Physical Fitness and Blood Pressure in School Children

GARY E. FRASER, M.B., CH.B., PH.D., M.P.H., ROLAND L. PHILLIPS, M.D., DR. P.H.,
AND RALPH HARRIS, M.B., CH.B.

SUMMARY We studied the relationship between physical fitness and blood pressure in 228 school children. The data were collected as part of the Loma Linda Child-Adolescent Blood Pressure Study. Systolic and diastolic blood pressures were lower in children above average fitness than in children below average fitness among preadolescent and adolescent boys and girls. On multivariate analysis, adjusting for skinfold thickness, an index of lean arm mass, height and age, the relationship between fitness and systolic blood pressure was statistically significant for preadolescent boys and for adolescents of both sexes. The multivariate relationship was not clearly seen for diastolic blood pressure. Multivariate techniques showed that significant correlates of fitness were obesity in preadolescents, age in adolescent boys and height in adolescent girls. Predicted pulse rates for stages 6–10 of a modified Balke treadmill protocol are given in appendix I for preadolescent and adolescent boys and girls.

BLOOD PRESSURE is a major determinant of health in adult life, and is apparently determined by both genetic and lifestyle factors. Age and sex, race, body build, alcohol consumption, and probably sodium and potassium consumption all appear to be important. Several sources of evidence suggest that there is tracking of blood pressure levels from childhood to adult life. This phenomenon implies that persons with blood pressure ranking high or low in the blood pressure distribution of a childhood population tend to retain that ranking during adult life. Therefore, the determinants of blood pressure during childhood may also be important predictors of adult blood pressure levels.

Several cross-sectional studies in adults have investigated the relationship between exercise and coronary risk factors, including blood pressure, in healthy subjects. Other investigators have reported the effects of exercise training as part of a rehabilitation program or in men at high coronary disease risk. Montoye et al. and Pickering reviewed these studies. There is evidence that exercise may lower blood pressure in adults. Such evidence does not exist for children.

In the present study, we investigated the relationship between physical fitness and blood pressure in children ages 7–17 years as part of the Loma Linda Child-Adolescent Blood Pressure Study. Although physical fitness correlates with habitual exercise, other factors, such as gender and probably genes, contribute to fitness.

Methods

The Loma Linda Child-Adolescent Blood Pressure Study is an epidemiologic study divided into three phases. During phase I, blood pressure and demographic data were documented on about 8000 Southern California children. Phase II documented dietary and psychosocial variables in a subgroup of these children. Phase III gathered similar data on the parents of a sample of the phase II children. About 40% of the phase II children were Seventh-day Adventist (SDA) and 60% were not. Blood pressures did not differ significantly between SDA and non-SDA children.

For the substudy reported in this article, we chose 300 white children from the phase I population who lived within a reasonable driving distance of Loma Linda University. One-half were SDA. One-third were randomly chosen from those who had blood pressures above the eighty-fifth percentile during the phase I portion of the study. One-third were chosen with blood pressures below the fifteenth percentile and the final third were chosen with blood pressures between the fifteenth and eighty-fifth percentiles.

A treadmill was chosen as the method of evaluating physical fitness in the 270 children who responded to the invitation to come to the testing center at Loma Linda University. This has the advantage of individual supervision and is superior to bicycle ergometry in that there is less effect of muscular fatigue in the test performance. The test was usually submaximal, in that the stopping rule was either maximal effort or a pulse rate of 185, whichever came first. A modified Balke treadmill protocol was used. Depending on the size of the child, the speed of the treadmill was either 2.6, 3.0 or 3.4 mph, so that smaller children did not have to run. During the first stage of exercise, the treadmill was level; the angulation of the treadmill was increased by 2° every minute.

The sequence of measurements and organization of the testing were as follows. When the child arrived at the testing center with the parents, simple demographic data were obtained; height, weight (shoes off) and resting pulse were measured; a single resting blood pressure was obtained with a standard mercury sphygmomanometer and an appropriate-sized cuff; a brief physical examination was performed and medical history obtained to ensure the child’s fitness to undergo the stress test. The stress test was monitored by electrocardiograph. A physician was in attendance.
each stage of the test, an electrocardiographic strip was obtained. About 15% of treadmill test results were discarded because of noncooperation from the child, because the protocol was not being correctly followed, or because of technical difficulties with the equipment.

A technician was trained by a cardiologist to measure pulse rate using the ECG strips obtained at each stage of the treadmill test. A sequence of six consecutive beats was chosen in each strip. These had to be free from major artifact and not at the beginning or the end of the strip. The RR distance was measured between the first and sixth beat to an accuracy of 0.5 mm. Pulse rate for that stage was then calculated by the formula 9000/X, where X is the number of millimeters for six consecutive beats (paper speed 25 mm/sec). The cardiologist checked a 20% sample and agreement with the technician was excellent.

The blood pressures used in the Results section are the resting blood pressures obtained on the day of the treadmill stress test. These were chosen as having the closest time proximity to the fitness testing. The blood pressure was measured during the less anxiety-provoking preliminary phase of the day’s activities, rather than immediately before exercise, when anxiety might have an effect.

Statistical Analysis

Maximal pulse rate is well defined for a given age. The rate of rise of pulse with exercise is linear until near the maximum, when some plateau effect may occur. This analysis takes advantage of these facts. For each child, for each treadmill stage, work load per kilogram of body weight (W_TOT) was modeled on the formula W_TOT = W_o + W = W_o + V(Sin θ), where W_o is the work per kilogram of body weight, while walking at VMiles per hour at no inclination, where V is the treadmill speed and where θ is the treadmill angulation.

W is actually a difference in work/kg performed, representing the increment between the work/kg of walking on the flat at VMiles per hour and total work/kg (W_TOT) at the nominated treadmill stage. W is measured as vertical feet per minute per kg of body weight.

An accepted method of measuring fitness is the pulse rate at a given work load, or, alternatively, the work capacity at a fixed pulse rate. To obtain such measures, we had to establish a relationship between pulse rate and work capacity for each child.

Pulse rate (P) was plotted against W for each child. For values of W less than 10 vertical feet per minute, the relationship between P and W was nonlinear and unpredictable, possibly because pulse rate is influenced substantially by apprehension or emotional factors. For values of W above 10 vertical feet per minute (corresponding to stage 3 and above for all three treadmill speeds), a clear linearity was apparent in virtually all individual plots. However, above 85% of the predicted maximal pulse, the relationship between P and W is often nonlinear. Consequently, data points outside the linear range were excluded from analysis. Any child with less than four valid data points in the remaining range was also excluded. The mean of the individual correlation coefficients (P vs W) of the remaining 228 plots was 0.97, showing excellent linearity for this relationship, in virtually all subjects.

For each child, the two related least-squares linear relationships were found by computer.

\[ P = \alpha + \beta W \]  
\[ W = \alpha' + \beta' P \]  

In the remainder of this report, reference will be made to two parameters derived from the above analyses: W170 and P70. P70 is the predicted pulse rate when the work increments/kg is 70 vertical feet per minute, using regression equation 1. W170 is the predicted increment in work/kg when the pulse rate is 170 beats/min using equation 2. The values of 170 for W170 and 70 for P70, were chosen because nearly all children achieved these values and they represent substantial work effort. Thus, W170 and P70 represent individual measures of fitness that are clearly interrelated. The values of W170 are directly related to fitness and the values of P70 are inversely related to fitness.

Stepwise regression analysis was then used to predict these fitness measures using triceps skinfold thickness, an index of arm lean mass (arm LMI), treadmill speed, height and age as potential predictor variables or covariates. These analyses were performed separately for preadolescent (≤ 12 years for girls and ≤ 13 years for boys) and adolescent children of each sex.

Regression analyses also examine the relationship between the fitness measures and blood pressure, adjusting for covariates such as treadmill speed, age, height, skinfold thickness and arm LMI. Analyses were again conducted for preadolescent and adolescent children of each sex. All regressions were performed with the SPSS programs.

Arm LMI is proportional to the cross-sectional area of the muscle and bony tissue of the upper arm: (C/π - S)^2, where S = triceps skinfold thickness (measured in mm but converted to cm for this calculation) and C = arm circumference (cm). Triceps skinfold thickness was measured midway between the acromion and olecranon processes using Harpenden calipers.

The results of regression 1, predicting pulse according to work, were used to form a model allowing prediction of pulse rate for any given stage of the treadmill (appendix 1). Only variables that were statistically significant predictors of fitness for a given sex-adolescent group were used. Standard deviations for the predictions are given. The method used to give these predictions deals appropriately with the situation of multiple observations on each of many subjects and is described in appendix 2.

Results

The means and standard deviations for W170 and P70, by age and treadmill speed are shown in table 1. For a given treadmill speed, P70 decreases as age increases only for the children younger than 11 years of age. At the same age and treadmill speed, boys seem
TABLE 1. *Observed Fitness Variables by Treadmill Speed, Sex and Age*

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Speed 2.6 mph</th>
<th>M</th>
<th>n</th>
<th>W170 Mean ± SD</th>
<th>P70 Mean ± SD</th>
<th>Speed 3.0 mph</th>
<th>M</th>
<th>n</th>
<th>W170 Mean ± SD</th>
<th>P70 Mean ± SD</th>
<th>Speed 3.4 mph</th>
<th>M</th>
<th>n</th>
<th>W170 Mean ± SD</th>
<th>P70 Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-8</td>
<td>12</td>
<td>64.3 ± 20.9</td>
<td>172.8 ± 17.9</td>
<td>9-10</td>
<td>11</td>
<td>80.7 ± 14.2</td>
<td>161.9 ± 9.0</td>
<td>12-14</td>
<td>17</td>
<td>77.8 ± 19.5</td>
<td>165.0 ± 16.0</td>
<td>12-14</td>
<td>31</td>
<td>79.5 ± 25.6</td>
<td>163.8 ± 17.5</td>
</tr>
<tr>
<td>9-10</td>
<td>14</td>
<td>60.2 ± 18.0</td>
<td>176.5 ± 16.3</td>
<td>13</td>
<td>15.9 ± 15.5</td>
<td>176.9 ± 13.3</td>
<td>16</td>
<td>16</td>
<td>58.9 ± 12.3</td>
<td>179.2 ± 10.2</td>
<td>15-17</td>
<td>31</td>
<td>71.6 ± 15.7</td>
<td>168.4 ± 13.4</td>
<td></td>
</tr>
<tr>
<td>12-14</td>
<td>11</td>
<td>76.5 ± 25.2</td>
<td>169.1 ± 18.2</td>
<td>17</td>
<td>16.0 ± 12.3</td>
<td>179.2 ± 10.2</td>
<td>12</td>
<td>12</td>
<td>60.4 ± 27.1</td>
<td>179.7 ± 21.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*A few children who did not fit these categories are omitted from this table.

Abbreviations: W170 = predicted increment in work/kg at a pulse rate of 170 beats/min; P70 = predicted pulse rate when work increment is 70 vertical feet per minute.

consistently fitter than girls. Although P70 and W170 are predicted values from regression lines fitted for each child, they would be very close to observed values because of the excellent fit of the individual plots to the fitted regression equations.

Multivariate linear regression showed that P70 and W170 were significantly predicted by skinfold thickness in preadolescent children, by chronologic age in adolescent boys and height in adolescent girls (table 2). These associations are further described in table 3, where the observed W170 values are reported for subgroups below and above mean values of skinfold thickness, age and height.

With both sexes combined, separate analyses were done for preadolescent and adolescent children with sex as an independent variable. These results show that sex is a powerful predictor of fitness (table 4). A comparison of fitness between SDA and non-SDA children showed no statistically significant difference. Similar results were found if ponderal index replaced skinfold thickness and arm LMI.

The relationship between blood pressure and fitness was also explored. A comparison of blood pressures was made between those above and below mean observed fitness levels (fig. 1). In a univariate sense for all sex-adolescent status groupings, for both systolic and diastolic pressures, the fitter group had lower pressures. This difference was statistically significant (p < 0.05) for preadolescent boys (systolic and diastolic) and adolescent girls (systolic only).

Tables 5 and 6 show the multivariate relationships between systolic and diastolic blood pressure, fitness, W170 and covariates representing adjustments for height, skinfold thickness, arm LMI and age. These regressions show that increasing fitness is associated with lower systolic blood pressure in preadolescent boys and in adolescents of both sexes. A significant relationship between fitness and diastolic blood pressure cannot be shown in multivariate analyses. Again, similar results were found if the ponderal index replaced skinfold and arm LMI as a covariate.

Detailed tables that may prove useful in assessing physical fitness of individual children are shown in appendix I.

**Discussion**

The use of submaximal exercise variables as indexes of fitness (maximal oxygen uptake) has long been established in adults. Data for children are sparser, but suggest that similar relationships hold between such measures and maximal oxygen uptake.

Consequently, this study provides evidence that increased physical fitness in preadolescent and adolescent boys and adolescent girls is associated with lower systolic blood pressure values. When comparing fit (mean ± 2 standard deviations of W170) and unfit (mean − 2 standard deviations of W170) children, the magnitude of predicted differences of systolic blood

---

**TABLE 2.** *Sex-specific Regression Coefficients from Stepwise Linear Regressions Predicting Fitness*

<table>
<thead>
<tr>
<th>Variable</th>
<th>P70</th>
<th>W170</th>
<th>P70</th>
<th>W170</th>
<th>P70</th>
<th>W170</th>
<th>P70</th>
<th>W170</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skinfold (mm)</td>
<td>1.24†</td>
<td>−1.44‡</td>
<td>1.33‡</td>
<td>−1.34‡</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Arm lean mass index (cm²)</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Age (years)</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>3.40†</td>
<td>−5.15†</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Height (inches)</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>2.62†</td>
<td>−2.92‡</td>
</tr>
<tr>
<td>Treadmill speed (mph)</td>
<td>---</td>
<td>---</td>
<td>−21.53†</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Constant</td>
<td>153.16</td>
<td>91.59</td>
<td>158.85</td>
<td>140.25</td>
<td>114.31</td>
<td>153.44</td>
<td>9.47</td>
<td>249.17</td>
</tr>
<tr>
<td>R²</td>
<td>0.133</td>
<td>0.086</td>
<td>0.190</td>
<td>0.210</td>
<td>0.067</td>
<td>0.083</td>
<td>0.121</td>
<td>0.108</td>
</tr>
</tbody>
</table>

*coefficients are reported only for variables that achieved statistical significance.

†p < 0.05.
‡p < 0.01.

Abbreviations: See table 1.
pressure is approximately 16 mm Hg for each of the three groups for whom evidence was found that fitness related to blood pressure.

This study is a cross-sectional investigation and does not provide proof that the relationship is dynamic (that is, that in children and adolescents changes in fitness produce changes in blood pressure). However, this hypothesis seems reasonable and deserves further investigation.

In view of the evidence that blood pressure tracks, an intervention displacing an individual’s track to a lower rank within the population may produce a permanent change in rank, persisting into adult life. Miall and Lovell,35 found that blood pressure “feeds on itself.” In their longitudinal studies, higher baseline pressures were associated with greater increases in blood pressure over time. Again, the ability to influence this cycle in childhood and adolescence would be very important. Physical activity may have potential as one component of such an intervention.

The association of fitness with blood pressure was not due to confounding by age, obesity or greater body size. This possibility was eliminated by including the skinfold measurement, arm LMI, height and age as covariates in the regression procedures of tables 5 and 6. Consequently, physical fitness predicts systolic blood pressure independently of these body build measures and age.

The relatively powerful effect of physical fitness on blood pressure in adolescent girls and our inability to detect such a relationship in preadolescent girls is an interesting contrast. The lack of effect of fitness on blood pressure in preadolescent girls in unexplained and needs to be confirmed by other data sets before being accepted.

Previous data34-37 and data from this study25 clearly show that the relationship between blood pressure and age changes during adolescence, particularly for boys. For this reason we considered it important to separate our analyses for preadolescents and adolescents. In an epidemiologic study of this sort it was not feasible to use an index of maturity (such as Tanner’s index); consequently, we are dependent on age alone. We recognize that there will be some error in such a maturity dichotomization based on age. However, most girls and boys ages 7–12 and 7–13 years, respectively, are prepubertal and most ages 13–17 and 14–17 years are postpubertal.

There is a constitutional component involved in fitness. However, there is evidence that fitness can be improved commonly by up to 15–20%.38-40 Further, the possible change depends on how sedentary the subjects are before training. Some studies show gains in fitness proportionately far greater than those reported above.41,42

---

**TABLE 3. Mean Values of W170 (Vertical feet/min) Within Subgroups Above and Below Mean Values* for Skinfold Thickness, Age, and Height**

<table>
<thead>
<tr>
<th></th>
<th>Preadolescent boys</th>
<th>Preadolescent girls</th>
<th>Adolescent boys</th>
<th>Adolescent girls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Skinfold</td>
<td>78.0†</td>
<td>68.8†</td>
<td>68.7†</td>
<td>54.3†</td>
</tr>
<tr>
<td>Age</td>
<td>75.2</td>
<td>74.4</td>
<td>67.0</td>
<td>57.7</td>
</tr>
<tr>
<td>Height</td>
<td>76.3</td>
<td>71.4</td>
<td>65.1</td>
<td>57.0</td>
</tr>
</tbody>
</table>

*aMean values of skinfold thickness, age, and height computed separately for each sex-adolescent status group.
†Significant difference in multivariate analysis (see table 2).
Abbreviation: W170 = predicted increment in work/kg at a pulse rate of 170 beats/min.

---

**TABLE 4. Regression Analysis Predicting W170 for Both Sexes Combined**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t score</th>
<th>Variable</th>
<th>Coefficient</th>
<th>t score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>-10.55</td>
<td>2.69</td>
<td>Sex</td>
<td>-16.98</td>
<td>3.93</td>
</tr>
<tr>
<td>Skinfold</td>
<td>-1.47</td>
<td>3.76</td>
<td>Age</td>
<td>-3.36</td>
<td>1.74</td>
</tr>
<tr>
<td>Constant</td>
<td>102.45</td>
<td></td>
<td>Constant</td>
<td>143.46</td>
<td></td>
</tr>
<tr>
<td>R^2</td>
<td>0.16</td>
<td></td>
<td>R^2</td>
<td>0.16</td>
<td></td>
</tr>
</tbody>
</table>

*Males = 1, females = 2. Sex, skinfold thickness, arm lean mass index, height, age and treadmill speed were available to the stepwise program. Only variables with t scores corresponding to p < 0.10 are reported.
Abbreviation: W170 = predicted increment in work/kg at a pulse rate of 170 beats/min.

---

**Figure 1. Univariate comparisons of systolic and diastolic blood pressures in children above and below average observed fitness. (Average fitness was calculated for each subgroup separately.)**
How this translates to possible changes in submaximal pulse rate can be estimated by, for instance, Astrand's equation.4 This equation shows that a decrease of 17–20 beats/min at a work load originally producing a heart rate of 170 beats/min represents about a 15% increase in maximal oxygen uptake. All this suggests the possibility that readily attainable increases in physical fitness may decrease systolic blood pressure by 4–5 mm Hg in children. In some instances, particularly where the subject was initially quite sedentary, changes may be greater.

Blood pressure is the result of two main hemodynamic influences: cardiac output and peripheral vascular resistance. The altered hemodynamics associated with exercise could reset the controls determining vascular resistance and affect blood pressure levels. Alternatively, cardiac output at rest could be decreased in physically fit people.

Some evidence suggests that resting cardiac output in physically fit adults does not differ from that in unfit adults.4 This evidence is available on the relationship between peripheral resistance and fitness. Pavlik et al.17 showed that highly trained adult athletes have lower resting cardiac output and higher resting peripheral resistance than nonathletes. However, less well trained athletes had lower resting peripheral resistance and higher resting cardiac output than nonathletes. Consequently, mechanisms whereby fitness may affect blood pressure are not well understood.

Obese persons are generally more sedentary than others.45 In this study, triceps skinfold thickness was the most important predictor of physical fitness in both preadolescent boys and girls. Part of the explanation for the usual univariate relationship between obesity and blood pressure in children may involve the decreased physical fitness of obese children.

Physical fitness in this data set was substantially and significantly different in the two sexes. On average, the pulse rates at a work load equivalent to raising oneself 70 vertical feet per minute were 10 beats/min faster in preadolescent girls than boys, and 14 beats/min faster in adolescent girls than boys.

This sex difference has been described by others.26 Part of the explanation is probably that females have a lower ratio of muscle to total body weight than males.46 However, our data suggest that the effect is well established, but less pronounced, well before the usual age of puberty.

As mentioned above, skinfold thickness is a predictor of fitness in preadolescents. Interestingly, for ado-
lescent boys and girls, obesity is not a predictor of fitness in either univariate or multivariate analyses; rather, age in boys and height in girls are predictors as fitness. This finding is not due to strong interrelationships between obesity and height or age. Height and age are moderately correlated in adolescent boys ($r = 0.40$), but neither the crude nor the partial correlation coefficients between height and blood pressure are far from zero. Thus, it is unlikely that age is a surrogate for height in the analysis for adolescent boys. In adolescent girls, height and age are not correlated, making it unlikely that height is a surrogate for age in this analysis.

As adolescent boys grew older, fitness declined. This may be related to increasing preoccupation with studies and vocational pursuits and less emphasis on physical activity. However, this was not found for adolescent girls, in whom the major relationship indicated that taller girls were less fit, as measured by pulse rate at a standard exercise intensity. We are not aware of any physiologic explanation for this relationship. We can only suggest that in this particular environmental setting, taller girls may have matured earlier, or may be physically less adroit and therefore less likely to participate regularly in active sports.

Others have also related physical fitness to age, sex and anthropometric measures. Matsui et al., found increasing maximal oxygen uptake with age in adolescent boys, but no age trend for adolescent girls. Krahenbuhl et al., found a similar sex differential favoring males in 8-year-old children. Mayhew and Gifford, related indexes of muscle mass and skinfold thickness to maximal oxygen uptake during bicycle exercise in preadolescent boys. Bonen et al. found useful equations predicting maximal oxygen uptake based on age, height and weight alone for boys 7–15 years old.

These data support the hypothesis that physical fitness is related to systolic blood pressure in preadolescent males and adolescents of both sexes. Because high blood pressure may afflict as much as one-third of the adult population, potential interventions in childhood merit further investigation.

References


5. Gillum RF: Pathophysiology of hypertension in blacks and whites. A review of the basis of racial blood pressure differences. Hypertension 1: 468, 1979


18. Haskell WL: Mechanisms by which physical activity may enhance the clinical status of cardiac patients. In Heart Disease and Rehabilitation, edited by Pollock ML, Schmidt DH. Boston, Houghton Mifflin, 1979, p 286


51. Hypertension Detection and Follow-up Program. Presentation of 5-year Mortality Results. Bethesda, MD, U.S. DHHS, October 1980, p 1

APPENDIX 1. Predicted Pulse Rates in Children, by Treadmill Stage and Other Significant Covariates of Fitness

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Covariate</th>
<th>Treadmill angulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10° 12° 14° 16° 18°</td>
</tr>
<tr>
<td>Preadolescent boys (n = 78)</td>
<td>Skinfold (mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>143 149 156 163 169</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>145 152 159 165 172</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>147 154 161 168 175</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>150 157 165 171 178</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>158 165 173 180 —*</td>
</tr>
<tr>
<td></td>
<td>Standard error of prediction (D)</td>
<td>14.0 14.8 15.7 16.7 17.8</td>
</tr>
<tr>
<td>Preadolescent girls (n = 49)</td>
<td>Skinfold (mm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>146 151 157 163 169</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>148 154 160 166 171</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>151 157 163 169 175</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>153 159 166 172 178</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>160 166 173 179 —*</td>
</tr>
<tr>
<td></td>
<td>Standard error of prediction (D)</td>
<td>12.4 12.7 13.1 13.6 14.3</td>
</tr>
<tr>
<td>Adolescent boys (n = 56)</td>
<td>Age (years)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>148 156 164 171 179</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>151 159 167 175 183</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>155 163 171 178 —*</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>158 166 174 182 —*</td>
</tr>
<tr>
<td></td>
<td>Standard error of prediction (D)</td>
<td>13.7 14.1 14.7 15.5 16.8</td>
</tr>
<tr>
<td>Adolescent girls (n = 37)</td>
<td>Height (inches)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>59</td>
<td>146 153 159 166 173</td>
</tr>
<tr>
<td></td>
<td>61</td>
<td>150 157 164 171 178</td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>155 162 170 177 184</td>
</tr>
<tr>
<td></td>
<td>65</td>
<td>160 167 175 182 —*</td>
</tr>
<tr>
<td></td>
<td>67</td>
<td>164 172 180 —*  —*</td>
</tr>
<tr>
<td></td>
<td>Standard error of prediction (D)</td>
<td>14.8 15.7 16.8 18.3 20.0</td>
</tr>
</tbody>
</table>

*Predicted pulse rate is possibly above linear portion of the relationship between work and pulse rate.*
Appendix 2.
Statistical Methods Used in Appendix 1 to Calculate Predicted Pulse Rate by Treadmill Stage

The data collected in this study allow the prediction of pulse rates at different levels of work and at different values of the relevant covariates. The standard error of the prediction is also calculated (see below), allowing the estimation of a prediction interval.

Splitting the observations to all reasonable combinations of these different variables results in small numbers and loss of predictive accuracy. Consequently, it seemed most efficient to use the linear model (which on inspection of residuals seemed satisfactory), and so allow the use of all the data to predict pulse rates.

The standard errors of the predictions may seem rather large (see appendix 1), but this is also in accord with the observed data. The predictions of appendix 1 could be useful to assess the fitness of children, relative to the performance of similar children.

For the ith individual at treadmill speed j and stage k (by regression 1):

\[ P_{ij} = \alpha_i + \beta_j w_i. \]

Two additional regressions were performed:

\[ \alpha_i = \hat{\alpha} + \sum_k (\gamma_k \cdot x_i k), \]
\[ \beta_j = \hat{\beta} + \sum_k (\delta_k \cdot x_j k), \]

where \( X_i, \ldots, X_k \) are variables that are significant predictors of fitness for that sex/adolescent status subgroup. In performing these regressions we invoked the well-known normality of errors of estimated parameters such as \( \alpha_i \) and \( \beta_j \) in regressions 1 and 2. In addition, plots of residuals from regressions 3 and 4 did not indicate any deviations from homoscedasticity.

Then for each treadmill speed 1, and stage j:

\[
\alpha_i + \beta_j \cdot w_i = \bar{\alpha} + \sum_k (\gamma_k \cdot x_i k) + (\bar{\beta} + \sum_k (\delta_k \cdot x_j k) \cdot w_i) \\
= \bar{\alpha} + \bar{\beta} \cdot w_i + \sum_k (\gamma_k + \delta_k \cdot w_i) \cdot x_i k \\
= \eta_{ij} + \sum_k (\gamma_k + \delta_k \cdot w_i) \cdot x_i k. 
\]

Then this model allows prediction of the fitted regression 1 as dependent variable, according to the effect of other predictor variables. Confidence intervals (CI, 95%) for the variation of the corresponding points calculated from the individual regressions (regression 1) about this multivariate prediction can be calculated by standard formulas:

\[
CI = \pm t_{N,0.975} \cdot S_{ij} \sqrt{1 + U_{ij}^T (X^T X)^{-1} U_{ij}} \\
= \pm t_{N,0.975} \cdot D_{ij},
\]

where \( S_{ij} \) is the mean residual sum of squares from regression 5 for a given work increment, \( W_i \). (Regression 5 was run for values of \( W_i \) corresponding to each treadmill speed and stage, to find the corresponding values of \( S_{ij} \). As expected, the values of \( \eta_{ij} \) and \( \xi_{ij} \) were those predicted from the synthesis of regressions 3 and 4). A is the design matrix corresponding to regression 5, and \( U_{ij} \) is the vector whose elements have the same form as a row of \( X \), and specify the values of \( X_i k \) used to make the particular prediction of interest. The standard errors (D) of the predictions are shown in appendix 1.

A close approximation to confidence intervals for actual measured pulse rates about the prediction of regression 5 can be obtained by using a value of D inflated by a factor of 1.03. This value was obtained by adding a mean sum of squares to \( D^2 \), resulting from variation of observed pulse rates about the regression lines corresponding to regression 1. This is a relatively insignificant addition, due to the very close fit of observed points to the regressions corresponding to regression 1.
Physical fitness and blood pressure in school children.
G E Fraser, R L Phillips and R Harris

*Circulation.* 1983;67:405-412
doi: 10.1161/01.CIR.67.2.405

*Circulation* is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1983 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:
http://circ.ahajournals.org/content/67/2/405