The Response of Healthy Men to Treadmill Exercise

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SUMMARY Heart rates, blood pressures, and functional responses to submaximal, maximal and postexertional treadmill testing are presented for a group of 704 healthy, asymptomatic aircrewmen referred to the USAF School of Aerospace Medicine. The indicated measurements are individually described by the use of percentiles. These data provide the practicing clinician with an accurate and complete description of the response of healthy men to treadmill exercise.

THE INTERPRETATION OF ELECTROCARDIOGRAPHIC CHANGES in response to exercise testing is of established value in the early detection, diagnosis, and subsequent management of coronary atherosclerotic heart disease (CAD). The major emphasis placed on interpretation of the exercise electrocardiogram (ECG) has, however, tended to de-emphasize the value and significance of other commonly acquired exercise performance measurements (i.e., heart rate, blood pressure, and functional capacity). These latter measurements are currently attracting renewed attention as part of an effort to improve the overall sensitivity and specificity of exercise testing. Recent reports have suggested that maximal oxygen consumption, functional aerobic capacity estimated from maximal treadmill time, maximal and submaximal heart rate and blood pressure, and the maximal heart rate-blood pressure product, may also be useful indices for identifying the presence and/or severity of CAD in patients.

The value of any measurement in providing useful diagnostic information from treadmill testing depends upon: a) the accuracy and completeness with which the measurement has been made in healthy individuals (the reference values); and b) the effectiveness with which certain limits of the measurement (discriminant values) separate healthy individuals from those with known health disorders. Previously published studies have reported reference values based on the response of healthy individuals to treadmill testing. Unfortunately, a majority of these studies were based on a small sample size, and statistics based on them are less likely to provide a true estimate of population parameters than is a comparable study based on a larger number. In the remaining few studies with a larger sample size, data for both submaximal and postexertional treadmill responses are fragmentary and incomplete. Hence, the practicing clinician has not had a complete and readily available set of reference values for use with his application of treadmill exercise testing.

The purpose of the present report is to establish a complete set of reference values for the response of healthy men to submaximal, maximal, and postexertional treadmill testing. In addition to diagnostic use, these reference values serve as a basis for monitoring individuals during treadmill testing to assure patient safety. Finally, this study may provide the basis for subsequent studies which seek to establish discriminant values that separate healthy individuals from those with specific health disorders.

Materials and Methods

The United States Air Force School of Aerospace Medicine (USAFSAM) provides a clinical consultation service for the evaluation of referred, ambulatory aircrewmen with a broad spectrum of suspected or manifested medical disorders. These medical disorders, though mild and usually asymptomatic, are potentially serious in view of modern aircrew responsibilities. All individuals in the present study were aircrewmen referred to this service.

All referred aircrewmen are given a complete and comprehensive medical evaluation at the USAFSAM. This medical evaluation includes a history and physical examination by flight surgeons, internists, ophthalmologists, and ENT consultants, with further specialist work-ups where indicated. Extensive clinical laboratory studies are completed. Additional procedures routinely accomplished include chest, abdominal and sinus X-rays, resting ECG and VCG, maximal treadmill exercise testing, at least four hours of Holter ECG monitoring, and spirometry.

More then 2500 aircrewmen were seen at the USAFSAM Consultation Service between 1973 and 1975; each of the individual medical records and results of the USAFSAM evaluation were reviewed for the purpose of identifying a subgroup of healthy individuals. We excluded all individuals with acute or chronic medical disorders or with any condition that might affect functional capacity. Additionally, men with bundle branch block, significant Q waves, significant ventricular arrhythmias, hypertension, on medication of any kind, or with any abnormality brought out by treadmill testing, were excluded. Men below age 25 or above age 54 were excluded because their numbers were too small to provide meaningful data. This left a subgroup of 704 healthy, asymptomatic aircrewmen; the treadmill test results from these 704 men serve as a basis for the present report.

Maximal treadmill testing was conducted in the morning with each individual fasting and well rested. This was the subject's first treadmill test and initial experience with treadmill walking. Ambient temperature was typically maintained in the range of 23 to 26°C. Multichannel ECG data were continuously collected using fluid column silver/silver
chloride electrodes and associated ECG electronic equipment as previously described. Blood pressure was measured at regular intervals in the left arm by auscultation; Phase V (disappearance of sounds) was taken as the diastolic endpoint. Expired air was collected at full minute intervals as maximum treadmill effort was approached; air collection was accomplished using a standard mouthpiece and nose clip, Koegel's valves and turret, and weather balloons. Gas volumes were measured with a Tissot spirometer corrected for pressure and temperature. Expired gas analysis for carbon dioxide and oxygen was performed with Beckman LB-1 and E-2 instruments, respectively; these instruments were calibrated daily with gases analyzed by the micro Schöflander technique.

The treadmill testing procedure included initial periods of supine rest (2 min), quiet standing (3 min) and hyperventilation (0.75 min); then followed a treadmill walk at 3.3 mph with 1% grade increases each minute until a maximum effort had been performed. Individuals were not allowed to support their weight on treadmill handrails during the test. All individuals were cooperative and gave what they and the monitoring physician considered a maximal effort. Maximum effort was followed by an 8-min supine recovery period.

All measurement data from each individual treadmill test were entered into a computer data base. This data base was subsequently used to calculate the median (50th percentile) and the 10th and 90th percentile limits for each stated measurement at selected treadmill protocol times. We chose this nonparametric approach in presenting our data because the use of percentiles 1) does not require an assumption of a normal distribution of the population reported, and 2) this type of presentation is easily understood by most people. Our specific use of the 10th and 90th percentiles was an arbitrary choice and provides relatively conservative limits for the response of healthy men to treadmill exercise. Finally, linear regression equations were computed for maximum heart rate on age and maximum oxygen consumption on age.

**Results**

For the 704 individuals that were studied, median (50th percentile) age was 37 years, with 26 and 47 years as the 10th and 90th percentiles. Median height was 178 cm, with the 10th and 90th percentiles at 170 and 185 cm, respectively. Median weight for the study population was 78 kg, with 67 and 89 kg being the 10th and 90th percentiles, respectively. These heights and weights are remarkably similar to those published for a non-service-related male population; our lower median age is characteristic of military populations in general.

Supine rest (control period) and submaximal treadmill ex-
Supine treadmill recovery data are shown in figure 3. As expected, heart rate and blood pressure data show a fall at recovery minute two and a further fall at minute five from values attained during maximal exercise.

All blood pressures were measured by auscultation, and our presentation of these data should not obscure the lack of accuracy inherent with this technique when applied to exercising subjects.\(^{19,20}\) On the other hand, auscultation is the method typically used during clinical exercise testing and is felt to be of value.\(^{11}\) Within these limitations, the present data are designed to provide a range of expected values for these conditions.

All patients were classified with respect to physical activity (i.e., active, moderately active, or sedentary) on the basis of a questionnaire.\(^{21}\) Linear regression equations were computed by activity status for maximum heart rate on age and maximum oxygen consumption on age. The maximal heart rate/age relationship was not statistically different between the three activity groups, and we have thus presented a single regression equation based on the total data (table 1). On the other hand, regression equations of maximal oxygen consumption on age differed in intercept but not slope for the three activity groups; we have presented separate intercepts and a common slope for this relationship. In all cases, maximal heart rate and maximal oxygen consumption declined with age, a finding consistent with earlier reports. However, the low correlation coefficients and high variability about each of the regression

Exercise test data are presented in figure 1. The control period heart rate and blood pressure data are in the expected range; the slight elevations in diastolic blood pressures are probably due to anticipation of the treadmill test. Next, submaximal treadmill test data are given for 5, 10 and 15 min (or 5, 10, and 15% grade) of the Balke-Ware treadmill protocol; time and treadmill percent grade are numerically the same within this protocol. As shown, heart rate and systolic blood pressure increased with time and workload, with the increase tapering off as maximum effort is approached. Diastolic blood pressure stayed constant or fell slightly with increasing effort. The relationship between the Balke-Ware submaximal workload levels and other well-known treadmill protocol stages is shown at the bottom of figure 1.\(^{18}\)

The response at maximal effort during treadmill testing is shown in figure 2; these data are presented by age decades. The observed drop in maximal heart rate, maximal oxygen consumption, and maximal treadmill time with increasing age is consistent with changes noted in earlier studies. Maximal systolic blood pressure and pressure-rate product change little across the three age decades studied, while diastolic pressure increases slightly.

**Figure 2.** Maximal response treadmill exercise measurement data are shown as median (■), with 10th and 90th percentiles, for each of three age decades.

The numbers of subjects with complete data for each of the measurements shown are (from left to right) 287, 317, and 100.
TABLE 1. Linear Regression Equations for Maximal Oxygen Consumption on Age, by Activity Status, and for Maximal Heart Rate on Age

<table>
<thead>
<tr>
<th>Activity Status</th>
<th>VO(_2) Max (mL/kg/min)</th>
<th>HR Max (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(For active)</td>
<td>(50.6 - 0.17 \times \text{age} (N = 99))</td>
<td>(204 - 0.6 \times \text{age} (N = 704))</td>
</tr>
<tr>
<td>(For mod active)</td>
<td>(45.8 - 0.17 \times \text{age} (N = 238))</td>
<td></td>
</tr>
<tr>
<td>(For sedentary)</td>
<td>(43.2 - 0.17 \times \text{age} (N = 345))</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: VO\(_2\) = oxygen consumption; HR = heart rate.

Discussion

Comparison with Other Healthy Populations

The report by Bruce and colleagues, based on 1275 healthy individuals, is the only previous sizable study presenting both control and submaximal treadmill response data.\(^7\) Mean heart rate and blood pressure values for the control period are essentially the same as our median control period data shown in figure 1. Further, mean heart rate and blood pressure values from the Bruce protocol stage I are similar to the 5% grade values we have demonstrated. Ellestad has graphically presented submaximal heart rate and blood pressure data over a series of age decades.\(^2\) The average responses seem to agree with our median responses; his 95% confidence values cannot be directly compared with the percentile limits presented here.

The response of heart rate and oxygen consumption to maximal treadmill exercise are presented in figure 2 and show agreement with other studies.\(^5\) \(^6\) \(^12\) \(^16\) \(^23\) The maximal blood pressure and pressure-rate product values presented by Bruce and colleagues\(^7\) are also in agreement with those shown in figure 2. Recovery heart rate data presented in figure 3 are very similar to those published from this laboratory on a smaller series.\(^21\) Visual inspection of the recovery data graphically presented by Ellestad across an 8 min recovery period\(^23\) again is quite similar to those presented in this report.

Some Important Variables Affecting Treadmill Testing

Age, physical fitness, and subject's treadmill experience are all known to have an effect on the treadmill measurements presented. With respect to age, there were some statistically significant age group differences within the separate measurements during control, submaximal exercise, and recovery periods. However, the differences were small and were not considered important for the purposes for which these data are presented. With the exception of maximal heart rate and oxygen consumption, differences in response to maximal exercise across the age decades were also small. Our presentation of the maximal measurement data by age decades was largely prompted by precedence and the desire to permit comparison with other published studies.

With regard to physical fitness, individuals with a high level of fitness are known to have lower heart rates at submaximal workloads, higher maximal oxygen consumptions, and quicker drops in recovery heart rate than sedentary individuals. However, we observed much overlap in the present study between physical activity groups, in part because of genetic and other biological differences, and also because of inadequacies in the available methods for classifying physical fitness. Given these limitations and the desire to keep our main data presentation simple and easy to use, the reference values in figures 1, 2 and 3 are presented without regard to physical activity.

Finally, learning to walk the treadmill more efficiently leads to lowered heart rates at submaximal workloads and an increase in maximal treadmill performance without improvement in cardiovascular status or physical fitness. This learning can be done by allowing an individual to perform a series of treadmill tests.\(^24\) Individuals used in the present study were receiving their first treadmill test; repeat users were excluded for the reasons given.

Responses Outside the 10th and 90th Percentiles

The 10th and 90th percentiles were arbitrarily presented; these are conservative reference values for the response of healthy men to treadmill exercise. Since 20% of our healthy population lay outside these limits, patients falling outside these limits may well be normal. However, our reference values help to exclude individuals having subclinical conditions that compromise treadmill performance. Thus, men with responses lying outside these limits should be evaluated since they may be at increased risk for having a health problem.

Elevated heart rate values at submaximal exercise, maximal exercise, or recovery, could be due to vasoregulatory asthenia\(^25\) or to any condition that decreases peripheral resistance. Prolonged bed rest could also explain such heart rate elevations.\(^26\) A relatively low heart rate at any point during submaximal work could be due to physical conditioning and/or an enlarged heart with enhanced stroke volume, or it could be due to drugs such as propanolol. Ellestad has reported chronotropic incompetence, which he defines as a heart rate below the age-adjusted 95% confidence limits for his treadmill protocol.\(^22\) His data demonstrate that chronotropic incompetence carries an increased risk for CAD, even if there is a normal electrocardiographic response to the treadmill test.\(^9\)

Systolic blood pressure has been seen to rise above the illustrated limits in hypertensives.\(^14\) Such elevations have not been associated with any complications or ominous implications in our laboratory. An inadequate blood pressure rise can be due to aortic valve disease or left ventricular impairment. The heart rate-blood pressure product at maximal exercise has been considered a measure of left ventricular function.\(^19\) An excessive elevation could cause a false positive exercise test because of a physiological imbalance between myocardial blood supply and demand. We have not seen this occur in our laboratory. Low values could be due to left ventricular dysfunction, outflow obstruction, poor patient cooperation, or medication.

Maximal oxygen consumption has been considered a valuable measurement since it noninvasively estimates maximal cardiac output\(^26\) and is an index of work capacity and maximal cardiovascular function.\(^4\) However, its practical diagnostic value is limited because of biological variability, the expense of measuring it accurately, and limitations in estimating it from treadmill time\(^27\) \(^28\) or by using some automated commercial devices. Possibly, determination of
an individual's maximal treadmill workload may be a more accurate and/or adequate measure of maximal cardiovascular function.

Recovery heart rates return to near basal levels faster in individuals who are physically fit. The rate of change toward basal is also dependent upon the integrity of the cardiovascular system and the health of an individual.

Relevance of Regression Data

Regression analysis indicated that maximal heart rate declined with age as has been shown by many investigators. Lester and colleagues reviewed the studies of maximal heart rates and presented their results in a group of 190 male volunteers ranging in age from 15 to 75. They found a regression slope of −0.41 beats/min/year for both active and sedentary subjects, but active subjects had a lower maximal heart rate at any age. Other investigators have suggested a decline in maximal heart rate of one beat/min/year. Our decline of −0.61 beats/min/year but without an effect of activity status numerically lies between these values. Maximal heart rate has clinical importance since many clinicians use heart rate-targeted submaximal exercise tests.

The analysis of maximal oxygen consumption regressed on age showed a decline with age as found by other investigators. Dehn and Bruce reviewed both cross-sectional and longitudinal studies of maximal oxygen consumption and presented their results in a group of 86 healthy men with various activity levels. Analysis of their cross-sectional data yielded a regression equation (VO₂ = 49.93 − 0.278 × age) comparable to the one obtained in our study. The poor correlation of maximal oxygen consumption and age is likely due to the fact that multiple factors besides age are involved; i.e., genetic make-up, current and previous activity status, blood volume, hematocrit, cardiovascular integrity, and environmental conditions.

Acknowledgment

The authors express their appreciation to Mrs. Rosa Linda Rodriguez for her support with the manuscript preparation.

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doi: 10.1161/01.CIR.55.1.153
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1977 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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