

# Exaggerated Blood Pressure Response to Maximal Exercise in Endurance-Trained Individuals

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Recent studies have suggested that an exaggerated blood pressure response to maximal exercise may be useful in detecting individuals who are prone to developing hypertension in later years. To examine the hypothesis that regular aerobic exercise results in a smaller blood pressure response to maximal exercise, 26 endurance-trained and 31 untrained individuals (matched on age and physical characteristics) performed graded maximal exercise tests on a cycle ergometer. Trained subjects achieved a significantly ( $P < .05$ ) higher level of maximal oxygen uptake (mean  $\pm$  SE:  $59.4 \pm 1.4$  v  $44.7 \pm 1.0$  mL/kg/min), as well as a greater maximal work rate. Although there was no significant difference in resting blood pressure between the groups,

endurance-trained individuals demonstrated significantly higher maximal systolic blood pressure levels compared to untrained subjects during maximal exercise ( $225 \pm 3$  v  $204 \pm 4$  mm Hg). The group differences in systolic blood pressure were also significant ( $P < .05$ ) at work rates of 180 W and higher. It is concluded that physically active individuals show higher blood pressure responses to maximal exercise, despite their reduced risk of future hypertension. This finding indicates that an exaggerated blood pressure response is not a valid prognostic test to indicate the likelihood of future hypertension in this population. *Am J Hypertens* 1996;9:1099-1103

**KEY WORDS:** Exaggerated blood pressure response, exercise test, hypertension.

**D**ue to the fact that hypertension is a major health problem in the United States,<sup>1</sup> the early detection and treatment of hypertension is a topic of paramount importance. Recent studies<sup>2-4</sup> have suggested that an exaggerated blood pressure response to maximal exercise may be useful in detecting persons who are prone to developing hypertension in later years. Jette et al<sup>2</sup> reviewed the literature and concluded that hyperresponders face a 2- to 10-fold greater likelihood of developing future hypertension. In addition, several groups at

risk for hypertension, including African-Americans, borderline hypertensives, and individuals with a parental history of hypertension, have been shown to exhibit this type of response.<sup>2,5</sup> It is possible that by observing the cardiovascular system's response to exercise, one may uncover latent tendencies towards hypertension that are not evident at rest.

Unfortunately, few studies have examined the maximal blood pressure response to exercise in trained and untrained individuals. An early study by Ekblom et al<sup>6</sup> found that after 16 weeks of endurance training,

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there was a 20 mm Hg increase in maximal systolic blood pressure in a group of eight subjects. Similarly, a subsequent study<sup>7</sup> reported that trained individuals had higher maximal blood pressure values than untrained subjects. However, other researchers have reported no difference in the maximal blood pressure response before and after endurance training<sup>8</sup> and between trained and untrained subjects.<sup>9</sup> Thus, the role of training state in determining the blood pressure response to dynamic exercise remains controversial.

If endurance-trained persons show an exaggerated blood pressure response to exercise, as preliminary studies suggest,<sup>6-8</sup> it would have important implications. Since it is well established that aerobic training reduces the risk of developing hypertension,<sup>1,10</sup> this finding would indicate that an exaggerated blood pressure response is not a valid prognostic test to indicate the likelihood of future hypertension in this population. Therefore, the purpose of this study is to compare the blood pressure responses to a maximal, graded exercise test between trained and untrained subjects. We hypothesized that physically-active subjects would demonstrate a smaller blood pressure response to maximal exercise than inactive subjects.

## METHODS

**Subjects** The subjects for this study were 31 (27 men and 4 women) untrained subjects and 26 (22 men and 4 women) well-trained endurance athletes. All subjects were normotensive (blood pressure < 140/90 mm Hg) and were free of overt cardiovascular disease. None of the subjects was a smoker and was taking any medication. Endurance-trained athletes were either competitive runners, road cyclists, or triathletes, and had been training a minimum of 2 years prior to the study. Untrained subjects had not engaged in any regular exercise programs in the preceding year. Following a verbal and written explanation of the procedures and potential risks involved in this study, subjects signed an informed consent approved by the Institutional Review Board. Additionally, subjects were requested to complete a questionnaire on parental history of hypertension.<sup>11</sup> Body composition was evaluated from the three-site skinfold thickness method.<sup>12</sup> Percent body fat (% Fat) and lean body mass (LBM) were subsequently estimated from the sum of the skinfold measurements. Physical characteristics of the subjects are presented in Table 1.

**Testing Procedures** Prior to the testing, subjects were familiarized with the exercise protocol. Subjects refrained from food intake and caffeinated and alcoholic beverages for at least 4 h prior to the tests. A stationary pendulum-style cycle ergometer (Model 868, Monark, Sweden) was used for the maximum oxygen uptake ( $\dot{V}O_2$  max) tests. The cycle ergometer was chosen in an

TABLE 1. SUBJECT CHARACTERISTICS

Variable	Trained (n = 26)	Untrained (n = 31)
Age (years)	25.4 ± .8	23.7 ± .8
Height (cm)	175.5 ± 1.1	175.1 ± 1.2
Body mass (kg)	68.5 ± 1.5	71.9 ± 1.6
LBM (kg)	61.2 ± 1.4	64.3 ± 1.7
Body fat (%)	10.7 ± 1.1	10.8 ± 0.8
BSA (cm <sup>2</sup> )	1.84 ± 0.02	1.90 ± 0.03
Parental history (yes/no)	8/17	13/17

BSA: body surface area; LBM: lean body mass; Parental history: parental history of hypertension of either or both parents.

attempt to minimize the movement artifacts associated with exercise. Following the standardized warm-up, the initial exercise intensity was set at 30 W (60 rpm), and the work rate was increased thereafter by 30 W at 1 min intervals. Endpoint determination of the maximal test was defined as volitional exhaustion (failure to maintain the pedal cadence).

Oxygen uptake was continuously monitored with a Rayfield system throughout the  $\dot{V}O_2$  max test. The Rayfield system consisted of an open spirometer interfaced with an Apple computer (Cupertino, CA). Inspired air volume was determined with a dry gas meter (Rayfield RAM 9200) calibrated against a 120 L Tissot spirometer (Collins, Braintree, MA). Gas fractions were analyzed with an Ametek S-3A O<sub>2</sub> analyzer (Sunnyvale, CA) and a Beckman LB-2 CO<sub>2</sub> analyzer (Fullerton, CA). Oxygen uptake and carbon dioxide production were calculated using the Haldane transformation of the Fick equation. Prior to each trial, these gas analyzers were calibrated with known gas samples analyzed by the micro-Scholar technique.

Blood pressure was measured in the right arm with "amplified auscultation" by trained observers who had normal auditory acuity bilaterally. The Korotkoff sound was amplified using a Colin STBP-780 automated BP monitor (Colin Medical Instruments, San Antonio, TX). Briefly, a mercury sphygmomanometer was joined to the pressure line using a Y-connector, and a stereo headset was used by the investigator to simultaneously monitor the Colin STBP-780 recordings. The rationale for using "amplified auscultation" is based on a recent report that the increase in ambient noise during exercise testing may mask the "conventional" auscultatory Korotkoff sounds, making detection of the proper Korotkoff sounds difficult.<sup>13</sup> The resting blood pressure was the mean of two blood pressure measurements taken after 15 min of supine rest under quiet, comfortable laboratory conditions. Throughout  $\dot{V}O_2$  max test, blood pressure was monitored in 1-min intervals. Blood pressure was measured with the subject's arm relaxed and hand removed from the handle bar. Phase V and IV

**TABLE 2. MEAN ( $\pm$  SE) RESTING HEART RATE AND BLOOD PRESSURE AND MAXIMAL HEART RATE AND OXYGEN UPTAKE VALUES**

Variable	Trained (n = 26)	Untrained (n = 31)
Resting		
HR (beats/min)	54.3 $\pm$ 1.5	61.1 $\pm$ 1.5*
SBP (mm Hg)	110 $\pm$ 2	112 $\pm$ 2
DBP (mm Hg)	64 $\pm$ 2	66 $\pm$ 1
MABP (mm Hg)	79 $\pm$ 2	81 $\pm$ 2
Maximal Exercise		
Work rate (W)	322 $\pm$ 9	267 $\pm$ 7*
$\dot{V}O_2$ (L/min)	4.1 $\pm$ .1	3.2 $\pm$ .1*
$\dot{V}O_2$ (ml/kg/min)	59.4 $\pm$ 1.4	44.7 $\pm$ 1.0*
HR (beats/min)	183.8 $\pm$ 2.0	182.8 $\pm$ 1.8
SBP (mm Hg)	225 $\pm$ 3	204 $\pm$ 4*
DBP (mm Hg)	87 $\pm$ 3	86 $\pm$ 1
MABP (mm Hg)	133 $\pm$ 2	126 $\pm$ 2*

\* indicates significant difference ( $P < .05$ ) from untrained.

HR: heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure; MABP: mean arterial blood pressure;  $\dot{V}O_2$ : oxygen uptake.

Korotkoff sounds were used for the diastolic blood pressure during rest and exercise, as recommended by Frohlich et al.<sup>14</sup>

**Statistical Analysis** A Student's unpaired *t* test was used to compare the subjects' physical characteristics and  $\dot{V}O_{2\max}$  values between trained and untrained subjects. Test data for the blood pressure response to graded maximal exercise were analyzed with a two-way (group  $\times$  time) analysis of variance with repeated measures. In an attempt to deal with the problem of differing numbers of subjects at the higher work rates near maximum, the absolute work rate was arranged from rest (ie, 0 W) to the work rate that most subjects (except one untrained female) tolerated (ie, 210 W), and then maximal work rate was added at the end. When indicated by a significant *F* value, a post-hoc test using a Newman-Keuls procedure was performed. Parental history for hypertension was examined using the  $\chi^2$  test. The level of significance was set at  $P < .05$  in all comparisons. Descriptive statistics were expressed as mean  $\pm$  SE.

## RESULTS

The subject characteristics are presented in Table 1. There were no significant differences in age and physical characteristics between the groups. Parental histories of hypertension in the trained and untrained group were 32.0% and 43.3%, respectively.

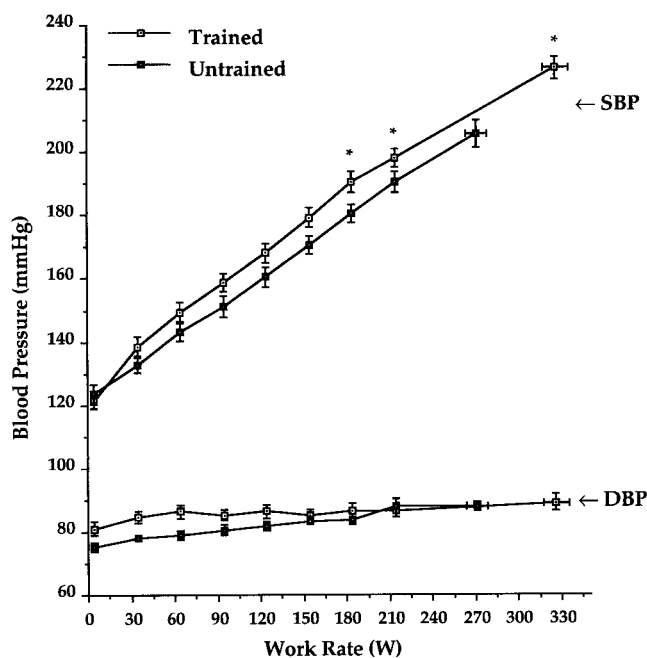
As shown in Table 2, endurance-trained subjects were characterized as having significantly ( $P < .05$ ) lower resting heart rate values and higher maximal work rate and  $\dot{V}O_{2\max}$  values compared to untrained

subjects. There were no significant differences in resting supine blood pressure between the two groups.

Figure 1 illustrates the changes in arterial blood pressure during graded maximal exercise tests. In both groups, systolic blood pressure increased linearly with increases in work rate, whereas diastolic blood pressure remained unchanged. However, trained subjects achieved significantly ( $P < .05$ ) higher maximum systolic blood pressure values compared to untrained subjects. The maximum values for systolic blood pressure were 225  $\pm$  3 mm Hg in the trained group and 204  $\pm$  4 mm Hg in the untrained group (Table 2). The group differences were also significant ( $P < .05$ ) at the work rates of 180 and 210 W. There were no significant group differences in diastolic blood pressure values throughout the exercise test.

## DISCUSSION

The major finding of this study was that endurance-trained individuals had significantly higher maximal systolic blood pressure values during graded exercise compared to untrained subjects, matched with respect to age and physical characteristics. The maximal systolic blood pressure value of 225 mm Hg in the trained group exceeds the values typically used to define an exaggerated blood pressure response ( $>200$  to 220 mm Hg).<sup>3,15,16</sup> It should also be noted that the group differences were manifested at lower intensities of exercise.



**FIGURE 1.** Blood pressure response to graded maximal exercise tests on a cycle ergometer. Results are expressed as mean  $\pm$  SE. SBP: systolic blood pressure; DBP: diastolic blood pressure. \* indicates significant difference from respective untrained value.

Our results are in general agreement with previous studies examining the role of physical training on maximal blood pressure during exercise. Ekblom et al<sup>6</sup> and Stratton et al<sup>7</sup> reported that 16 to 24 weeks of endurance training increased maximal systolic blood pressure by 18 to 20 mm Hg. Svedenhag et al<sup>8</sup> found higher systolic blood pressures in high-fit versus low-fit subjects (229 *v* 216 mm Hg). When they trained the low-fit group for 16 weeks the value showed an increase of approximately 6 mm Hg. Conversely, Steinhaus et al<sup>9</sup> reported that there was no effect of training state on maximal systolic blood pressure. However, a close examination of their data shows that there was probably an age  $\times$  fitness interaction. The young high-fit subjects had greater systolic pressures than the young low-fit subjects (206 *v* 188 mm Hg), whereas no difference was seen in the old high-fit and old low-fit groups (188 *v* 186 mm Hg).<sup>9</sup> Taken together, these collective studies indicate that young endurance-trained individuals have elevated levels of systolic blood pressure during maximal exercise.

Prospective, longitudinal studies have reported that increased levels of systolic blood pressure during exercise are predictive of future hypertension<sup>2-4</sup> and cardiovascular mortality.<sup>17</sup> Since endurance-trained individuals exhibit this type of exaggerated blood pressure response, it implies that they are at increased risk of subsequent hypertension. However, numerous studies have shown that trained individuals have a lower-than-normal risk of developing hypertension.<sup>1,10</sup> For example, Blair et al<sup>10</sup> performed maximal treadmill tests on 4820 men and 1219 women aged 20 to 65 years. High-fit persons had a lower relative risk of developing hypertension compared to the low-fit group.<sup>10</sup> Thus, it appears that the blood pressure response to exercise is not a valid prognostic test in physically active individuals.

It is likely that the difference in maximal systolic blood pressure between the groups is attributable to the difference in maximal work rate achieved. However, the mechanism for the increased maximal systolic blood pressures seen in trained subjects is not clear. It has been demonstrated that trained subjects have 15% to 30% increases in maximal stroke volume and cardiac output, compared to untrained persons.<sup>18</sup> However, trained subjects also have a greater maximal vascular conductance, reflecting alterations in vascular structure within skeletal muscle.<sup>18,19</sup> The enhanced capacity for vasodilation in trained subjects probably contributes to a greater outflow of blood from the arterial compartment to the venous compartment during diastole. This may be part of the explanation for why diastolic pressures were not different in trained and untrained subjects.

It should be noted that the trained group also had increased levels of systolic blood pressure at submaxi-

mal intensities of exercise (eg, 180 and 210 W). This finding is in agreement with a longitudinal study by Ekblom et al,<sup>6</sup> who reported significantly increased systolic blood pressure levels during submaximal exercise after endurance training. Since cardiac output is likely to be similar between trained and untrained subjects exercising at the same work rate,<sup>18</sup> these results suggest that a higher vascular resistance already exists in trained subjects during submaximal exercise. One plausible explanation for this observation is that the trained subjects vasodilate to a lesser extent because they do not produce as many vasodilator metabolites (eg, hydrogen ions and adenosine diphosphate [ADP]) compared to the untrained subjects.

The hemodynamic mechanisms responsible for increased maximal systolic blood pressures are likely to be different in the physically-active than in the untrained "hyperresponders." The higher systolic blood pressure in the trained individuals may be a normal adaptive response that is associated with increased cardiac output, and may be required to maintain simultaneous perfusion pressure to widely dilated skeletal muscle and vital organs under the conditions of low systemic vascular resistance.<sup>20</sup>

A limitation of this study was the use of auscultatory blood pressure measurement during exercise. While the validity of auscultation is well established at rest,<sup>21</sup> there continues to be concern about this technique during exercise. Lightfoot<sup>22</sup> recently reviewed the topic and concluded that auscultation may provide an adequate representation of intraarterial systolic blood pressure, but not diastolic blood pressure. Of the six published articles, three<sup>23-25</sup> found close agreement between auscultation and direct, intraarterial systolic blood pressure measurements. The other three<sup>26-28</sup> found that auscultation underestimated systolic blood pressure in the brachial or radial artery by 15 to 30 mm Hg. However, systolic pressures in a peripheral artery overestimate the central aortic pressure due to pulse-wave amplification.<sup>22</sup> Thus, it may be that the auscultatory values are closer to central aortic pressure than values from a peripheral, indwelling catheter. Our use of the auscultatory method does not invalidate group comparisons, since this method should not underestimate blood pressure to a greater extent in untrained subjects versus trained subjects. More importantly, most studies examining the exaggerated blood pressure response as a predictor of future hypertension have used the auscultatory method.<sup>3,4,15,29</sup>

In summary, trained individuals exhibited significantly higher levels of systolic blood pressure during maximal exercise than a similar group of untrained subjects. The average value for maximal systolic blood pressure was within the range usually classified as an exaggerated blood pressure response (>200 to 220

mm Hg). We conclude that endurance-trained individuals do not have smaller blood pressure responses to maximal exercise despite their reduced risk of future hypertension.

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### REFERENCES

- National High Blood Pressure Education Program Working Group: National High Blood Pressure Education Program Working Group report on primary prevention of hypertension. *Arch Intern Med* 1993; 153:186–208.
- Jette M, Landry F, Sidney K, Blumchen G: Exaggerated blood pressure response to exercise in the detection of hypertension. *J Cardiopulmonary Rehabil* 1988;8:171–177.
- Fragola PV, Romitelli S, Moretti A, et al: Precursors of established hypertension in borderline hypertensives. a two-year follow-up. *Int J Cardiol* 1993;39:113–119.
- Wilson NV, Meyer BM: Early prediction of hypertension using exercise blood pressure. *Prev Med* 1981; 10:62–68.
- Walker AJ, Bassett DR, Jr., Duey WJ, et al: Cardiovascular and plasma catecholamine responses to exercise in blacks and whites. *Hypertension* 1992;20:542–548.
- Eklblom B, Astrand PO, Saltin B, et al: Effect of training on circulatory response to exercise. *J Appl Physiol* 1968; 24:518–528.
- Stratton JR, Levy WC, Cerqueira MD, et al: Cardiovascular responses to exercise: effects of aging and exercise training in healthy men. *Circulation* 1994;89:1648–1655.
- Svedenhag J, Martinsson A, Eklblom B, Hjemdahl P: Altered cardiovascular responsiveness to adrenaline in endurance-trained subjects. *Acta Physiol Scand* 1986; 126:539–550.
- Steinhaus LA, Dustman RE, Ruhling RO, et al: Cardiorespiratory fitness of young and older active and sedentary men. *Br J Sports Med* 1988;22:163–166.
- Blair SN, Goodyear NN, Gibbons LW, Cooper KH: Physical fitness and incidence of hypertension in healthy normotensive men and women. *JAMA* 1984; 252:487–490.
- Anderson NB, Williams RB, Lane JD, et al: Parental history of hypertension and cardiovascular responses to behavioral stress in young black women. *J Psychosom Res* 1987;31:723–729.
- Pollock ML, Schmidt DH, Jackson AS: Measurement of cardiorespiratory fitness and body composition in the clinical setting. *Comprehensive Therapy* 1980;6:12–27.
- Lightfoot JT, Tuller B, Williams DF: Ambient noise interferes with auscultatory blood pressure measurement during exercise. *Med Sci Sports Exerc* 1996;28:502–508.
- Frohlich ED, Grim C, Labarthe DR, et al: Recommendations for human blood pressure determination by sphygmomanometers: report of a special task force appointed by the steering committee, American Heart Association. *Hypertension* 1988;11:210A–222A.
- Manolio TA, Burke GL, Savage PJ, et al: Exercise blood pressure response and 5-year risk of elevated blood pressure in a cohort of young adults: the CARDIA study. *Am J Hypertens* 1994;7:234–241.
- Gottdiener JS, Brown J, Zoltick J, Fletcher RD: Left ventricular hypertrophy in men with normal blood pressure: relation to exaggerated blood pressure response to exercise. *Ann Int Med* 1990;112:161–166.
- Mundal R, Kjeldsen SE, Sandvik L, et al: Exercise blood pressure predicts cardiovascular mortality in middle-aged men. *Hypertension* 1994;24:56–62.
- Clausen JP. Effect of physical training on cardiovascular adjustments to exercise in man. *Physiol Rev* 1977; 57:779–815.
- Snell PG, Martin WH, Buckley JC, Blomqvist CG: Maximal vascular leg conductance in trained and untrained men. *J Appl Physiol* 1987;62:606–610.
- Rowell LB: Blood pressure regulation during exercise. *Ann Med* 1991;23:329–333.
- Perloff D, Grim C, Flack J, et al: Human blood pressure determination by sphygmomanometry. *Circulation* 1993;88:2460–2470.
- Lightfoot JT: Can blood pressure be measured during exercise? *Sports Med* 1991;12:290–301.
- Kaijser L: The indirect method of recording blood pressure during exercise—can the diastolic blood pressure be measured? *Clin Physiol* 1987;7:175–179.
- Karlefors T, Nilsen R, Westling H: On the accuracy of indirect auscultatory blood pressure measurements during exercise. *Acta Med Scand* 1966;180:81–87.
- Nagle FJ, Naughton J, Balke B: Comparisons of direct and indirect blood pressure with pressure-flow dynamics during exercise. *J Appl Physiol* 1966;21:317–320.
- Gould BA, Hornung RS, Altman DG, et al: Indirect measurement of blood pressure during exercise testing can be misleading. *Br Heart J* 1985;53:611–615.
- Henschel A, Vega F, Taylor HL: Simultaneous direct and indirect blood pressure measurements in man at rest and work. *J Appl Physiol* 1954;6:506–508.
- Rasmussen PH, Staats BA, Driscoll DJ, et al: Direct and indirect blood pressure during exercise. *Chest* 1985; 87:743–748.
- Jackson AS, Squires WG, Grimes G, Beard EF: Prediction of future resting hypertension from exercise blood pressure. *J Cardiac Rehab* 1983;3:263–268.
- ACSM Position Stand: Physical activity, physical fitness, and hypertension. *Med Sci Sports Exerc* 1993; 25:i–x.