Exercise characteristics and the blood pressure response to dynamic physical training

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ABSTRACT

FAGARD, R. H. Exercise characteristics and the blood pressure response to dynamic physical training. *Med. Sci. Sports Exerc.,* Vol. 33, No. 6, Suppl., pp. S484–S492, 2001. **Purpose:** The purpose of this study was to assess the influence of the characteristics of the exercise program, particularly exercise intensity, on the blood pressure response to dynamic physical training in otherwise healthy normotensive and hypertensive subjects. **Methods:** This study is a meta-analysis of randomized controlled intervention trials and a description of studies in which different training regimens have been compared. **Results:** The weighted net reduction of blood pressure in response to dynamic physical training averaged 3.4/2.4 mm Hg ($P < 0.001$). Interstudy differences in the changes in pressure were not related to weekly frequency, time per session, or exercise intensity, which ranged from approximately 45–85%; these three characteristics combined explained less than 5% of the variance of the blood pressure response. The response of diastolic blood pressure was not different according to training intensity in studies that randomized patients to training programs with different intensities. Some studies reported a greater reduction of systolic blood pressure when intensity was about 40% than when participants exercised at about 70%, but this finding was not consistent, neither within nor between studies. **Conclusion:** Training from three to five times per week during 30–60 min per session at an intensity of about 40–50% of net maximal exercise performance appears to be effective with regard to blood pressure reduction. The evidence that higher intensity exercise would be less effective is at present inconsistent. **Key Words:** AEROBIC POWER, BLOOD PRESSURE, EXERCISE, EXERCISE INTENSITY, TRAINING PROGRAM

Weight reduction, salt restriction, moderation of alcohol consumption, and increased physical activity are generally accepted lifestyle measures for the management of hypertension (24,56). Whereas epidemiological studies suggest an inverse relationship between habitual physical activity and blood pressure (14,16), meta-analyses of controlled intervention trials concluded that adequate dynamic physical training contributes to the control of blood pressure (13,16,20). However, the optimal characteristics of the training program are still a matter of debate, particularly with regard to the intensity of exercise. In the present review we will address this question, first by analyzing relationships between exercise characteristics and blood pressure response across randomized controlled trials by use of meta-analytical techniques, and second by examining the results from studies in which different training regimens have been applied.

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METHODS

Selection of articles. Articles relevant to the aims of the present review were identified by a computer-assisted literature search and by checking the reference lists of published articles on the topic. The database used for the meta-analysis contains articles published before August 1998 (13) and the following criteria were applied with regard to their acceptability: randomized controlled trials of at least 4-wk duration concerning normotensive or hypertensive subjects, or both, in whom cardiovascular diseases were reasonably well excluded; random allocation to intervention groups and control groups or control phases in case of crossover design; full publication in a peer-reviewed journal; and absence of confounding by some other intervention during the intervention of interest. When the effects of different training programs were compared within studies, random allocation to the intervention groups or phases was required; however, a control group without intervention was not a prerequisite for inclusion. Finally, studies were accepted only when the actual blood pressures for the intervention and the control groups or phases, or the pressure changes during the intervention and control periods, were available.

Statistical analysis. Database management and statistical analyses were performed with the SAS software (SAS Institute, Inc., Cary, NC). Meta-analyses consisted of analyses of pooled data with study groups as the units of analysis, with weighting for the number of participants in each group. The net effects of physical training were assessed by weighted pooled analyses of the changes in the intervention groups, adjusted for control data. Results are reported as weighted means and 95% confidence limits (95% CL). Finally, weighted metaregression analysis was applied to assess whether variations in the results were related to variations in study group or training characteristics (15).

RESULTS

Physical Training and Blood Pressure Control: Overall Results

We identified 44 randomized controlled trials on the effect of dynamic aerobic or endurance exercise on blood pressure at rest in otherwise healthy normotensive or hypertensive individuals (1–5,7–11,17–19,21–23,25–34,36, 37,39–49,51–55). Sixty-five percent of the 2674 participants were men. Nineteen studies comprised only men, four included only women, and the others included both sexes (or sex unknown in one). Some of these studies involved several groups of subjects or applied different training regimens in the same participants, so that a total of 68 training groups/programs are available for analysis. Average age of the groups ranged from 21 to 79 yr (median, 44). Duration of training involved 4 to 52 wk (median, 16). Training frequency ranged from one to seven sessions per week, but it is noteworthy that two thirds of the training programs applied three sessions per week and all but five programs three to five sessions per week. Each session lasted from 30 to 60 min in all but two programs (15 min), after exclusion of warm-up and cool-down activities (median exercise time, 40 min). The exercises involved walking, jogging, running in 69% of the studies, cycling in 50%, swimming in 3%, and other exercises were included in 23% of the training regimens. Average training intensity in the various groups varied between 30 and 87% of net maximal exercise performance (median, 65%). Exercise intensity was reported in percent of maximal oxygen uptake (3,5,9,19,33,43–45,53–55) or maximal work load (7,8,23,26,36,37,40) in 11 and seven of the 44 studies, respectively, and in percent of heart rate reserve (4,18,21,28,32,39,49,52) or maximal heart rate (1,2,10,11,17,22,25,27,29–31,34,42,47) in eight and 14 studies. Finally, two studies trained participants at the lactate threshold, which corresponded to approximately 50% of maximal oxygen uptake (48,51), and two did not give details on exercise intensity (41,46). When exercise intensity was expressed as a percent of maximal oxygen uptake or maximal heart rate, intensity was recalculated as percent of oxygen uptake reserve or heart rate reserve by accounting for resting oxygen uptake or heart rate, respectively (percent of net maximal exercise performance).

Table 1 summarizes the overall results. In the 68 study groups, the changes of blood pressure in response to training, after adjustment for the control observations, ranged from +9 to −20 mm Hg for systolic blood pressure and from +11 to −11 mm Hg for diastolic pressure. The overall net changes averaged −3.4/−2.4 mm Hg ($P < 0.001$), that is, after adjustment for control observations and after weighting for the number of trained participants who could be analyzed in each study group, their total number amounted to 1529. Baseline blood pressure was an important determinant of the blood pressure response. The training-induced weighted net change of blood pressure averaged −2.6 (95% CL, −3.7, −1.5)/−1.8 (95% CL, −2.6 −1.1) mm Hg in the 52 normotensive groups and −7.4 (95% CL, −10.5, −4.3)/−5.8 (95% CL, −8.0, −3.5) mm Hg in the 16 hypertensive groups. Hypertension was defined as systolic blood pressure ≥ 140 mm Hg or diastolic pressure ≥ 90 mm Hg at baseline (24,56). Peak oxygen uptake increased significantly by 11.8% (95% CL, 10.3%, 13.4%), whereas heart rate and body mass index decreased, 6.8% (95% CL, 5.5%, 8.2%) and 1.2% (95% CL, 0.8%, 1.7%), respectively.

Evidence statement. Dynamic aerobic training reduces blood pressure. The blood pressure lowering effect is more pronounced in hypertensive than in normotensive subjects. Evidence Category A.

Influence of Training Characteristics

Across-study analysis. Thirty-five randomized controlled trials, comprising 45 study groups or interventions, applied only one training intensity, which ranged from 43–87% of net maximal exercise performance (median, 64%) (1–3,5,7–10,17,18,21–23,27–32,34,36,37,39,40,42–44,47–49,51–55). Figures 1 and 2 illustrate the relationships between the net changes in systolic and diastolic blood pressure, respectively, and net training intensity for the 45 study groups. Weighted single metaregression analysis showed that these relationships were significant for neither systolic ($y = -9.24 + 0.087 * x$; $r = 0.19$; $P = 0.21$) nor diastolic ($y = -2.56 - 0.004 * x$; $r = -0.01$; $P = 0.93$) blood pressure. The changes in blood pressure were not significantly related to the weekly training frequency ($P \geq 0.44$)

TABLE 1. Baseline data and net changes in response to training.

	Baseline		Net Change	
	N	Mean (95% CL)	Mean (95% CL)	*P* Value
Blood pressure (mm Hg)				
Systolic	68	126.2 (123.3, 129.0)	−3.4 (−4.5, −2.3)	<0.001
Diastolic	68	79.9 (77.9, 82.0)	−2.4 (−3.2, −1.6)	<0.001
Peak $\dot{V}O_2$ (mL·min^{-1}·kg^{-1})	59	31.4 (29.6, 33.2)	+3.7 (+3.2, +4.3)	<0.001
Heart rate (beats·min^{-1})	48	71.1 (69.3, 72.9)	−4.9 (−5.9, −3.9)	<0.001
BMI (kg·m^{-2})	64	25.6 (25.0, 26.1)	−0.34 (−0.46, −0.22)	<0.001

N, number of groups; $\dot{V}O_2$, oxygen uptake; BMI, body mass index.
Values are weighted means and 95% confidence limits (CL).

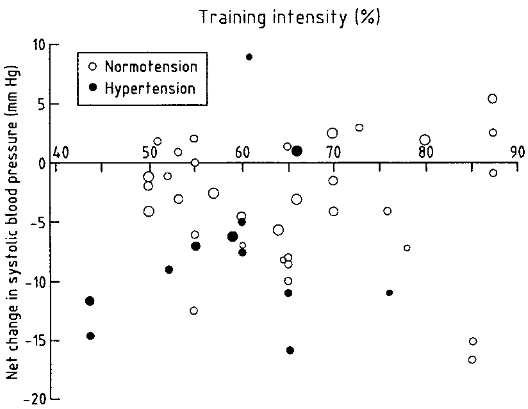

FIGURE 1—Changes in systolic blood pressure with training, adjusted for control data, versus training intensity, in normotensive (*open circles*) and hypertensive (*closed circles*) study groups. Training intensity is expressed as percent of maximal work load, heart rate reserve, or oxygen uptake reserve. The four sizes of the circles represent the number of analyzable trained subjects in each group, i.e., < 10, 10–19, 20–29, and ≥ 30, respectively. The weighted meta-regression coefficient r = 0.19 (*P* = 0.21).

or to the time per session ($P \geq 0.61$). Training frequency, time per session, and exercise intensity taken together explained 4.9% of the variance of the response of systolic blood pressure ($P = 0.56$) and 1.1% for diastolic blood pressure ($P = 0.92$). The total duration of the training program was a significant determinant of the response of systolic ($r = 0.32$; $P < 0.05$), but not of diastolic pressure ($P = 0.37$), the blood pressure reduction becoming less pronounced with longer program duration.

Within-study analysis. We identified 14 studies in which sedentary normal subjects (4,6,11,18,23,25,26) or hypertensive patients (19,33,35,38,40,45,50) were randomly allocated to different training programs, either in a parallel group or in a crossover design. The characteristics of the participants and of the training programs are summarized in Tables 2 and 3. Three studies assessed the influence of differences in weekly frequency, with identical remaining training characteristics (18,23,40). Eleven studies applied different exercise intensities, without changes in the other characteristics (6,33,38,45), or with differences in frequency, time per session, or type of exercises (4,11,19,25,26,35,50). Training frequency and/or time per session were usually lower in the higher intensity regimens. The results on blood pressure and on physical work capacity are given in Tables 4 and 5. Figures 3 and 4 illustrate the blood pressure changes in the studies that compared the effects of different exercise intensities regardless of differences in the other training characteristics.

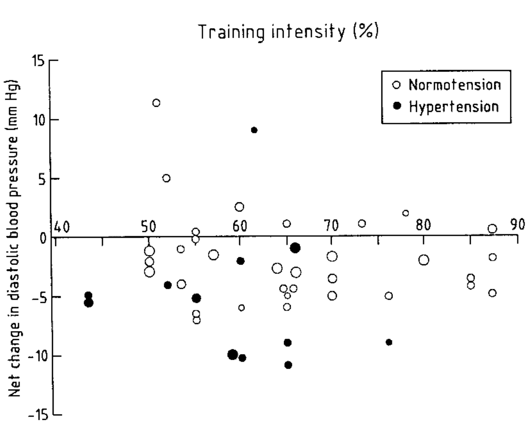

FIGURE 2—Changes in diastolic blood pressure with training, adjusted for control data, versus training intensity, in normotensive (*open circles*) and hypertensive (*closed circles*) study groups. Training intensity is expressed as percent of maximal work load, heart rate reserve, or oxygen uptake reserve. The four sizes of the circles represent the number of analyzable trained subjects in each group, i.e., < 10, 10–19, 20–29, and ≥ 30, respectively. The weighted metaregression coefficient r = 0.01 (*P* = 0.93).

Gettman et al. (18) examined the response of young normotensive men to running programs of 1-d, 3-d, and 5-d·wk^{-1} frequencies, 30 min per session, at 85–90% of heart rate reserve. Results indicated no significant blood pressure changes in any of the three groups in comparison with a recreational activity control group. Jennings et al. (23) found that training three times 30 min·wk^{-1} at 60–70% of maximal work load reduced supine blood pressure by 10/7 mm Hg, which was close to the response obtained with seven sessions per week (−12/−7 mm Hg). Nelson et al. (40) compared the results of three and seven exercise sessions per week in hypertensive patients. Training at the lower frequency reduced supine and standing blood pressure by 11/9 mm Hg and 12/11 mm Hg, respectively. The reductions were slightly but significantly ($P < 0.05$) more pronounced when subjects exercised seven times per week.

Duncan et al. (11) assessed the effects of aerobic walking (8 km·h^{-1}), brisk walking (6.4 km·h^{-1}), and strolling (4.8 km·h^{-1}) in sedentary premenopausal women. The participants walked 4.8 km·d^{-1} on a 1.6-km track, 5 d·wk^{-1}, during 24 wk. There were no significant changes in resting seated blood pressure in any of the walking groups. King et al. (25) recruited healthy, sedentary older men and women to determine the effectiveness of group- versus home-based exercise training of lower and higher intensities. Again, there were no significant training-induced changes in blood pressure within or between groups. Kingwell and Jennings (26) compared three levels of exercise intensity, that is, 50%, 60–70%, and 80–90% of maximal work load in normal men and women during a 4-wk program, but it should be noted that all other training characteristics differed among the groups. The authors concluded that the greatest blood pressure reduction was obtained with hard exercise; moderate exercise produced smaller reductions and short bursts of very hard exercise produced no changes at all. Braith et al. (4) studied healthy normotensive subjects 60–79 yr of age. Training at 70% of heart rate reserve and at 80–85% of heart rate reserve led to quite similar net reductions in blood pressure of approximately 8 mm Hg. Cox et al. (6) recruited healthy sedentary nonsmoking women aged 40–65 yr. Participants were randomly assigned to either a center-based or a home-based exercise program for an initial 6 months, whereafter both groups exercised at home for the next 6 months. Within each arm, subjects were further randomized to exercise at moderate intensity or at vigorous or hard

TABLE 2. Characteristics of the subjects and of the training programs in studies that randomized normotensive participants to different training regimens.

				Training Programs					
							Intensity (%)		
Study	Mean Age (range)	Gender	Design	Dur (wk)	Freq (per wk)	Time (min) (wu/ex/cd)	Reported	Adjusted	Methods
Different weekly frequency									
Gettman et al., 1996 (18)	24	M	PG	1. 20	1	30	85–90 (HRr)	—	W, R
	(20–35)			2. 20	3	30	85–90	—	W, R
				3. 20	5	30	85–90	—	W, R
				c. Nonendurance recreational activity group					
Jennings et al., 1986 (23)	22	M + F	CO	1. 4	3	5/30/5	60–70(WLm)	—	C
	(19–27)			2. 4	7	5/30/5	60–70	—	C
				c. Nonexercise control phase					
Different intensity with/without differences in time/frequency/methods									
Duncan et al., 1991 (11)	20–40	F	PG	1. 24	5	60	56 (HRm)	~30 (HRr)	Track-W
				2. 24	5	45	67	~47	Track-W
				3. 24	5	36	86	~78	Track-W
				c. Nonexercise control group					
King et al., 1991 (25)	50–65	M + F	PG	1. 52	5	30	60–73 (HRm)	~41 (HRr)	W, J, C (home)
				2. 52	3	40	73–88	~66	W, J, C (home)
				3. 52	3	40	73–88	~66	W, Tr-W, J, C (center)
				c. Nonexercise control group					
Kingwell and Jennings, 1993 (26)	37	M + F	CO	1. 4	5	60	50 (WLm)	—	W
	(22–59)			2. 4	3	30	65–70	—	C
				3. 4	5	15	80–90	—	C
				c. Nonexercise control phase					
Braith et al., 1994 (4)	66	M + F	PG	1. 26	3	45	70 (HRr)	—	W
	(60–79)			2. 26	3	35	80–85	—	Tr-W
				c. Nonexercise control group					
Cox et al. (6)	48	F	PG	1. 52	3	30	40–55 (HRr)	—	W + others
	(40–65)			2. 52	3	30	65–80	—	W + others

M, male; F, female; PG, parallel group; CO, crossover; Dur, duration; Freq, frequency; wu, warm-up; ex, exercise; cd, cool-down; HRr, heart rate reserve; WLm, maximal work load; HRm, maximal heart rate; W, walking; J, jogging; R, running; C, cycling; Tr, treadmill.

intensity, i.e., 40–55% or 65–80% of heart rate reserve, respectively. At 6 months, there was a significant fall in systolic, but not in diastolic blood pressure, with moderate-intensity, but not with vigorous-intensity exercise; the age- and weight-adjusted change in systolic blood pressure was estimated at 2.7 mm Hg ($P < 0.05$). This effect was no longer significant at 12 months. It is noteworthy that continuing participation in any regular exercise was a consistent predictor of the change in systolic blood pressure in this study.

TABLE 3. Characteristics of the subjects and of the training programs in studies that randomized hypertensive participants to different training regimens.

				Training Programs					
							Intensity (%)		
Study	Mean Age (range)	Gender	Design	Dur (wk)	Freq (per wk)	Time (min) (wu/ex/cd)	Reported	Adjusted	Methods
Different weekly frequency									
Nelson et al., 1986 (40)	44	M + F	CO	1. 4	3	5/35/5	60–70 (WLm)	—	C
	(25–62)			2. 4	7	5/35/5	60–70	—	C
				c. Nonexercise control phase					
Different intensity with/without differences in time/frequency/methods									
Hagberg et al., 1989 (19)	64	M + F	PG	1. 37	3	60	50 ($\dot{V}O_{2max}$)	~41 ($\dot{V}O_{2r}$)	W (home)
	(SD = 3)			2. 37	3	45–60	70–85	~73	W, Tr-W, J, C(sup)
				c. Nonexercise control group					
Matsusaki et al., 1992 (35)	47	M + F	PG	1. 10	3	5–10/60/5	50 ($\dot{V}O_{2max}$)	~40 ($\dot{V}O_{2r}$)	C
	(40–64)			2. 10	3	5–10/30–40/5	75	~65	C
Tashiro et al., 1993 (50)	46	M + F	CO + PG	1. 10	3	5–10/60/5	50 ($\dot{V}O_{2max}$)	~40 ($\dot{V}O_{2r}$)	C
	(33–57)			2. 10	3	5–10/30–40/5	75	~65	C
Marceau et al., 1993 (33)	43	M + F	CO	1. 10	3	5/45/10	50 ($\dot{V}O_{2max}$)	~44 ($\dot{V}O_{2r}$)	C
	(35–54)			2. 10	3	5/45/10	70	~67	C
				c. Nonexercise control phase					
Rogers et al., 1996 (45)	41	?	PG	1. 12	3	45	40–50 ($\dot{V}O_{2max}$)	~37 ($\dot{V}O_{2r}$)	Tr-W
	(SD = ~8)			2. 12	3	45	70–80	~71	Tr-W
				c. Nonexercise control group					
Moreira et al., 1999 (38)	50	M + F	PG	1. 10	3	5/30/5	20 (WLm)	~39 (HRr)[a]	C
	(SD = ~9)			2. 10	3	5/30/5	60	~70	C

M, male; F, female; PG, parallel group; CO, crossover; Dur, duration; Freq, frequency; wu, warm-up; ex, exercise; cd, cool-down; HRr, heart rate reserve; WLm, maximal work load; W, walking; J, jogging; C, cycling; Tr, treadmill; sup, supervised; $\dot{V}O_{2max}$, maximal oxygen uptake; $\dot{V}O_{2r}$, oxygen uptake reserve.
[a] Calculated from reported training heart rate.

TABLE 4. Results on blood pressure and physical work capacity in studies that randomized normotensive participants to different training regimens.

	Number		Systolic BP (mm Hg)			Diastolic BP (mm Hg)		
Study	Ne	Na		SED	Δ TR	SED	Δ TR	Δ PWC (%)
Gettman et al., 1976 (18)	24	11	CBP	1. 120	–3	77	–1	+11 ($\dot{V}O_{2max}$)
	26	20		2. 114	+3	76	+4	+13
	30	13		3. 120	0	73	+2	+17
	20	11		c. 118	–3	73	+4	–3
Jennings et al., 1986 (23)	12	12	SUP	1. 132	–10	69	–7	+11 ($\dot{V}O_{2max}$)
				2.	–12		–7	+24
			SIT	1. 111	–8	77	–5	+11
				2.	–10		–6	+24
Duncan et al., 1991 (11)	26	18	CBP	1. 108	–3	73	0	+4.4 ($\dot{V}O_{2max}$)
	26	12		2. 109	+1	74	–1	+9.3
	29	13		3. 105	0	70	0	+16
	21	10		c. 108	+2	74	+1	–5.8
King et al., 1991 (25)	197	45	CBP M	1. 115	–1	74	–2	+4.5 ($\dot{V}O_{2max}$)
	—	42		2. 117	–3	75	–2	+4.0
	—	40		3. 118	–3	75	–1	–5.9
	—	41		c. 119	–1	76	–2	–1.0
	160	29	F	1. 117	–6	73	–3	+4.0 ($\dot{V}O_{2max}$)
	—	35		2. 116	–3	73	–2	+6.1
	—	34		3. 119	–5	75	–2	+2.5
	—	34		c. 117	–3	72	–2	–3.8
Kingwell and Jennings, 1993 (26)	14	12	SUP	1. 123	–3	76	–2	+3 ($\dot{V}O_{2max}$)[a]
				2.	–5		–3	+3
				3.	0		–1	0
			ST	1. 120	–2	84	–1	+3
				2.	–4		–5	+3
				3.	–1		–2	0
Braith et al., 1994 (4)	19	19	CBP	1. 121	–9	72	–8	+17 ($\dot{V}O_{2max}$)
	14	14		2. 120	–8	75	–7	+25
	11	11		c. 121	+2	74	–1	0
Cox et al., 1996 (6)	126	53	CBP 6 mo	1. 111	–1.7	65	? (NS)	NS ($\dot{V}O_{2max}$)
	—	49		2.	+0.5		? (NS)	+6.9%
			12 mo	1. 111	+0.7	65	? (NS)	NS
				2.	+0.7		? (NS)	NS

Ne, number entered; Na, number analysed; M, male; F, female; CBP, conventional blood pressure; SUP, supine; SIT, sitting; ST, standing; BP, blood pressure; SED, sedentary; TR, training; NS, not significant; PWC, physical work capacity; $\dot{V}O_{2max}$, maximal oxygen uptake.
[a] Versus nonexercise sedentary control phase, when $\dot{V}O_{2max}$ was 17% above baseline values.

Hagberg et al. (19) were the first to compare the blood pressure response to moderate- and hard-intensity exercise training, i.e., training at 50% and 77% of maximal oxygen uptake, respectively, in older hypertensives. It should be noted that the moderate-intensity program consisted of walking at home, whereas the other group performed a variety of supervised exercises. The authors reported that the blood pressure reduction was more pronounced after moderate-intensity training, but this was not the case for the blood pressure measured during the hemodynamic assessment testing session. Moreover, blood pressure during fixed submaximal exercise was reduced after training in the hard-intensity group but not in the moderate-intensity group. Matsusaki et al. (35) and Tashiro et al. (50) compared exercise at two workloads in patients with mild hypertension. The lower workload corresponded to the workload at the first lactate breaking point, i.e., approximately 50% of maximal oxygen uptake, and the subjects in the higher workload group exercised at the load corresponding to 4 $mmol \cdot L^{-1}$ of blood lactate, which was approximately 75% of maximal oxygen uptake. Whereas Matsusaki et al. (35) found that the reduction in systolic but not diastolic blood pressure was greater at lower intensity exercise, Tashiro et al. (50) observed a slightly better response of diastolic but not of systolic pressure in the higher work-load group. Marceau et al. (33) evaluated previously sedentary subjects with mild to moderate hypertension in a crossover fashion after a sedentary control period and after training at moderate and hard intensity corresponding to 50% and 70% of maximal oxygen uptake, respectively. Blood pressures measured at supine rest and during submaximal exercise were not significantly influenced by training, whereas both training intensities reduced average 24-h blood pressure by about 5 mm Hg; however, the lower intensity training reduced daytime blood pressure and the higher intensity training only nighttime pressure. Rogers et al. (45) compared the effects of training at about 45% and at about 75% of maximal oxygen uptake in patients with borderline hypertension and found that the lower intensity exercise was more effective than the higher intensity exercise in reducing resting blood pressure and, in addition, the blood pressure responses to stress. Finally, Moreira et al. (38) randomized hypertensive patients to two different levels of aerobic physical training, i.e., 20% or 60% of their maximal work load on a cycle ergometer. However, from the reported heart rate during exercise training, it can be calculated that training intensity corresponded to approximately 39% and 70% of heart rate reserve, respectively. The results on conventional blood pressure and on 24-h ambulatory blood pressure were slightly more pronounced in the higher intensity group, but the differences were not significant.

Evidence statement. There is no convincing evidence that the blood pressure response to dynamic aerobic training differs according to training intensity when between 40%

TABLE 5. Results on blood pressure and physical work capacity in studies that randomized hypertensive participants to different training regimens.

Study	Number		Systolic BP (mm Hg)			Diastolic BP (mm Hg)		
	Ne	Na		SED	Δ TR	SED	Δ TR	Δ PWC (%)
Nelson et al., 1986 (40)	17	13	SUP	1. 143	−11	96	−9	+17 ($\dot{V}O_{2max}$)
				2.	−16		−11	+19
			ST	1. 147	−12	101	−11	+17
				2.	−14		−13	+19
Hagberg et al., 1989 (19)	14	11	CBP	1. 164	−22	94	−12	+10 ($\dot{V}O_{2max}$)
	10?	10?		2. 157	−10	99	−11	+28
	9?	9?		c. 154	−2	90	−2	+5
			HEM	1. 158	−7	90	−3	+10
				2. 160	−6	100	−9	+28
				c. 152	−1	90	−1	+5
Matsusaki et al., 1992 (35)	16	16	CBP	1. 152	−9	96	−6	+29 (WLlt)
	14	10		2. 153	−3	99	−5	+56
Tashiro et al., 1993 (50)	10	8	CBP	1. 154	−6	93	−4	+35 (WLlt)
				2. 149	−7	96	−9	+24
Marceau et al., 1993 (33)	11	9	CBP	1. 130	+2	87	+3	+2.9 ($\dot{V}O_{2max}$)
				2.	−2		0	+14
			24-h	1. 145	−4	91	−3	+2.9
				2.	−3		−3	+14
Rogers et al., 1996 (45)	8	6	CBP	1. 140	−15	93	−6	+3.7 ($\dot{V}O_{2max}$)
	9	7		2. 138	−4	91	−1	+28
	6	5		c. 140	−1	93	−3	−1.1
Moreira et al., 1999 (38)	14	14	CBP	1. 156	−9	98	−7	(Δ WLm
	14	14		2. 153	−15	97	−8	similar in two
			24-h	1. 137	−2	92	−3	groups)
				2. 144	−6	93	−3	

Ne, number entered; Na, number analyzed; CBP, conventional blood pressure; HEM, hemodynamic measurements; SUP, supine; SIT, sitting; ST, standing; BP, blood pressure; SED, sedentary; TR, training; PWC, physical work capacity; $\dot{V}O_{2max}$, maximal oxygen uptake; WLm, maximal work load; WLlt, work load at lactate threshold.

and 70% of net maximal exercise performance (moderate to hard intensity). There are insufficient data on the effects of light and very hard exercise. Evidence Category A.

Evidence statement. The blood pressure response to dynamic aerobic training appears to be similar for frequencies between three and five sessions per week and for session times between 30 and 60 min. There are few data on other exercise regimens except that seven sessions per week may elicit a slightly greater blood pressure response than three sessions per week. Evidence Category B.

Influence of Volume of Physical Activity

Net energy expenditure (kilocalories per week) resulting from the training programs was calculated according to the following formula: (baseline peak $\dot{V}O_2$ ($mL \cdot min^{-1} \cdot kg^{-1}$) − 3.5) × 0.005 ($kcal \cdot mL^{-1}$ $\dot{V}O_2$) × body mass (kg) × net training intensity (%) × training frequency ($n \cdot wk^{-1}$) × time per session (min).

Data were available in 57 of the 68 study groups, 30 from single program randomized controlled studies and 27 from studies in which subjects were randomized to different training regimens and that included a control group or period. Net extra energy expenditure ranged from 363 to 1866 $kcal \cdot wk^{-1}$ (median, 850 $kcal \cdot wk^{-1}$). Overall, there were no significant relationships between the net changes of systolic blood pressure ($y = -5.66 + 0.0021 * x$; $r = 0.14$; $P = 0.20$) and of diastolic blood pressure ($y = -2.34 - 0.0002 * x$; $r = -0.02$; $P = 0.86$) with the net weekly energy expenditure.

DISCUSSION

There is good evidence from randomized controlled trials that dynamic physical training reduces blood pressure (13,16,20). In our recent meta-analysis of such trials of at least 4-wk duration (13), we concluded that the blood pressure lowering effect is small but significant in normotensive subjects, averaging approximately 3/2 mm Hg after adjustment for control data, and that the net effect is more pronounced in hypertensives who benefit from an average blood pressure reduction of 7/6 mm Hg. Net training intensity was reported or could be calculated in most of these studies and averaged approximately 65% of maximal work load, heart rate reserve, or oxygen uptake reserve. Our cross-sectional analysis of studies in which only one training intensity was applied in one or more training groups or phases revealed that divergent blood pressure responses between study groups could not be explained by training intensity, which ranged from 43–87% (Figs. 1 and 2). Also, other characteristics of the training regimens, i.e., weekly frequency and time per session, were not related to the blood pressure response; it should be noted, however, that the training programs were designed to elicit an increase in exercise performance and that the ranges of these training characteristics were small. When frequency, time per session, and exercise intensity were combined in multivariable regression analysis, they explained less than 5% of the variance of the blood pressure response. The slightly lesser reduction of systolic pressure with longer duration of training, which could last up to 1 yr, may be explained by decreased adherence as shown by Cox et al. (6).

Several authors addressed the dose-response question by randomizing participants to training programs involving different training frequencies. Whereas Gettman et al. (18) found no differences in blood pressure response between training one, three, and five times per week, Jennings et al. (23) and Nelson et al. (40) observed slightly greater blood pressure falls at a frequency of seven times per week than at

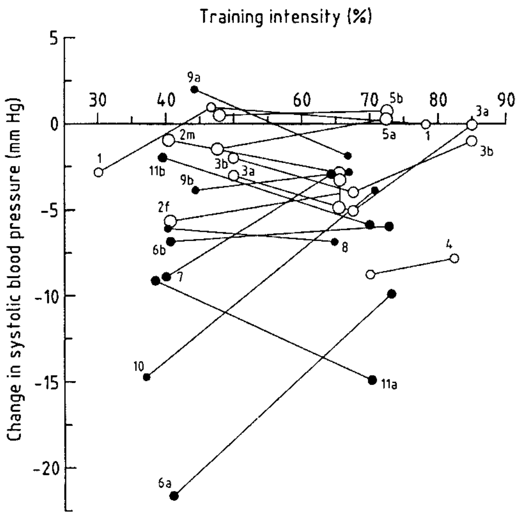

FIGURE 3—Changes in systolic blood pressure with training versus exercise intensity in studies in which two or more intensities have been compared, either in normotensive (*open circles*) or in hypertensive subjects (*closed circles*). The sizes of the circles correspond to the number of analyzable subjects. Training intensity is expressed as percent of maximal work load, heart rate reserve, or oxygen uptake reserve. The numbers in the figure correspond to the following references: 1, Duncan et al. (11); 2, King et al. (25) (m = male; f = female); 3, Kingwell and Jennings (26) (a, supine BP; b, standing BP); 4, Braith et al. (4); 5, Cox et al. (6) (a, 6 months; b, 12 months); 6, Hagberg et al. (19) (a, conventional BP; b, BP during hemodynamic study); 7, Matsusaki et al. (35); 8, Tashiro et al. (50); 9, Marceau et al. (33) (a, conventional BP; b, average 24-h BP); 10, Rogers et al. (45); and 11, Moreira et al. (38) (a, conventional BP; b, average 24-h BP).

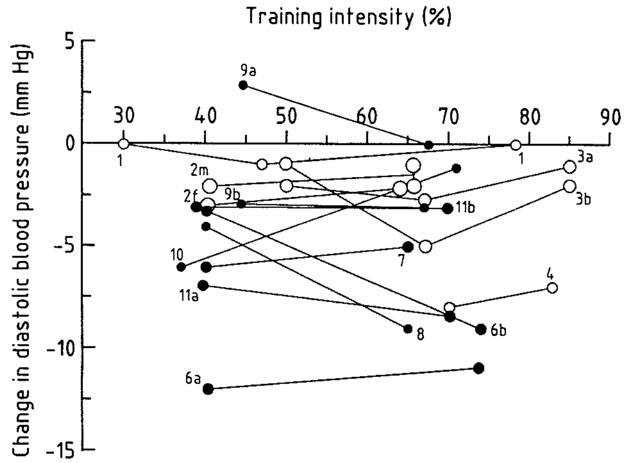

FIGURE 4—Changes in diastolic blood pressure with training versus exercise intensity in studies in which two or more intensities have been compared, either in normotensive (*open circles*) or in hypertensive subjects (*closed circles*). The sizes of the circles correspond to the number of analyzable subjects. Training intensity is expressed as percent of maximal work load, heart rate reserve, or oxygen uptake reserve. The numbers in the figure correspond to the following references: 1, Duncan et al. (11); 2, King et al. (25) (m = male; f = female); 3, Kingwell and Jennings (26) (a, supine BP; b, standing BP); 4, Braith et al. (4); 5, Cox et al. (6) (a, 6 months; b, 12 months); 6, Hagberg et al. (19) (a, conventional BP; b, BP during hemodynamic study); 7, Matsusaki et al. (35); 8, Tashiro et al. (50); 9, Marceau et al. (33) (a, conventional BP; b, average 24-h BP); 10, Rogers et al. (45); and 11, Moreira et al. (38) (a, conventional BP; b, average 24-h BP).

three times per week. Others compared different training intensities. Changes in blood pressure were small to nonexistent in normotensive subjects and there was no consistent evidence that a net intensity of around 70% would lead to different results in comparison with an intensity of 30–50% (6,11,25,26). Kingwell and Jennings (26) suggested that training at 80–90% of maximal work load was less effective than training at 65–70%, but Braith et al. (4) observed similar net blood pressure reduction of about 8 mm Hg when training at 70% and at 80–85% of heart rate reserve. The results were more variable in hypertensives. Three studies (19,35,45) found a lesser reduction of systolic blood pressure after training at exercise intensities between 65% and 75% of oxygen uptake reserve than at about 40%. These results were not observed for diastolic blood pressure, except in one study (45). It should furthermore be noted that in one study (19) the higher training intensity led to similar or even greater reductions in systolic pressure than did the lighter exercise when pressure was measured in other circumstances, that is, during the hemodynamic measurements and on exercise testing, respectively. The results of Matsusaki et al. (35) were not confirmed in another study of the same group, in which the same training regimen was applied (50). Marceau et al. (33) found no significant effects of moderate and hard exercise on supine, sitting, and exercise blood pressure, but 24-h ambulatory blood pressure was equally reduced by about 5 mm Hg. The unexpected finding that moderate exercise reduced daytime blood pressure and hard exercise nighttime pressure needs confirmation. Only Moreira et al. (38) attempted to compare moderate to hard exercise (60% of maximal work load) with light exercise (20% of maximal work load). However, recalculation of exercise intensities from the reported heart rates indicates that participants have been training at about 70% and 40% of heart rate reserve, respectively. The response of particularly systolic blood pressure tended to be greater with hard exercise, but the between-group differences were not significant. In agreement with previous data (52), the ambulatory blood pressure response was confined to daytime pressure. It should also be considered that the training programs of several of these studies did not only differ in intensity, as shown in Tables 2 and 3. The duration of the training sessions was often shorter in the high-intensity programs. The lighter exercise programs could be home-based and unsupervised, whereas the higher intensity exercises were usually supervised and performed in a specialized center. Finally, the type of exercises could differ among the groups.

The question was addressed whether the blood pressure response was related to the volume of physical activity or the net extra weekly energy expenditure associated with the various training programs. We have not found such relationships in the 57 training groups or programs in which energy expenditure could be calculated from the available data. Such a far-reaching analysis should, however, be interpreted with great caution.

Two further studies may be of interest. Dunn et al. (12) compared a lifestyle physical activity counseling intervention with a traditional gymnasium-based structured exercise intervention at 50–85% of maximal aerobic power in healthy sedentary, middle-aged men and women. Changes in blood pressure were similar after 6 months. However, training intensity was not reported in the lifestyle group, and it cannot be excluded that the results were influenced by the application of cognitive and behavioral strategies. Young et al. (57) randomized sedentary older adults to a 12-wk moderate-intensity aerobic exercise program at 40–60% of heart rate reserve and a T'ai Chi program of light activity. Both programs led to small and similar reductions in blood pressure compared with preexercise control data. Absence of control groups, however, precludes judgment of the net effect on blood pressure of these programs.

In conclusion, training from three to five times per week during 30–60 min per session reduces blood pressure, particularly in hypertensives. There is some evidence that exercising seven times per week would be slightly more effective than three sessions per week. Training at about 40–50% of net maximal exercise performance (moderate exercise) does not appear to be less effective than training at about 70% (hard exercise) with regard to blood pressure reduction. The suggestion that hard-intensity training would be less effective than training at lower intensity cannot be definitely accepted. Insufficient data are available on exercise intensities of less than about 40%, that is, light and very light exercise, and of more than 84%, or very hard exercise.

Research Priorities

We have previously pointed out that several important scientific criteria have not always been observed in studies that assessed the influence of physical training on blood pressure, such as regular follow-up of control subjects, attention to other lifestyle factors, adequacy of the statistical analyses, and blinded or automated blood pressure measurements. Furthermore, the mechanisms of the training-induced blood pressure changes remain largely unknown (13). Such remarks also apply to studies in which different training regimens have been compared. Furthermore, uncertainty remains whether hard- and particularly very hard-intensity training would be less effective than moderate-intensity training with regard to blood pressure control. However, this question may be of scientific interest but has little practical value for the exercise physiologist or the clinician because he or she will be happy to prescribe moderate rather than hard exercise, particularly in the hypertensive patient. There is a lack of controlled data on the blood pressure response to exercise intensities below approximately 40% of net maximal exercise performance. Finally, when one aims to investigate the effect of variations in a particular exercise characteristic on the blood pressure response, care should be taken to keep the remaining characteristics of the training program as constant as possible.

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