Effects of Different Training Intensities on 24-Hour Blood Pressure in Hypertensive Subjects

Mireille Marceau, MSc; N’guessan Kouamé, MSc; Yves Lacourcière, MD; Jean Cléroux, PhD

Background. It is generally accepted that physical training decreases blood pressure in hypertensive subjects, but the importance of training intensity has not been established. This study compared the effects of endurance training at different intensities on ambulatory blood pressure and on blood pressure load (percentage of readings above 140/90 and 120/80 mm Hg during the waking and sleeping periods, respectively).

Methods and Results. Previously sedentary subjects with mild to moderate hypertension were evaluated in a crossover fashion according to a Latin square after a sedentary control period and after training at low and at moderate intensity corresponding to 50% and 70% of maximal oxygen uptake, respectively. Each period lasted 10 weeks. After training at moderate intensity, a higher maximal oxygen uptake was found compared with sedentary values but not after training at low intensity. Both training intensities exerted a similar antihypertensive effect of about 5 mm Hg for systolic and diastolic 24-hour blood pressures. However, training at low intensity reduced blood pressure exclusively during the waking hours, whereas training at a moderate intensity reduced blood pressure only during the evening and sleeping hours. Waking blood pressure load decreased from 66% to 49% after training at low intensity, whereas sleeping blood pressure load decreased from 61% to 34% after training at moderate intensity (both P<.05).

Conclusions. Low- and moderate-intensity training produce similar 24-hour blood pressure reductions, but each training intensity may interfere with different pathogenic effects associated with different blood pressure profiles. (Circulation. 1993;88:2803-2811.)

Key Words • hypertension • blood pressure • blood volume • oxygen • exercise

Over the past decade, several studies with well-controlled experimental designs examined the effects of exercise training in hypertension and generally found that training exerted a significant antihypertensive effect (see reviews by Fagard et al,1 Hagberg,2 and Tipton3). This recently prompted the World Hypertension League to conclude that exercise training can contribute to the management of essential hypertension.4 These investigations were carried out by measuring blood pressure over short periods with a sphygmomanometer and a stethoscope in a laboratory environment. In recent years, ambulatory blood pressure monitoring has become a useful tool to examine the effects of antihypertensive treatment in subjects undergoing daily life activities during the course of a 24-hour cycle. Since the recommendation of the World Hypertension League,4 four studies used this approach to examine the blood pressure lowering effects of training in hypertensive subjects. However, two studies found a decrease in ambulatory blood pressure5,6 and two studies did not report any difference after training.7,8

Among various possibilities for these discrepancies, differences in training regimen, and more specifically in training intensity, might have been involved. Indeed, in their reviews, Hagberg2 and Tipton3 noted that a significant reduction of (sphygmomanometric) blood pressure was found more often in the studies that used a low training intensity than in those that used a more strenuous intensity. One study in hypertensive animals9 and another in hypertensive elderly subjects10 further indicated that training at a low intensity may exert a more pronounced blood pressure lowering effect than training at a higher intensity. Among the studies that used ambulatory monitoring, Seals and Reiling6 reportedly trained their subjects at an intensity approximating 50% of maximal oxygen uptake, whereas Blumenthal et al8 and Gilders et al7 used an intensity close to 70% of maximal oxygen uptake. However, different training modes (walking, jogging, bicycling) were used, and the training intensity or the maximal oxygen uptake was not systematically measured. Furthermore, no single study has yet examined the effects of different training intensities on ambulatory blood pressure in hypertensive subjects.

In the present study, we compared the effects of endurance training on cycle ergometers at a low intensity and at a moderate intensity, i.e., training at 50% versus 70% of maximal oxygen uptake, respectively, on 24-hour ambulatory blood pressure. A Latin square

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crossover design that comprised an evaluation after a sedentary control period in addition to a baseline evaluation was used.

Methods

Subjects

Eleven sedentary subjects (10 men and 1 woman) with uncomplicated established mild to moderate hypertension gave informed consent to participate in this study, which was approved by our institutional ethics committee on human research. Secondary hypertension was ruled out by clinical and laboratory evaluation. None of the patients was receiving antihypertensive therapy or any other medication during the study. Medication was gradually withdrawn in those previously on antihypertensive therapy, and they remained without treatment during an additional 6-week period before entering the study.

Except for the prescribed level of physical activity, the patients were encouraged to maintain their usual lifestyle and dietary habits. To assess the sedentary lifestyle of the subjects who took part in this study, standardized questions were asked. These were categorized by type of activity, eg, home activities (gardening or shoveling snow according to season, dish washing, cooking, laundry, etc), travel to work (car, bicycle, bus, walking), work (desk work, walking around work area, etc), occasional sports (racket sports, swimming, walking, golf, etc). When appropriate, the subjects were asked how many hours per week were spent doing a given activity. The general format of the questions was: "How many hours per week do you spend doing this activity and how intense do you feel this activity is, ie, light, moderate, heavy?" Subjects were considered to be sedentary if they did not practice any activity requiring more than 3 kcal/kg body wt per hour (3 METs) on a regular basis, ie, at least 3 hours per week. Average weekly energy expenditure in routine activities\(^1\) was assessed at entry into the study as well as at midpoint and at the end of each study period. This allowed verification that the subjects did not vary systematically their level of activities outside of the prescribed exercises during the course of the study. Body weight and urinary excretion of electrolytes were monitored to take into account the possible confounding effects of changes in dietary intake.

All patients had their blood pressure measured weekly during 1 month preceding entry into the study. Office blood pressure was taken as the mean of three measurements in the seated position at 5-minute intervals not differing by more than 5 mm Hg. Hypertensive patients qualified for the study if their diastolic blood pressure was between 90 and 114 mm Hg in the last two visits of this period. As part of the screening procedure, all subjects underwent a clinical treadmill test (Bruce protocol) with 12-lead ECG recording under supervision of a cardiologist to rule out ischemic heart disease.

Study Protocol

This study used a 3×3 Latin square crossover design to compare the effects of training at two different intensities with those of a control sedentary period on blood pressure. The subjects were evaluated at four time points. The first evaluation occurred after a 4-week baseline period. The subsequent evaluations were performed after each of three 10-week periods during which the patients remained sedentary, trained at 50% of maximal oxygen uptake, and trained at 70% of maximal oxygen uptake, according to the Latin square sequences. These sequences were "train 70%—sedentary—train 50%," "sedentary—train 50%—train 70%," and "train 50%—train 70%—sedentary" in the present study.

The following measurements were performed at each evaluation: 24-hour ambulatory blood pressure and heart rate, 24-hour urinary electrolyte excretion, blood volume, supine blood pressure in the laboratory, and maximal oxygen uptake. These were made on three separate days at 2- to 3-day intervals. Additional exercise sessions were performed during these intervals such that each measurement was performed 40 to 64 hours after the previous exercise session. Twenty-four-hour ambulatory blood pressure and urinary electrolyte measurements were made first. Blood volume was measured next. Laboratory supine blood pressure and maximal oxygen uptake determinations were made last. Seated blood pressure and heart rate were also measured during the week preceding each evaluation.

Training Program

The patients exercised three sessions per week on cycle ergometers (model 819, Monark, Varberg, Sweden) in a well-ventilated room in the research center under supervision of trained personnel. The sessions were held between 4:30 PM and 6:30 PM on Mondays, Wednesdays, and Fridays. Each exercise session included a 5-minute warm-up period, a period of exercise at the predetermined work rate that gradually increased from 30 to 45 minutes over 2 weeks, and a 10-minute cool-down period. The work rate required to induce an increase in oxygen uptake up to 50% or 70% of maximal values was determined by interpolation of results during the maximal oxygen uptake test. The individual heart rate at each work rate was noted at 15 and 30 minutes during the first training sessions and was used as reference in order to keep the training intensity constant over the entire 10-week period. The work rate was increased when heart rate was 5 beats per minute lower than the reference value for two consecutive exercise sessions. Exercise blood pressure and heart rate were monitored every 15 minutes.

Measurements

Seated blood pressure and heart rate. Blood pressure (standard mercury sphygmomanometer and stethoscope) and heart rate (palpation at the wrist) were measured twice at 2-minute intervals after the subjects had remained seated on a chair (baseline and sedentary periods) or on a cycle ergometer (before each exercise session during the training programs at 50% and 70% of maximal oxygen uptake) for 10 minutes. A cuff with a large bladder (15x31 cm) was used,\(^2\) and the first and fifth Korotkoff sounds were taken as the systolic and diastolic values, respectively. The average of three series of measurements (six measurements total) made on three different days at a 1-day interval during the week preceding each evaluation is reported. These measurements were made between 4:30 and 6:30 PM, ie, during
the time of the training sessions, and were always performed by the same investigator (M.M.).

Twenty-four-hour blood pressure and heart rate. Twenty-four-hour ambulatory blood pressure and heart rate measurements were made using an automatic noninvasive recorder (model 90202, SpaceLabs Inc, Redmond, Wash) that uses an oscillometric method for the determination of systolic and diastolic blood pressures. The accuracy and reproducibility of blood pressure determined with this device were previously established. Measurements were made at 30-minute intervals between 6:00 AM and 6:00 PM and at 60-minute intervals between 6:00 PM and 6:00 AM. The patients were encouraged to go about their usual daily activities and to relax their arm during cuff inflation and deflation. Ambulatory blood pressure monitoring was always performed on a working day. All patients worked on daytime shifts, and their tasks involved mainly desk work. After the 24-hour recording, the data were downloaded from the monitor to a computer for analysis. Values of systolic pressure less than 70 or more than 250 mm Hg, diastolic pressure less than 40 or more than 150, and heart rate less than 40 or more than 150 beats per minute were excluded from the analysis. Average blood pressure was calculated from single readings for each 1-hour period, for waking (7:00 AM to 10:00 PM) and sleeping (11:00 PM to 6:00 AM) segments, and for the entire 24-hour period.

The blood pressure load was calculated as the percentage of ambulatory systolic and diastolic pressure readings exceeding 140/90 mm Hg, respectively, during the waking period, and 120/80 mm Hg during the sleeping period. Average blood pressure load values are given separately for waking and sleeping periods and also for the entire 24-hour period.

Twenty-four-hour urinary electrolytes. The 24-hour urinary excretion of sodium, potassium, and chloride was determined with standard analytical methods by the clinical biochemical laboratory of our institution.

Blood volume. Blood volume was measured with a technique using radioactive sodium chromate to tag red blood cells. In this procedure, a blood sample is withdrawn, the red blood cells are tagged with sodium chromate, and the sample is re injected into the subject. Blood samples are withdrawn at 10 and 30 minutes after the injection, and the volume occupied by the red blood cell is calculated by the principle of dilution. Plasma volume and whole blood volume were obtained by taking the hematocrit into account. This technique has been shown to have a between-measurement variation under 6% both for red blood cell and plasma volume.

Blood volume was always measured in the morning in the present study.

Supine blood pressure and heart rate. Supine blood pressure and heart rate were measured between 8:00 and 10:00 AM in the laboratory over 60 minutes during three 10-minute baseline periods at 10-minute intervals. During intervals, leg raising and lower body negative pressure maneuvers were applied. The responses to these maneuvers are discussed elsewhere (unpublished results). The maneuvers did not affect resting values. Two measurements were made during the last 5 minutes of each 10-minute period. The values reported therefore represent the mean of six baseline blood pressure and heart rate measurements. Blood pressure was measured with the same sphygmomanometer and cuff and by the same investigator (M.M.) as during measurement of seated blood pressure. Heart rate was measured with a tachograph triggered by the R wave of the ECG (model 7P4, Grass Instrument Co, Quincy, Mass).

Exercise evaluation. Maximal oxygen uptake was determined by analysis of expired gases (Energy Expenditure Unit 2900, Sensormedics, Anaheim, Calif) during an increased work test schedule on a cycle ergometer (Ergomedic 829E, Monark, Varberg, Sweden) with increments of 50 W every 2 minutes up to the point of volitional exhaustion. Blood pressure and heart rate were measured twice at each step. Maximal oxygen uptake was considered to be reached when the respiratory exchange ratio was greater than 1.10 and oxygen uptake and heart rate did not further increase with increasing work rate. This test took place between the hours of 9:00 and 11:00 AM, ie, after the supine evaluation.

Statistical Analysis

The results are reported as mean±SEM and were compared by ANOVA for repeated measurements. A probability of <.05 was set as the level of significance. Differences were located using Fisher's protected least significant difference test.

Results

Of the 11 mild to moderate hypertensive subjects enrolled in the study, 9 (1 woman and 8 men; age, 43±2 years; height, 175±2 cm) completed all the stages and were included in the analysis (Table 1). Two patients withdrew for reasons unrelated to the study. The randomization with the Latin square design was therefore complete, with 3 subjects receiving each of the predetermined sequences. In addition, analysis of variance of hemodynamic variables during the first, second, third, and fourth evaluations, irrespective of the intervention, showed no significant differences, indicating there was no significant order effect.

During the baseline evaluation, seated blood pressure was 156±4 mm Hg systolic (range, 138 to 180 mm Hg) and 102±2 mm Hg diastolic (range, 90 to 111 mm Hg), whereas average ambulatory blood pressure between 7:00 AM and 10:00 PM was 152±3 mm Hg systolic (range, 136 to 163 mm Hg) and 97±2 mm Hg diastolic (range, 87 to 106 mm Hg) in this group of subjects. Average energy expenditure assessed during baseline evaluation (16 490±605 kcal/wk) was unchanged during the sedentary period (16 595±585 kcal/wk, P=.91, NS). Energy expenditure for routine activities outside of prescribed exercises during training at 50% (16 532±689 kcal/wk, P=.94, NS) and at 70% of maximal oxygen uptake (16 749±610 kcal/wk, P=.86, NS) remained constant compared with the sedentary period. Thus, the subjects did not systematically vary their level of activities outside of the prescribed exercises during the course of the study.

The mean heart rate and work rate were 123±9 beats per minute and 90±8 W, respectively, during training at 50% of maximal oxygen uptake and 145±9 beats per minute and 124±9 W during training at 70% of maximal oxygen uptake. Training at 50% and at 70% of maximal oxygen uptake was associated with excess weekly energy expenditures of 852±75 and 1068±69 kcal/wk (P<.01), respectively. Training at 50% of maximal oxygen uptake
TABLE 1. Characteristics of Subjects Including Type and Duration of Previous Antihypertensive Pharmacotherapy

<table>
<thead>
<tr>
<th>Subject</th>
<th>Sex</th>
<th>Age, y</th>
<th>Previous Treatment</th>
<th>Duration of Treatment, y</th>
<th>Height, cm</th>
<th>Weight, kg</th>
<th>ΔWeight</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>54</td>
<td>. . .</td>
<td>0</td>
<td>173</td>
<td>69.0</td>
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</tr>
<tr>
<td>2</td>
<td>M</td>
<td>46</td>
<td>βB</td>
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<td>80.0</td>
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</tr>
<tr>
<td>3</td>
<td>M</td>
<td>52</td>
<td>ACEI</td>
<td>3</td>
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</tr>
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<td>4</td>
<td>F</td>
<td>47</td>
<td>βB</td>
<td>2</td>
<td>175</td>
<td>75.0</td>
<td>-1.2</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>40</td>
<td>. . .</td>
<td>0</td>
<td>173</td>
<td>70.0</td>
<td>-1.0</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>35</td>
<td>ACEI</td>
<td>2</td>
<td>168</td>
<td>65.0</td>
<td>-2.0</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>45</td>
<td>DIUR</td>
<td>4</td>
<td>181</td>
<td>92.0</td>
<td>3.0</td>
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<tr>
<td>8</td>
<td>M</td>
<td>39</td>
<td>ACEI</td>
<td>2</td>
<td>175</td>
<td>76.9</td>
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<tr>
<td>9</td>
<td>M</td>
<td>51</td>
<td>βB</td>
<td>4</td>
<td>170</td>
<td>72.0</td>
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</tr>
</tbody>
</table>

ΔWeight

<table>
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<tr>
<th>T50-SED, kg</th>
<th>T70-SED, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3.0</td>
<td>-2.0</td>
</tr>
<tr>
<td>-3.0</td>
<td>-1.0</td>
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<tr>
<td>0.1</td>
<td>-1.4</td>
</tr>
<tr>
<td>-1.2</td>
<td>-1.0</td>
</tr>
<tr>
<td>-1.0</td>
<td>-0.9</td>
</tr>
<tr>
<td>-2.0</td>
<td>-0.8</td>
</tr>
<tr>
<td>3.0</td>
<td>0.0</td>
</tr>
<tr>
<td>-0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>-1.5</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

Individual changes in weight (Δweight) after training at 50% (T50) and at 70% of maximal aerobic capacity (T70) compared with the sedentary period (SED) are shown. None of the subjects received antihypertensive pharmacotherapy during the study. βB indicates β-blocker; ACEI, angiotensin converting enzyme inhibitor; and DIUR, diuretic.

did not significantly affect maximal aerobic capacity (P > .10), whereas training at 70% of maximal oxygen uptake induced a 14% increase (P < .01) (Fig 1). Maximal oxygen uptake was found to be higher after the sedentary period than at baseline (P < .05). Training at 50% and 70% of maximal oxygen uptake induced small and similar decreases in body weight, although only the difference after training at 70% was statistically significant (P < .05) (Table 1 and Fig 1). Compliance was 98±2% during training at 50% of maximal oxygen uptake and 96±3% during training at 70% of maximal aerobic capacity.

The hourly blood pressure and heart rate values during a 24-hour cycle at each evaluation appear in Figs 2 through 4. In each figure, the results are compared with those of the sedentary control evaluation. Fig 2 shows that blood pressure and heart rate were similar during the baseline and sedentary evaluations along the 24-hour period. Figs 3 and 4 illustrate that blood pressure was significantly (P < .05) lower at several time points after training at 50% and 70%, respectively, of maximal oxygen uptake. Heart rate was not altered after training at 50% of maximal oxygen uptake, but a significant reduction was found at one time point after training at 70% of maximal aerobic capacity.

Fig 5 shows that the mean systolic and diastolic blood pressure values calculated over the 24-hour cycle decreased similarly after both interventions, although the difference was only significant (P < .05) for systolic blood pressure after training at 50% of maximal aerobic capacity. In addition, blood pressure load was reduced to a similar extent after both training regimens, although the difference was significant after training at 70% (P < .05) but not after training at 50% of maximal aerobic capacity (P = .06, NS). Fig 5 also illustrates that the 24-hour mean data was superimposable during the baseline and sedentary evaluations. Although training at 50% and 70% of maximal oxygen uptake induced similar effects on average 24-hour

![Fig 1. Maximal oxygen uptake (VO₂ max) and weight of subjects at the end of the initial 4-week baseline period and, in a crossover fashion according to a 3x3 Latin square, after 10-week periods while remaining sedentary and training at 50% and 70% of maximal oxygen uptake. *P < .05 vs sedentary.](http://circ.ahajournals.org/)

![Fig 2. Hourly systolic (SBP) and diastolic (DBP) blood pressure and heart rate (HR) of the subjects over 24 hours after the sedentary period and at the end of the baseline period.](http://circ.ahajournals.org/)
blood pressure and blood pressure load, the blood pressure lowering effect was distributed differently during the course of the day according to the intensity of the training program. Thus, during the waking period, systolic blood pressure (−6±2 mm Hg, \(P<.01\)), diastolic blood pressure (−5±2 mm Hg, \(P<.05\)), and blood pressure load (−17±7%, \(P<.05\)) were all significantly reduced after training at 50% of maximal oxygen uptake, whereas no significant changes (all \(P>.05\)) were seen after training at 70% of maximal oxygen uptake (Fig 6). On the other hand, during sleep, diastolic blood pressure (−5±1 mm Hg, \(P<.01\)) and blood pressure load (−27±9%, \(P<.01\)) were significantly reduced after training at 70% of maximal oxygen uptake, but no significant changes (all \(P>.10\)) were seen after training at 50% of maximal oxygen uptake (Fig 7).

Further detailed examination of the blood pressure patterns during specific time segments after each training regimen indicated that the maximal antihypertensive effect of training at 50% of maximal oxygen uptake was seen during the morning hours (Fig 3), whereas the maximal effect of training at 70% of maximal oxygen uptake was seen during the evening hours (Fig 4). Also, training at 50% of maximal oxygen uptake affected mostly diastolic blood pressure, whereas training at 70% of maximal oxygen uptake reduced mostly systolic blood pressure. Thus, from 7:00 to 11:00 AM, diastolic blood pressure increased by 14±3 mm Hg (from 88±3 to 102±3 mm Hg) after the sedentary period but increased only by 5±2 mm Hg (from 88±3 to 93±3 mm Hg) after training at 50% of maximal oxygen uptake, amounting to a net antihypertensive effect of 9 mm Hg (\(P<.05\)). From 4:00 to 9:00 PM, systolic blood pressure remained stable after the sedentary period (153±4 and 151±3 mm Hg), whereas it decreased by 16±6 mm Hg (from 152±3 to 136±5 mm Hg) after training at 70% of maximal oxygen uptake, representing a net antihypertensive effect of 14 mm Hg (\(P<.05\)). The changes in ambulatory blood pressure (calculated over specific time segments or over 24 hours) did not correlate with the changes in maximal oxygen uptake or in body weight after training at 50% or 70% of maximal oxygen uptake.
or with age, duration of previous treatment, or waking ambulatory blood pressure at baseline.

With regard to blood pressure measured during 60 minutes of supine rest, during 10 minutes in the sitting position, or during 2 minutes of submaximal exercise at 100 W, no differences were seen after training at 50% or 70% of maximal oxygen uptake compared with after the sedentary period (Table 2). In the supine position and during submaximal exercise, somewhat higher blood pressure values were found during the baseline evaluation compared with the sedentary evaluation. Supine heart rate was not different after either training regimen, but in the seated position, higher values were found after training at 50% of maximal aerobic capacity and during the baseline evaluation than after the sedentary period (Table 2).

Blood volume and plasma volume were not significantly affected by training, but blood volume was significantly higher at the baseline evaluation than after the sedentary period (Table 3). Red blood cell volume was found to be increased after training at 50% and 70% of maximal oxygen uptake compared with after the sedentary period, but it was also increased during the baseline evaluation. The 24-hour urinary excretion of sodium, potassium, and chloride ions was not different during the study.

Discussion

The results of the present study show that 10 weeks of closely supervised physical training on cycle ergometers at 50% of maximal oxygen uptake and at 70% of maximal oxygen uptake induce comparable decreases in average 24-hour ambulatory blood pressure and in average 24-hour blood pressure load. However, blood pressure and blood pressure load were reduced exclusively during the waking period after training at 50% of maximal oxygen uptake, whereas they were reduced only during the evening and sleeping periods after training at 70% of maximal oxygen uptake. In earlier studies that assessed blood pressure with a sphygmomanometer and a stethoscope, measurements were made during the waking period. Our findings may therefore help explain why a reduction in blood pressure was found more often in the studies that used a low training intensity than in those that used a more strenuous intensity.2,3

In addition, training at 50% of maximal oxygen uptake almost completely blunted the morning blood pressure rise. This effect would appear to be unique to physical training since pharmacological antihypertensive therapy has been reported to lower 24-hour blood pressure without affecting the normal pattern of the circadian blood pressure curve, ie, the morning blood pressure rises by the same amount but starts from a
TABLE 2. Effects of Two Intensities of Physical Training on Blood Pressure and Heart Rate at Rest in Supine and Seated Positions and During Submaximal (100 W) Cycle Ergometer Exercise

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Sedentary</th>
<th>Train 50%</th>
<th>Train 70%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supine rest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBP, mm Hg</td>
<td>138±4*</td>
<td>130±3</td>
<td>132±3</td>
<td>128±3</td>
</tr>
<tr>
<td>DBP, mm Hg</td>
<td>94±2*</td>
<td>87±1</td>
<td>90±2*</td>
<td>87±2</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>65±3</td>
<td>64±3</td>
<td>65±3</td>
<td>62±3</td>
</tr>
<tr>
<td><strong>Seated rest</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>SBP, mm Hg</td>
<td>156±4</td>
<td>152±4</td>
<td>153±2</td>
<td>155±3</td>
</tr>
<tr>
<td>DBP, mm Hg</td>
<td>102±2</td>
<td>100±3</td>
<td>99±3</td>
<td>103±2</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>80±4*</td>
<td>74±3</td>
<td>79±3*</td>
<td>75±3</td>
</tr>
<tr>
<td><strong>Submaximal exercise</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBP, mm Hg</td>
<td>176±6</td>
<td>169±8</td>
<td>166±6</td>
<td>167±6</td>
</tr>
<tr>
<td>DBP, mm Hg</td>
<td>97±2*</td>
<td>89±2</td>
<td>93±2</td>
<td>90±2</td>
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<tr>
<td>Heart rate, bpm</td>
<td>135±5</td>
<td>128±7</td>
<td>130±5</td>
<td>128±5</td>
</tr>
</tbody>
</table>

Values are mean±SEM. SBP and DBP indicate systolic and diastolic blood pressures, respectively; train 50% and train 70%, training at 50% and at 70% of maximal aerobic capacity, respectively; bpm indicates beats per minute.

*P<.05 vs sedentary.

to expect that these activities may produce similar effects. A word of caution is in order concerning the adequacy of brisk walking or jogging, since only the effects of exercising on cycle ergometers in the laboratory were examined in the present study.

With regard to blood pressure load, mild hypertension on ambulatory monitoring is defined as the presence of at least 50% of the total awake readings greater than 140/90 mm Hg and of at least 50% of the total asleep readings greater than 120/80 mm Hg.26 Our results show that the awake blood pressure load decreased from 66% after the sedentary period to 49% after training at 50% of maximal oxygen uptake. The asleep blood pressure load decreased from 61% after the sedentary period to 34% after training at 70% of maximal oxygen uptake. Thus, each training regimen exerted clinically relevant reductions of blood pressure load based on the definition of mild hypertension, albeit each during specific time periods.

Our findings are based on the comparison of the results obtained after each training regimen with those obtained after the control sedentary period. Because training and sedentary periods occurred in a crossover fashion according to a Latin square, it is not likely that the differences were related to any significant extent to ambulatory blood pressure monitoring habituation. In fact, identical 24-hour blood pressure profiles were observed during the sedentary and baseline evaluations. The concordance of baseline and sedentary results agrees with earlier results showing the good reproducibility of ambulatory blood pressure monitoring13 and further indicate that a period of 10 weeks was sufficient to reverse the antihypertensive effects of a previous training period. It is noteworthy that the higher maximal oxygen uptake found after the sedentary period than after the initial baseline period was not associated with a change in the circadian blood pressure curve.

The findings of the present study were independent of a change in body weight, in 24-hour urinary excretion of electrolytes, or in blood volume. This is in agreement with previous reports showing that the antihypertensive effect of training was unrelated to weight loss25 or to a change in urinary excretion of electrolytes10,22,26 and that blood volume was not different after low- and moderate-intensity training.10 Urata et al28 reported a fall in blood volume in hypertensive subjects after training at a low intensity. In that study,28 the posttraining results were compared with those obtained after a 4-week baseline period. It should be noted that the comparison of our results after training at

TABLE 3. Effects of Two Intensities of Physical Training on Blood Volume and on 24-Hour Urinary Excretion of Electrolytes

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Sedentary</th>
<th>Train 50%</th>
<th>Train 70%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood volume, mL</td>
<td>4573±208*</td>
<td>4333±191</td>
<td>4354±233</td>
<td>4457±240</td>
</tr>
<tr>
<td>Plasma volume, mL</td>
<td>2810±141</td>
<td>2721±105</td>
<td>2669±144</td>
<td>2705±137</td>
</tr>
<tr>
<td>RBC volume, mL</td>
<td>1764±99*</td>
<td>1611±111</td>
<td>1684±95*</td>
<td>1753±109*</td>
</tr>
<tr>
<td>Na+, mmol/L</td>
<td>157±18</td>
<td>156±10</td>
<td>166±16</td>
<td>162±24</td>
</tr>
<tr>
<td>K+, mmol/L</td>
<td>73±7</td>
<td>73±5</td>
<td>75±6</td>
<td>64±8</td>
</tr>
<tr>
<td>Cl-, mmol/L</td>
<td>164±16</td>
<td>155±10</td>
<td>172±17</td>
<td>174±27</td>
</tr>
</tbody>
</table>

Results are mean±SEM. RBC indicates red blood cells; train 50% and train 70% indicate training at 50% and at 70% of maximal aerobic capacity, respectively.

*P<.05 vs sedentary.
50% of maximal oxygen uptake with those obtained after the initial 4-week baseline period yields a similar conclusion. Thus, the fall in blood volume reported by Urata et al may be related to their study design. The antihypertensive effect also was not related to the increase in physical fitness, as evidenced by the lack of correlation between the changes in blood pressure and in maximal oxygen uptake after each training regimen. This is further supported by the observation of decreased circadian blood pressure curves in the presence of an unchanged maximal oxygen uptake after training at 50% of maximal aerobic capacity compared with the sedentary evaluation.

Relation With Previous Studies
Concerning the discrepancies between the few studies that used ambulatory monitoring to assess the antihypertensive effect of training, several considerations support our hypothesis that differences in training intensity may have been involved. Our results showing a reduced ambulatory blood pressure during the waking period and an unchanged blood pressure during the sleeping period after training at 50% of maximal oxygen uptake agree with the results of Somers et al and Seals and Reiling in hypertensive subjects and also with those of Van Hoof et al in normotensive subjects. The amplitude of the blood pressure reduction during the waking period was similar in the present study (−6/−5 mm Hg) and in the study of Somers et al (−5/−8 mm Hg). Seals and Reiling and Van Hoof et al also reported similar but isolated decreases in awake systolic (−7 mm Hg) and diastolic blood pressures (−5 mm Hg), respectively. The subjects from the study of Seals and Reiling trained by walking at a pace eliciting ≈50% of maximal oxygen uptake as determined by the measurement of individual heart rates. The studies of Somers et al and Van Hoof et al involved mixed exercises including calisthenics, walking, and jogging for continuous periods of less than 10 minutes, during which training intensity was not monitored. Because these exercises usually elicit a mild increase in energy output, it can be assumed that the training intensity was closer to 50% than to 70% of maximal oxygen uptake.

On the other hand, our results showing that daytime ambulatory blood pressure was not different after training at 70% of maximal oxygen uptake agree with the results of the studies by Blumenthal et al and Gilders et al. In those studies, training intensity was closely monitored to ensure that at least 70% of maximal oxygen uptake was sustained for periods exceeding 35 minutes of continuous exercise. Thus, the results from the present study and those from Blumenthal et al and Gilders et al are concordant in indicating that waking blood pressure is unchanged after training at 70% of maximal oxygen uptake. Although Blumenthal et al did not measure sleeping blood pressure, Gilders et al did not report any change in evening or sleeping blood pressure, whereas our results show that ambulatory blood pressure was significantly lower during the evening and sleeping hours after training at 70% of maximal oxygen uptake. The present results after training at 50% and 70% of maximal oxygen uptake are therefore consistent with the hypothesis that discrepancies between earlier studies with ambulatory blood pressure monitoring, at least during waking hours, may have been related to differences in training intensity.

Comparison With Sphygmomanometer Measurements
In the present study, a significant decrease in supine blood pressure was found after the sedentary period compared with the baseline evaluation. Reduction in sphygmomanometric blood pressure during a control period is a well-known phenomenon in hypertension studies. For example, Blumenthal et al and Seals and Reiling noted that clinic blood pressure decreased after 4 and 6 months, respectively, in their control group of hypertensive subjects. Kiyonaga et al reported that clinic blood pressure decreased during a control period of 4 weeks and thereafter stabilized. Since the baseline evaluation also occurred after a period of 4 weeks in the present study, we interpret our findings as indicating that a longer period may be required for stabilization of sphygmomanometric blood pressure. This further underlines the importance of the control sedentary period, or of evaluating a parallel group of control sedentary subjects, to avoid artificial amplification of the antihypertensive effect when blood pressure is measured by sphygmomanometry.

Supine, seated, and submaximal exercise blood pressures measured with the sphygmomanometer were unaltered after either training regimen compared with after the sedentary period. The absence of a change after training at 70% of maximal oxygen uptake is in accordance with our findings with ambulatory monitoring during the waking period. However, there is an inconsistency between the decrease in awake ambulatory blood pressure and failure to detect a lower blood pressure with the sphygmomanometer after training at 50% of maximal oxygen uptake. The reasons for this discrepancy are not readily apparent. Nonetheless, the time of day at which measurements were made may have intervened, at least for seated measurements. In the present study, seated blood pressure during baseline and sedentary periods was measured during the regular training hours, i.e., between 4:30 and 6:30 PM. It can be advocated that the failure to detect lower values in the seated position at the end of training at 50% of maximal oxygen uptake may have been related to the time of day, since ambulatory blood pressure was not different during these hours after the same intervention. It may be noted that seated blood pressure values also agree with ambulatory blood pressure values during this specific time frame after training at 70% of maximal oxygen uptake.

Further support of this hypothesis would have required measurement of seated blood pressure with the sphygmomanometer during the morning hours, which was not done in the present study. Nevertheless, among other studies on the effects of low-intensity training in hypertensive subjects that found significant reductions in seated blood pressure, it can be safely presumed that a greater proportion of measurements took place during morning and early afternoon hours compared with late afternoon hours.

Potential Mechanisms
Several mechanisms, including hemodynamic, metabolic, and neural mechanisms, have been proposed to participate in the antihypertensive action of physical training. With regard to mechanisms underlying the ambulatory blood pressure reduction during waking hours after training at a low intensity versus during evening and night hours after training at a moderate intensity, these can only...
be speculated upon. Training at a low intensity induced its antihypertensive action during the active period of the day, ie, when one changes from a seated to a standing position most often. Thus, mechanisms involving reflex regulation of circulation in response to a change in venous return were probably solicited to the greatest extent during this period. One possible theory could therefore implicate an exercise intensity–specific alteration in baroreflex regulation of circulation. This hypothesis is supported by the observation that low-intensity training was found to potentiate cardiopulmonary baroreflex control of forearm vascular resistance,\(^2\) whereas moderate-intensity training was reported to attenuate this reflex response in normotensive subjects.\(^2\)

Conclusions

The results of the present study demonstrate that ambulatory blood pressure is decreased during the waking period—mainly during the morning hours—after training at a low intensity corresponding to 50% of maximal oxygen uptake, whereas the antihypertensive effect occurs during the evening and the sleeping period after training at a moderate intensity corresponding to 70% of maximal oxygen uptake. Notwithstanding some inconsistencies between training-induced changes in blood pressure as assessed by ambulatory monitoring and sphygmomanometry, and taking into account the limitations inherent to the present study in a relatively small sample of subjects, these results, taken together with evidence that morning blood pressure elevation may contribute to precipitation of cardiovascular events and that night blood pressure may be linked to left ventricular hypertrophy, suggest that training at 50% and at 70% of maximal oxygen uptake may be equally efficacious in preventing cardiovascular events linked to high blood pressure.

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