>
<td>Sedentary</td>
<td>14</td>
<td>61.4±1.4</td>
<td>Treadmill</td>
<td>0.44</td>
</tr>
<tr>
<td>Jackson et al. (21)</td>
<td>Masters athletes</td>
<td>15</td>
<td>62.0±2.3</td>
<td>Treadmill</td>
<td>0.32</td>
</tr>
<tr>
<td>Kasch et al. (25)</td>
<td>Endurance trained</td>
<td>11</td>
<td>76.1±5.7</td>
<td>Treadmill</td>
<td>0.27</td>
</tr>
<tr>
<td>Katz el et al. (26)</td>
<td>Sedentary</td>
<td>42</td>
<td>64.0±1</td>
<td>Treadmill</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Values for age are means ± SD with range in parentheses. \( n \), No. of subjects. NASA, National Aeronautics and Space Administration; BLSA, Baltimore Longitudinal Study of Aging.
the men at age 63.5 yr was 26.5 ml·kg\(^{-1}\)·min\(^{-1}\), and at age 73.5 yr it was 22.0 ml·kg\(^{-1}\)·min\(^{-1}\). Babcock et al. (5) reported a similar \(V\dot{O}_2\)max of 23.1 ml·kg\(^{-1}\)·min\(^{-1}\) for men of mean age 71.4 yr. Others have reported mean values of 28–29 ml·kg\(^{-1}\)·min\(^{-1}\) for samples aged 60+ yr (12, 34, 37). The present values for the \(V\dot{O}_2\)max of women were 22.1 ml·kg\(^{-1}\)·min\(^{-1}\) at age 62.0 yr and 20.2 ml·kg\(^{-1}\)·min\(^{-1}\) at age 72.1 yr. For groups aged 60+ yr, the literature gives mean values of 23.6 (13), 20.3 (34), 22.4 (39), and 23.1 ml·kg\(^{-1}\)·min\(^{-1}\) (38). Overall, the sample of the present longitudinal study appears to be a reasonable representation of the healthy older population, for both the men and the women.

As anticipated, \(V\dot{O}_2\)max showed a decline with age in both men and women. The longitudinal rate of decline in men (−0.43 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\)) was greater than that observed for the cross-sectional data of the original sample at −0.31 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\) (31). Other studies have generated the age-related decline from samples of a much broader age range and of mean age considerably younger. Nevertheless, other cross-sectional reports (Tables 7 and 8), have reported similar age-related rates of decline of −0.44 (24), −0.39 (17), −0.42 (42), and −0.46 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\) (21). Generally, the reported decline has been lower with values of −0.28 (12), −0.36 (34), −0.28 (5), and −0.33 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\) (38). One report gave a decline of −0.52 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\) (2). Compared with longitudinal reports (Table 7), the present findings were similar to the report by Åstrand et al. (2) of −0.44 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\) in former physical education students and by Rogers et al. (35) of −0.44 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\) in a sedentary group; however, they were greater than the decline of −0.32 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\) for masters athletes (35) and −0.27 of endurance-trained older men (25) and less than the rate of decline reported for a healthy sample by Dehn and Bruce (12) of −0.94 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\).

Contrary to the findings for the men, the longitudinal rate of decline for women of −0.19 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\) was slower than the cross-sectional report of −0.25 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\) (31). Compared with the decline given in other cross-sectional (−0.25 to 0.62 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\)) and longitudinal (−0.44 to 0.62 ml·kg\(^{-1}\)·min\(^{-1}\)·yr\(^{-1}\)) studies (Table 8), the present finding for women showed a considerably lower rate of decline. This is likely a reflection of the concept that those remaining independent in old age require a minimum level of aerobic fitness. With their lower \(V\dot{O}_2\)max compared with men, only those experiencing a small decline in \(V\dot{O}_2\)max would remain mobile and independent. Thus there may be a gender-related selective “survivorship.”

The decline in men was double the rate of that in women. Also, although the men had a greater initial \(V\dot{O}_2\)max, the percent decline over the 10 yr was 14.7% in men and 7.0% in women. Previous reports (17, 21, 22, 42) have found a greater decline for \(V\dot{O}_2\)max (ml·kg\(^{-1}\)·min\(^{-1}\)) in men. In the present longitudinal sample, this appears to be the case for men (−0.43 ml·kg\(^{-1}\)·min\(^{-1}\)) vs. women (−0.19 ml·kg\(^{-1}\)·min\(^{-1}\)) (\(P = 0.064\)).

Previous cross-sectional reports have shown a decrease in \(T\dot{V}\) in age with including older samples (5, 8, 31, 34, 41). However, in the present longitudinal data, the change with age was not significant (ml·kg\(^{-1}\)·min\(^{-1}\)) for either men or women. It appears that the cross-sectional results of the original study (31) closely predicted the longitudinal decline in men (−0.15 vs. −0.13 ml·kg\(^{-1}\)·min\(^{-1}\)) but overestimated the longitudinal decline in women (−0.14 vs. −0.09 ml·kg\(^{-1}\)·min\(^{-1}\)). Similar to Paterson et al. (31), the present data indicated no difference between men and women in the age-related rate of decline in \(T\dot{V}\). However, this is in contrast with Posner et al. (34), who found a greater decline in men vs. women. The present finding of a slower rate of decline in \(T\dot{V}\) (ml·kg\(^{-1}\)·min\(^{-1}\)) than

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**Table 8. Rate of decline in \(V\dot{O}_2\)max with age as reported for women in cross-sectional and longitudinal studies**

<table>
<thead>
<tr>
<th>Study</th>
<th>Population</th>
<th>n</th>
<th>Age, yr</th>
<th>Test Mode</th>
<th>Rate of Decline, ml·kg(^{-1})·min(^{-1})·yr(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cross-sectional</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Åstrand et al. (3)</td>
<td>Healthy</td>
<td>44</td>
<td>20–65</td>
<td>Cycle</td>
<td>0.35</td>
</tr>
<tr>
<td>Drinkwater et al. (13)</td>
<td>General population</td>
<td>123</td>
<td>10–68</td>
<td>Treadmill</td>
<td>0.27</td>
</tr>
<tr>
<td>Jones et al. (24)</td>
<td>General population</td>
<td>50</td>
<td>15–71</td>
<td>Cycle</td>
<td>0.36</td>
</tr>
<tr>
<td>Posner et al. (34)</td>
<td>Healthy</td>
<td>103</td>
<td>20–89</td>
<td>Cycle</td>
<td>0.26</td>
</tr>
<tr>
<td>Fleg and Lakatta (17)</td>
<td>Subset of BLSA</td>
<td>101</td>
<td>51.9±6.3</td>
<td>Treadmill</td>
<td>0.25</td>
</tr>
<tr>
<td>Toth et al. (42)</td>
<td>Healthy</td>
<td>224</td>
<td>47±17.0</td>
<td>Treadmill</td>
<td>0.45</td>
</tr>
<tr>
<td>Jackson et al. (22)</td>
<td>Healthy NASA employees</td>
<td>409</td>
<td>39±9.6</td>
<td>Treadmill</td>
<td>0.54</td>
</tr>
<tr>
<td>Tanaka et al. (39)</td>
<td>Endurance trained</td>
<td>84</td>
<td>21–73</td>
<td>Treadmill</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>Sedentary</td>
<td>74</td>
<td>20–75</td>
<td></td>
<td>0.32</td>
</tr>
<tr>
<td>Fitzgerald et al. (16)</td>
<td>Meta-analysis</td>
<td>911</td>
<td>33.1±14.1</td>
<td>Treadmill and cycle</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>Endurance trained</td>
<td>1,717</td>
<td>34.7±17.2</td>
<td></td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>Active</td>
<td>2,256</td>
<td>40.5±19.4</td>
<td></td>
<td>0.35</td>
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<tr>
<td>Paterson et al. (31)</td>
<td>Random sample</td>
<td>146</td>
<td>70.0±8.1</td>
<td>Treadmill</td>
<td>0.25</td>
</tr>
<tr>
<td>Talbot et al. (38)</td>
<td>General population</td>
<td>497</td>
<td>49.4±16.3</td>
<td>Treadmill</td>
<td>0.27</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Study</th>
<th>Population</th>
<th>n</th>
<th>Follow-up, yr</th>
<th>Age, yr</th>
<th>Test Mode</th>
<th>Rate of Decline, ml·kg(^{-1})·min(^{-1})·yr(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Longitudinal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Åstrand et al. (4)</td>
<td>Former physical education students</td>
<td>35</td>
<td>20</td>
<td>42.9±41–46</td>
<td>Cycle</td>
<td>0.44</td>
</tr>
<tr>
<td>Jackson et al. (22)</td>
<td>Healthy NASA employees</td>
<td>43</td>
<td>4</td>
<td>44.2±8.9</td>
<td>Treadmill</td>
<td>0.62</td>
</tr>
<tr>
<td>Eskurza et al. (15)</td>
<td>Sedentary</td>
<td>8</td>
<td>7</td>
<td>57.1±1.7</td>
<td>Treadmill</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>Endurance trained</td>
<td>16</td>
<td></td>
<td>51.0±2.3</td>
<td></td>
<td>0.40</td>
</tr>
</tbody>
</table>

Values for age are means ± SD with range in parentheses. n, No. of subjects.
$V_{O2 \text{max}}$ with age (one-third to one-half) is consistent with previous reports (5, 10, 31, 34, 38).

For the $HR_{\text{max}}$, in the longitudinal data, compared with the common predictive equation ($HR_{\text{max}} = 220 - \text{age}$), the initial $HR_{\text{max}}$ exceeded the predicted by 7 beats/min and the follow-up data were 6.6 beats/min below the predicted. Longitudinal analysis of the decline of $HR_{\text{max}}$ yielded a significant reduction of 2.4 beats·min·yr$^{-1}$ in both men and women. The decline for both men and women was greater than cross-sectional reports of a reduction of  1.6 beats·min·yr$^{-1}$ (21, 31). In both men and women, the decline in $V_{O2 \text{max}}$ (l/min) was explained by the decline in $HR_{\text{max}}$ such that there was no significant decline in $O_2$ pulse, indicating the decline in $V_{O2 \text{max}}$ occurred without a reduced maximal stroke volume and/or arteriovenous $O_2$ difference.

The rate of decline of $V_{O2 \text{max}}$ has also been related to changes in body composition (23) and reductions in activity levels (1, 21, 42). Toth et al. (42) in the study of men and women across ages 17–81 yr found that, when controlling for both fat mass and fat-free mass, the rate of decline of $V_{O2 \text{max}}$ was decreased by 50%. In the present study of older adults, however, there was no increase in percent body fat for men over the decade, the women showed only a moderate increase in body fat, and the fat-free mass was maintained across the 10-yr period for both men and women. For the present sample, the changes in percent body fat and fat-free mass were not significantly correlated with the decline of $V_{O2 \text{max}}$ with age. Analysis of covariance showed no significant effect on the change in $V_{O2 \text{max}}$ with the change of lean body mass as a covariate. The maintenance of fat-free mass contrasts to results of a 12-yr longitudinal study of nine similarly healthy male older subjects (19) who showed a 15–17% decline of muscle mass. It is possible that fat-free mass becomes overestimated with increasing age and that we could not detect the loss of fat-free mass or a relationship with the decline in $V_{O2 \text{max}}$. In addition, the conflicting results may be sample dependent. That is, our returning sample was highly mobile and may not demonstrate the same rate of decline in lean body mass as in more frail samples described in strength studies. The quality of the muscle component of fat-free mass can also be compromised with age. Conley et al. (7) reported a decline in quadriceps oxidative capacity with age resultant from reductions in both muscle volume and oxidative capacity. However, reduced quality of oxidative capacity might not have occurred in the present subjects, who maintained their estimated lean body mass.

Cross-sectional analysis of physical activity scores with age showed no significant decline for this age group, which is in contrast to studies of a much greater age span (21, 22, 42). In fact, in this successful aging group, physical activity scores were increased over the 10-yr period. However, total LTPA (and also total score in activities characterized as heavy intensity) was not correlated with $V_{O2 \text{max}}$, nor was the variance in the change in $V_{O2 \text{max}}$ affected by differences in physical activity; <3% of the variance in change in $V_{O2 \text{max}}$ could be accounted for by activity. Thus, contrary to findings that particularly relate to middle-age (21, 22, 42), in the older age groups, the present data showed that regular leisure time daily activities did not influence $V_{O2 \text{max}}$. This finding warrants further investigation.

The observation of a decline in $V_{O2 \text{max}}$ over the 10-yr period was not an exclusive one. Although it has been shown that $V_{O2 \text{max}}$ declines with age, it has also been shown that increases in $V_{O2 \text{max}}$ after a training stimulus can occur in older adults (10). In the present study, checking the activity questionnaire at 10 yr revealed that 10 of the 13 subjects who demonstrated an increase in aerobic power were involved in a structured exercise program. Furthermore, analysis of the physical activity questionnaire data reflecting participation in structured exercise indicated a significant ($P = 0.04$) increase in participation by the 13 subjects who increased their $V_{O2 \text{max}}$. Clearly, this is one factor related to the variability in age-related changes.

Conclusions. The purpose of the present investigation was to examine the longitudinal decline in $V_{O2 \text{max}}$ and $T_V$, in a general population of community-dwelling older adults and to analyze the data relative to gender and effects of body mass and composition and physical activity. Returning subjects were reasonably representative of the original larger sample. There was no significant loss of body mass or fat-free mass over the 10-yr period. The present 10-yr longitudinal description of older adults remaining independent showed a loss of body mass-adjusted $V_{O2 \text{max}}$ of 14.7% per decade for men and of 7.0% per decade for women. No significant decline in $T_V$ was observed for men or women or in the $T_V$ as a percentage of $V_{O2 \text{max}}$, confirming that $T_V$ declines at a slower rate than $V_{O2 \text{max}}$. The variance in the decline was not affected by the variability in LTPA scores. Comparison of cross-sectional and longitudinal rates of $V_{O2 \text{max}}$ decline derived from the same sample concur with previous reports of generally greater rates of decline obtained by longitudinal vs. cross-sectional study methods for the men; however, this was not the case for women. The older subgroup of women showed a maintenance of $V_{O2 \text{max}}$ over the 10 yr. Further research into the longitudinal contribution of various factors in the decline of $V_{O2 \text{max}}$ with age will assist in identifying potentially modifiable factors and thereby assist in the maintenance of independence throughout adult life.

GRANTS

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REFERENCES

AERobic power in older men and women


