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Effects of hydraulic circuit training on cardiovascular function

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ABSTRACT

HAENNEL, R., K.-K. TEO, A. QUINNEY, and T. KAPPAGODA. Effects of hydraulic circuit training on cardiovascular function. *Med. Sci. Sports Exerc.*, Vol. 21, No. 5, pp. 605–612, 1989. The effect of hydraulic circuit training (HCT) on cardiovascular (CV) function was assessed in 32 healthy middle-aged males ($\overline{X}$ age = 42.2 ± 2.1 yr). Maximal aerobic power ($\dot{V}O_{2max}$), with simultaneous measurement of stroke volume (SV) and cardiac output (CO), by impedance cardiography, was assessed pre- and post-training. Subjects were randomly assigned to a nonexercising control group, a cycle training group (cycle), or one of the two HCT groups. Training groups participated in a 9 wk program, 3 $d \cdot wk^{-1}$. Subjects assigned to HCT exercised on a 9 station circuit, completing 3 $circuits \cdot d^{-1}$. Each circuit consisted of three 20 s work intervals at each station with a 1:1 work:rest ratio. One HCT group (HCT_{max}) completed the maximal repetitions possible (RM) during each work interval. The other HCT group (HCT_{sub}) exercised at 70–85% of RM. Following training $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} min^{-1}$) was significantly increased in all training groups (18.0, 12.5, and 11.3% for cycle, HCT_{sub}, and HCT_{max} groups, respectively; $P < 0.05$). The increase in $\dot{V}O_{2max}$ observed in the cycle group was significantly greater than that recorded by the two HCT groups ($P < 0.05$). For all three training groups, the increase in $\dot{V}O_{2max}$ was associated with increases in SV_{max} and CO_{max} ($P < 0.05$ for both). These findings suggest that both maximal and submaximal HCT programs can elicit improvements in cardiovascular fitness.

PHYSICAL TRAINING, OXYGEN UPTAKE, WEIGHT TRAINING, HYDRAULIC CIRCUIT TRAINING, EXERTION, CARDIAC OUTPUT

Circuit weight training (CWT) is a form of strength training in which a series of exercises are performed using resistance equipment in a predetermined sequence. In most CWT programs, 8 to 12 different exercises are performed, usually at an intensity equivalent to 40–60% of the maximum force generated by the participating muscles (10). Short work bouts incorporating 10–20 repetitions of each exercise are alternated with periods of rest, during which time the individual moves from one station to another. Although there is little doubt that CWT improves muscular strength and endurance (2,9,20), its overall effect upon the cardiovascular system remains controversial. Several investigators (11,20) have reported small but significant improvements in maximal aerobic power, as assessed by treadmill tests and bicycle ergometry, after CWT. Others have failed to confirm such an effect (2,13). Further, it has been reported that the heart rate response to submaximal exercise on a bicycle ergometer (2) or a treadmill (13) is unchanged following CWT.

These differences in the effects of CWT on cardiovascular fitness could be attributed to the relative intensity of exercise used in the programs (10,20). For instance, the intensity of exercise may be inadequate to achieve certain hypothetical targets for heart rate and aerobic demand for enhancing maximal aerobic power (12,13) (see Discussion).

One possible method of circumventing this problem is to use devices that provide accommodating resistance from variable hydraulic cylinders in the circuit training program. It is suggested that such devices allow high intensity concentric exercise for both the agonist and antagonist muscle groups, thus creating both the metabolic and cardiovascular demands necessary for the enhancement of maximal aerobic power (15). The purpose of the present study is to determine whether the changes in maximal aerobic power, cardiac output, and stroke volume induced by hydraulic circuit training (HCT) were comparable to those induced by a conventional program of bicycle training.

METHODS

Subject selection. Thirty-two male volunteers participated in this study. The subjects were instructed as to the nature of the study, and written informed consent was obtained. Before training, a medical history, physical examination, resting ECG, and graded exercise test (GXT) on a bicycle ergometer were performed. None of the subjects had clinical evidence of heart disease. The subjects were assigned to one of the following groups (N = 8 in each): 1) a nonexercising group (control); 2) an HCT group, which completed the max-

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imum number of repetitions possible during each work interval (HCT$_{max}$); 3) an HCT group, which completed 70–85% of the maximum number of repetitions possible during each work interval (HCT$_{sub}$); and a group which participated in a dynamic exercise training program on bicycle ergometers (cycle).

Measurement of maximal aerobic power. Maximal aerobic power was assessed by measuring the oxygen uptake ($\dot{V}O_{2max}$) achieved during a GXT on a bicycle ergometer (model 740, Siemens Electric Ltd.). The initial workload was set at 20 W. At 3 min intervals it was increased successively to 30, 50, and 80 W, and in steps of 50 W thereafter. For both the pre- and post-assessments the exercise test continued until one of the following end points was attained: a plateau, or decrease in $\dot{V}O_2$ with increasing workloads; attainment of 95% age predicted maximal heart rate; or volitional exhaustion (defined as a Borg scale reading >18 or an inability to maintain the cycling velocity of 60 rpm). The $\dot{V}O_2$ was measured at each workload using a continuous flow technique (1). The peak $\dot{V}O_2$ value obtained during the exercise test was recorded as $\dot{V}O_{2max}$.

Measurement of cardiac output. Stroke volume (SV), cardiac output (CO), and heart rate (HR) were measured by impedance cardiography (Minnesota Impedance Cardiograph, model 304A, Surcom, Inc.). Use of this technique has been validated in this laboratory for endurance trained young male subjects and cardiac patients, both at rest and during exercise (19).

Recordings were made at rest and immediately (within 3 s) upon completion of each workload during the exercise test. During the measurements, subjects were required to hold their breath at normal end-expiration to avoid artifact due to respiratory movement. The average of five cardiac cycles was used in the calculation of SV.

Blood pressure was measured using a mercury sphygmomanometer during the second minute of each stage of the GXT. Mean arterial pressure (mm Hg) was calculated as the diastolic blood pressure ± 1/3 pulse pressure.

Training program. All subjects assigned to training exercises 27 $min \cdot d^{-1}$, three times a week for a 9 wk period. Each training session was preceded by a 5 min warm-up and followed by a 5 min cool-down period. The dynamic training group (cycle) exercised on bicycle ergometers for 27 min at a workload that corresponded to 70–85% of their heart rate reserve (14). The resting heart rate for this calculation was recorded following 15 min of quiet rest in the seated position before the pre-training GXT.

Subjects assigned to HCT exercised on nine discrete work stations of variable resistance hydraulic equipment (Hydra-Fitness Canada Ltd). The following movement patterns were used: knee extension and flexion; hip extension and flexion; elbow extension and flexion; shoulder extension and flexion: and planter flexion. A list of the various exercise stations incorporated into the circuit is presented in Table 1. Over the 2 wk immediately preceding training the subjects assigned to HCT were familiarized with the equipment and the training circuit. Stations were arranged so as to exercise the upper and lower body alternately whenever possible. The circuit consisted of three 20 s work intervals at each station with a 1:1 work:rest ratio. The first two work intervals were followed by 20 s rest intervals, and the third work interval was followed by an 80 s rest period to allow time for moving from one station to the next.

One HCT group (HCT$_{max}$) was asked to complete the *maximum* number of repetitions possible during each work interval. The initial cylinder settings for the three successive work intervals were 1, 3, and 2. However, throughout the training program, the valve settings were adjusted so that the subjects could not exceed a work rate greater than one repetition$\cdot s^{-1}$ (16).

The second HCT group (HCT$_{sub}$) had an initial as-

TABLE 1. Initial valve settings and repetitions achieved by the two HCT groups during maximal exercise on the hydraulic equipment.

	HCT$_{sub}$ Group	HCT$_{max}$ Group
Bilateral knee		
Setting	2.2 ± 0.2	2.3 ± 0.2 (2.8 ± 0.2)
Repetitions	16.9 ± 0.9 (13.9 ± 0.4)	17.0 ± 0.4 (16.6 ± 0.4)
Shoulder press		
Setting	1.7 ± 0.2	1.7 ± 0.2 (2.2 ± 0.3)
Repetitions	16.1 ± 0.7 (13.4 ± 0.3)	16.2 ± 0.3 (16.1 ± 0.3)
Leg press		
Setting	1.8 ± 0.2	1.9 ± 0.3 (2.5 ± 0.3)
Repetitions	17.4 ± 0.5 (14.9 ± 0.5)	17.6 ± 0.3 (15.4 ± 0.7)
Arm curls		
Setting	1.3 ± 0.1	1.6 ± 0.2 (1.8 ± 0.2)
Repetitions	16.8 ± 0.5 (13.8 ± 0.2)	15.8 ± 0.2 (14.6 ± 0.3)
Unilateral knee (R)		
Setting	3.6 ± 0.2	4.3 ± 0.2* (4.8 ± 0.2)
Repetitions	18.6 ± 0.6 (15.6 ± 0.6)	17.3 ± 0.3 (15.4 ± 0.3)
Unilateral knee (L)		
Setting	3.6 ± 0.2	4.3 ± 0.2* (4.9 ± 0.3)
Repetitions	18.7 ± 0.7 (15.2 ± 0.4)	17.5 ± 0.3 (15.1 ± 0.4)
Bench press		
Setting	1.4 ± 0.1	1.4 ± 0.3 (1.9 ± 0.4)
Repetitions	14.2 ± 0.6 (11.6 ± 0.3)	14.0 ± 0.5 (14.2 ± 0.5)
Runner		
Setting	1.3 ± 0.2	1.3 ± 0.2 (1.8 ± 0.3)
Repetitions	14.8 ± 0.6 (11.5 ± 0.3)	13.8 ± 0.3 (14.2 ± 0.4)
Chest press		
Setting	2.3 ± 0.2	2.4 ± 0.3 (2.7 ± 0.4)
Repetitions	17.9 ± 0.5 (14.8 ± 0.4)	16.8 ± 0.4 (16.1 ± 0.4)

Values reported represent the mean values achieved for a given exercise over the three work intervals. Values in parentheses represent the average valve settings and repetitions achieved in the first 3 wk of training.

* Significant difference between the two HCT groups ($P < 0.05$).

sessment similar to that undertaken by the HCT$_{max}$ group. The training intensity for the HCT$_{sub}$ group was set in a manner that permitted completion of 70–85% of the maximum repetitions possible for a particular valve setting. The number of repetitions completed during each work interval was controlled by having the subjects exercise to a set cadence. For the HCT$_{sub}$ group the maximum repetitions for each 20 s work interval was established before training and was reassessed at the end of the 3rd and 6th wk of the program. The adjusted programs were used for the subsequent weeks of training.

The average repetitions *completed* by both HCT groups during the initial 3 and final 3 wk of training are presented in Tables 1 and 2, respectively. Over the course of the study, the peak torque and work completed during one lower and one upper extremity exercise was measured using a Cybex II isokinetic system. This study was undertaken to monitor the changes in muscular strength resulting from the training programs. The improvements in peak torque and work in the HCT$_{max}$ and HCT$_{sub}$ groups were similar over the period of study. [These findings are available in a Ph.D. dissertation at the University of Alberta (R. H. Haennel).]

TABLE 2. Averaged repetitions and HR response achieved during the final 3 wk of the HCT program.

	HCT$_{sub}$ Group	HCT$_{max}$ Group
Bilateral knee		
Setting	3.2 ± 0.3	3.5 ± 0.2
Repetitions	15.8 ± 0.4	16.4 ± 0.6
Heart rate	130.1 ± 2.1	132.2 ± 4.1
Shoulder press		
Setting	2.9 ± 0.3	3.1 ± 0.3
Repetitions	14.6 ± 0.7	16.2 ± 0.5
Heart rate	131.7 ± 3.0	139.4 ± 2.9
Leg press		
Setting	2.9 ± 0.3	3.8 ± 0.3*
Repetitions	16.3 ± 0.3	17.4 ± 0.4
Heart rate	135.7 ± 1.4	145.9 ± 3.1*
Arm curls		
Setting	2.0 ± 0.2	2.6 ± 0.3
Repetitions	15.8 ± 0.4	16.9 ± 0.3
Heart rate	130.7 ± 4.2	142.4 ± 4.6*
Unilateral knee (R)		
Setting	4.7 ± 0.4	5.6 ± 0.1*
Repetitions	17.7 ± 0.3	17.5 ± 0.2
Heart rate	131.7 ± 2.4	139.8 ± 5.0*
Unilateral knee (L)		
Setting	4.7 ± 0.5	5.7 ± 0.2*
Repetitions	17.7 ± 0.4	17.4 ± 0.3
Heart rate	132.6 ± 2.4	139.4 ± 4.7
Bench press		
Setting	2.4 ± 0.2	2.9 ± 0.3
Repetitions	12.4 ± 0.5	14.0 ± 0.5
Heart rate	132.7 ± 3.4	136.6 ± 6.1
Runner		
Setting	2.3 ± 0.2	3.1 ± 0.3*
Repetitions	14.3 ± 0.4	15.1 ± 0.5
Heart rate	135.8 ± 2.2	146.6 ± 4.2*
Chest press		
Setting	3.4 ± 0.4	4.0 ± 0.3
Repetitions	15.8 ± 0.4	16.8 ± 0.4
Heart rate	137.6 ± 2.2	147.7 ± 4.9*

Values reported represent the mean values achieved for a given exercise over the three work intervals.

* Significant difference ($P < 0.05$) between the HCT$_{sub}$ and HCT$_{max}$ groups.

Acute response to training sessions. The HR and blood pressure was monitored daily, before exercise and in response to the various training regimes. The HR was monitored with Sport Testers (models pe 2000, and pe 3000; Polar/electro Ltd.). The blood pressure response to training was assessed using an electronic sphygmomanometer (Infrasonde, model D4000, Puritan-Bennett Canada Ltd). For the cycle training group HR and blood pressure were measured during *steady* state exercise. For the HCT groups, the HR response was recorded at the end of each work and rest interval. It is emphasised that for the HCT training groups, the heart rates were not measured during a steady state session. The blood pressure response was assessed during completion of the bilateral knee extension/flexion exercise. The rate pressure product was calculated using both the HR and blood pressure responses to the bilateral knee extension/flexion exercise.

Statistical analysis. Group data presented are expressed as means ± SEM. A comparison of pre-training measurements was made using a two-way analysis of variance to assess discrepancies between groups (18). The effects of training in each group were assessed by a two-way analysis of variance of the post-training data. The magnitude of the changes produced by training in the four groups was compared by an analysis of variance on the difference (pre- and post-training). A probability level of $P < 0.05$ was accepted as the minimum value for statistical significance between groups. For a given variable, if a significant F value was obtained, a test of least significant difference was performed to assess the significance of the specific differences among the mean values.

In circumstances in which there were differences in the base-line data related to certain discrete variables (e.g., heart rate), an additional analysis of covariance was performed to confirm the existence of a training effect.

RESULTS

The study was completed on 32 middle-aged males. Mean values for their physical characteristics were: age 42.2 ± 2.1 yr; height 178.6 ± 2.4 cm; and weight 83.2 ± 4.2 kg. The $\dot{V}O_{2max}$ for the entire sample, assessed by bicycle ergometry, was 32.4 ± 1.6 $ml \cdot kg^{-1} \cdot min^{-1}$. There were no significant differences among the four groups for any of these variables. The cardiac output and $\dot{V}O_2$ values at rest were not significantly different in the four groups in the pre-training state. The average heart rate in the HCT$_{sub}$ group was significantly higher, with a corresponding "downward" adjustment in stroke volume (Table 3). Body weight did not change significantly over the course of the study.

Acute Cardiovascular Response during the Training Sessions

Mean HR responses during training sessions in the HCT$_{sub}$ and HCT$_{max}$ groups were significantly lower than those recorded in the cycle training group ($P < 0.05$). Diastolic blood pressure recorded during the training sessions was significantly higher in the HCT$_{max}$ than for either the cycle or HCT$_{sub}$ training groups ($P < 0.05$). Rate pressure product, calculated from the training HR and SBP data, was significantly lower for the HCT groups than in the cycle trained group ($P < 0.05$). These observations are summarized in Table 4.

Responses of the Cardiovascular System to Training

Rest. Following training, the resting HR was reduced significantly in the HCT$_{sub}$ group ($P < 0.05$). Both the cycling and HCT$_{sub}$ groups demonstrated significant increases in SV ($P < 0.05$). Mean arterial pressure was unchanged in the three training groups. These data are summarized in Table 3.

TABLE 3. The cardiovascular parameters at rest.

	Control	Cycle	HCT$_{sub}$	HCT$_{max}$
		Pre-Training		
VO$_2$	0.33 a ±0.02	0.30 a ±0.02	0.35 a ±0.02	0.34 a ±0.02
HR	76 ab ±4	70 a ±4	81 b ±5	72 ab ±2
SV	68 ab ±4	77 b ±5	64 a ±5	72 ab ±3
CO	5.1 a ±0.2	5.3 a ±0.2	5.1 a ±0.2	5.2 a ±0.3
MAP	91 a ±2	88 a ±1	85 a ±2	91 a ±3
		Post-Training		
$\dot{V}O_2$	0.33 a ±0.03	0.31 a ±0.02	0.33 a ±0.03	0.35 a ±0.03
HR	70 a ±2	64 a ±4	71 a* ±4	67 a ±4
SV	71 a ±4	91 b* ±6	75 a* ±4	77 a ±5
CO	5.0 a ±0.3	5.8 a ±0.5	5.3 a ±0.4	5.2 a ±0.3
MAP	84 a* ±3	88 a ±3	85 a ±2	88 a ±2

Values are expressed as means ± SEM. $\dot{V}O_2$ = oxygen uptake ($l \cdot min^{-1}$); HR = heart rate ($beats \cdot min^{-1}$); SV = stroke volume ($ml \cdot beat^{-1}$); CO = cardiac output ($l \cdot min^{-1}$); MAP = mean arterial pressure (mm Hg). Values with a similar suffix (a, b, or ab) are not significantly different ($P > 0.05$).

* Significant difference between pre- and post-training data ($P < 0.05$).

Submaximal exercise. Following training, there was a significant reduction in the HR responses to exercise in the cycling and HCT$_{sub}$ groups. Because there were small differences in the pre-training HRs at rest (Table 3), an analysis of covariance was used to compare the pre- and post-training regression lines related HR to load. In these two training groups, the elevations of the regression lines, as indicated by the adjusted means (18), were significantly reduced by training (cycle: $F = 21.1$, $P < 0.01$; HCT$_{sub}$: $F = 28.2$, $P < 0.01$). Corresponding differences were not observed in the control group and in the HCT$_{max}$ group (control: $F = 0.31$, $P > 0.05$; HCT$_{max}$: $F = 2.41$, $P > 0.05$) (Fig. 1).

For the cycling and HCT$_{sub}$ groups, the reduction in HR was associated with an increase in SV at corresponding values of HR. This effect was not evident in the control group or in the HCT$_{max}$ group (Fig. 2).

Maximal exercise. Following training, $\dot{V}O_{2max}$ (Table 5) was significantly increased in all training groups ($P < 0.05$). There was no significant change in the control group. The increment in maximal aerobic power observed in the cycle training group was significantly greater than that observed in both HCT groups ($P < 0.05$). Maximum HR was unchanged in all four groups, but there was a significant increase in maximum SV in the three training groups ($P < 0.05$). Thus, the maximal CO was increased significantly in all three training groups ($P < 0.05$). At maximal exercise there were no significant changes in mean arterial pressure (Table 5).

DISCUSSION

The present study was undertaken to determine the effect of HCT on the cardiovascular system of previously untrained middle-aged adult males and to compare these effects with those induced by a conventional program of cycle training. The main responses of the

TABLE 4. Overall mean HR, blood pressure, and rate pressure responses to the training programs averaged over the 9 wk.

		Cycle	HCT$_{sub}$	HCT$_{max}$
HR	pre-exercise	79 ± 3 a	78 ± 3 a	84 ± 2 a
	exercise	152 ± 4 d	134 ± 2 b	143 ± 3 c
% HR$_{max}$ reserve	exercise	80%	60%	75%
SBP	pre-exercise	123 ± 4 a	121 ± 2 a	128 ± 2 a
	exercise	150 ± 2 b	147 ± 3 b	149 ± 3 b
DBP	pre-exercise	83 ± 2 b	74 ± 3 a	81 ± 2 b
	exercise	78 ± 3 ab	81 ± 2 b	90 ± 2 c
RPP	pre-exercise	97 ± 4 a	94 ± 4 a	107 ± 4 a
	exercise	228 ± 10 c	197 ± 2 b	208 ± 3 b

Values are expressed as means ± SEM. Values with a similar suffix (a, b, c, d, or ab) are not significantly different ($P > 0.05$). HR = heart rate ($beats \cdot min^{-1}$); SBP = systolic blood pressure (mm Hg); DBP = diastolic blood pressure (mm Hg); RPP = rate pressure product ($HR \times SBP \times 10^{-2}$). For the HCT groups, RPP was calculated using the HR and SBP response to the bilateral knee exercise. % HR$_{max}$ reserve = $[(\text{exercise HR} - \text{rest HR})/(HR_{max} - \text{rest HR})] \times 100$.

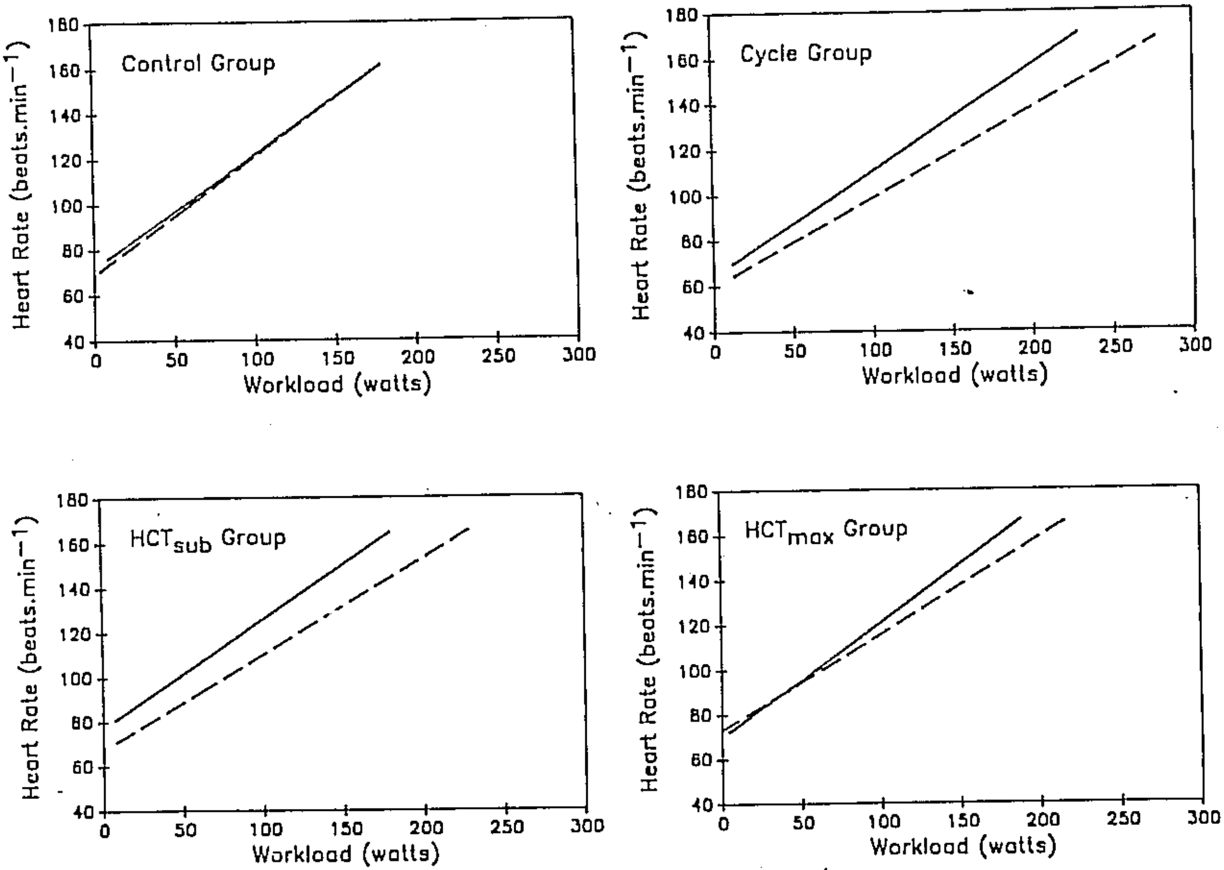

Figure 1—Regression lines relating HR (y) to workload (x) for the four groups before (——) and after (---) training. *Top left*, control group: (——) $y = 0.42(x) + 73.4$; (---) $y = 0.46(x) + 71.2$. *Top right*, cycle group: (——) $y = 0.43(x) + 73.4$; (---) $y = 0.40(x) + 64.2$. *Bottom left*, HCT_{sub} group: (——) $y = 0.44(x) + 80.5$; (---) $y = 0.42(x) + 71.2$. *Bottom right*, HCT_{max} group: (——) $y = 0.44(x) + 72.3$; (---) $y = 0.42(s) + 67.4$.

cardiovascular system to HCT included a significant increase in $\dot{V}O_{2max}$, maximal SV, and maximal CO.

Effects of Training on the Cardiovascular Responses to Submaximal Exercise

The cardiovascular adaptations to submaximal exercise were assessed at all workloads. Following training, HR was reduced at all submaximal workloads in both the HCT_{sub} and the cycling groups (Fig. 2). This response, a classical cardiovascular adaptation to exercise training, has been attributed to a combination of increased parasympathetic tone and diminished sympathetic activity (6,17).

The pre-training HR/SV profiles for the four groups were characterized by an increase in SV from the resting state through to a maximum value, which was achieved at a HR between 120–130 beats·min^{-1}. This peak SV was maintained through to maximal HRs and workloads. These observations are similar to previously published data for untrained middle-aged males (4). Following training, the HR/SV profiles of the HCT_{sub} and cycling groups were altered, such that for a given HR there was an increase in SV (Fig. 2). although this relative increase in SV is likely to be a consequence of an increase in ventricular volume, a change in myocardial contractility cannot be excluded (6). In the HCT_{max} group an increase in SV was evident only at high HRs (and workloads).

Effect of Training on the Cardiovascular Responses to Maximal Exercise

There is no general agreement on the effects of CWT on cardiovascular responses to maximal exercise. These differences, which are particularly evident in the changes in $\dot{V}O_{2max}$ (2,8,11,13,20), have been attributed either to differences in training protocols (10) or to characteristics of the population examined (20). In the present study $\dot{V}O_{2max}$ increased by 12.5 and 11.3% in the HCT_{sub} and HCT_{max} groups, respectively. The increase in $\dot{V}O_{2max}$ observed in the cycle training group (18.0%) was greater than that observed in both HCT groups ($P < 0.05$).

One explanation for this difference may relate to the "specificity principle," whereby the changes induced by physical training are specific to the muscles involved and to the pattern in which they are used during training (7). Thus, using a bicycle ergometer to compare the effects of cycle training with HCT would bias the results

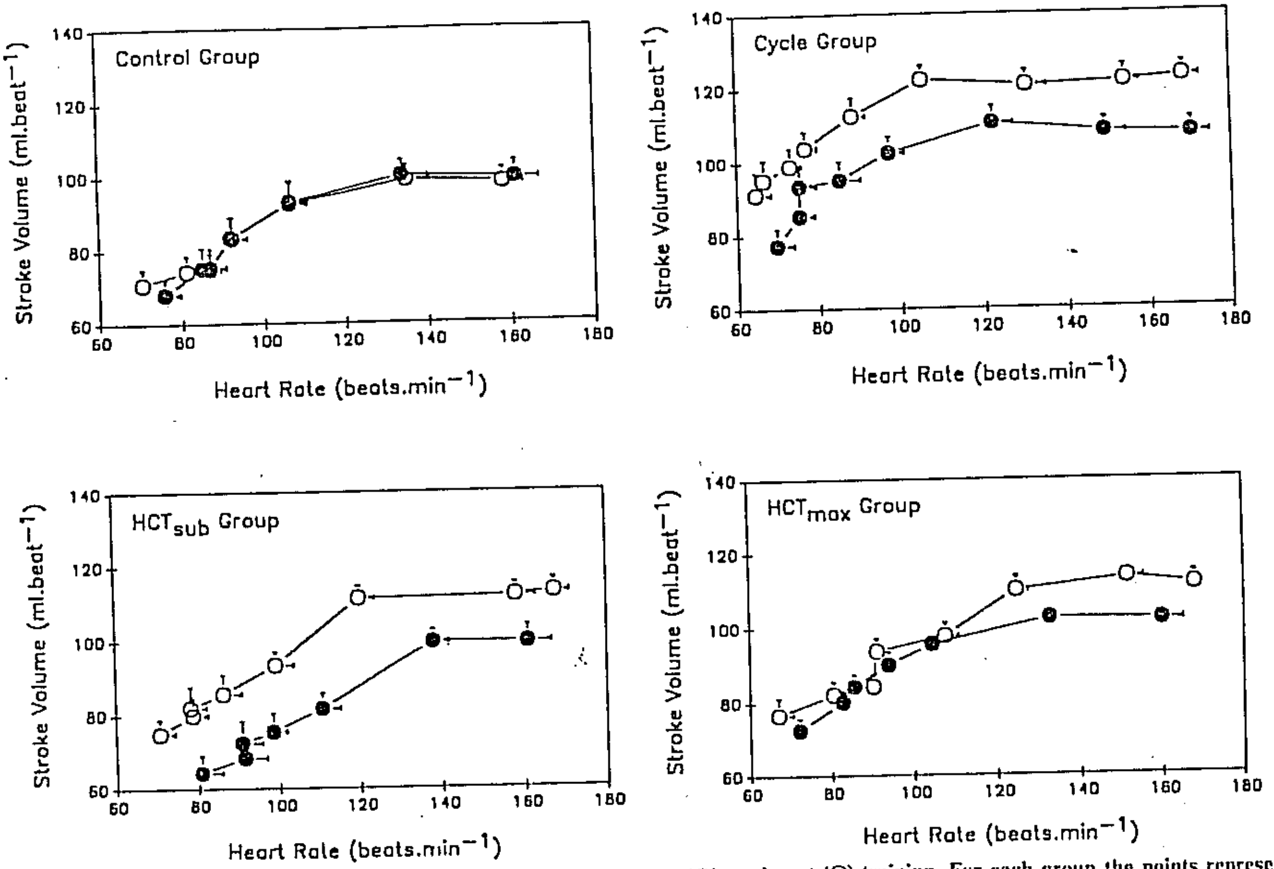

Figure 2—Mean heart rate/stroke volume profile of the four groups; pre (●)- and post (○)-training. For each group the points represent the coordinates of the mean heart rate/stroke volume responses to the particular workload during the GXT. The data presented are limited to those workloads which all the subjects in each group completed. The maximal SV is increased in all three exercising groups following training.

TABLE 5. Cardiovascular responses at maximal exercise on a bicycle ergometer.

	Control		Cycle		HCT_{sub}		HCT_{max}	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
$\dot{V}O_{2max}$ (a)	2.52 ab ±0.09	2.47 a ±0.10	2.82 de ±0.09	3.22 f ±0.10	2.68 cd ±0.13	2.91 e ±0.12	2.66 bc ±0.10	2.96 e ±0.15
$\dot{V}O_{2max}$ (b)	32.8 a ±1.9	31.8 a ±2.2	32.9 a ±2.9	38.8 c ±1.7	31.2 a ±1.9	35.1 b ±1.7	32.8 a ±1.8	36.5 b ±1.6
HR	167 a ±5	167 a ±4	172 a ±4	168 a ±4	171 a ±5	167 a ±4	167 a ±3	168 a ±2
SV	100 ab ±5	99 a ±4	109 bc ±4	123 d ±4	100 ab ±4	112 c ±4	102 ab ±3	111 c ±3
CO	16.6 a ±0.7	16.4 a ±0.7	18.6 b ±0.6	20.6 c ±0.5	17.1 a ±0.7	18.7 b ±0.7	17.1 a ±0.3	18.5 b ±0.4
MAP	115 abc ±2	109 a ±3	116 bcd ±3	112 abc ±2	112 abc ±3	110 ab ±2	121 d ±4	117 cd ±2
GXT terminated due to:								
Fatigue	1	2	2	2	1	1	1	—
$\dot{V}O_2$	4	3	4	4	4	5	4	4
HR_{max}	3	3	2	2	3	2	3	4

(ml·beat⁻¹); CO = cardiac output (l·min⁻¹); MAP = mean arterial pressure (mm Hg); RPP = rate pressure product (HR × SBP × 10^{-2}). Values with a similar suffix (a, b, c, d,

(ml·beat⁻¹); CO = cardiac output (l·min⁻¹); MAP = mean arterial pressure (mm Hg); RPP = rate pressure product (HR × SBP × 10^{-2}). Values with a similar suffix (a, b, c, d,

e, f, etc.) are not significantly different ($P > 0.05$).

favor of cycle training. However, the influence of the specificity principle was assessed by Gettman and Pollock (10), who used arm ergometry to estimate the effects of CWT and dynamic exercise training. The changes induced by the training programs were evident even in the nonspecific tests.

The aerobic demand imposed by the two modes of exercise may be an additional factor contributing to the differences in the magnitude of the increase in $\dot{V}O_{2max}$ in the cycle trained and HCT groups. At half of the stations in the HCT programs the muscle mass involved (arms) was smaller than that used in cycling. It has been shown that the oxygen cost of arm work is approximately 70% of leg work at comparable heart rates (7,20). Therefore, it is likely that the overall stimulus for aerobic improvement may have been less for HCT than for cycle training.

The similarity in the improvement in $\dot{V}O_{2max}$ for the two HCT groups merits scrutiny. There are two aspects of any training program that have a bearing upon the improvement in $\dot{V}O_{2max}$, i.e., the metabolic demand imposed by the training schedule and the heart rate response to the program. In the absence of a direct measurement of the oxygen cost of the HCT programs, an indirect assessment could be made using an index derived by multiplying the valve settings by the repetitions. On this basis one might infer from the data in Tables 1 and 2 that the HCT_{max} group had a greater metabolic demand than the HCT_{sub} group. However, the findings of Ballor et al. (5), who measured the metabolic demand associated with maximum hydraulic resistance exercise, suggest that such a simple index does not correlate with the oxygen cost of the activity. Although the study reported by Ballor et al. (5) was done on an apparatus not identical to the Hydra Gym used in the present study, both systems incorporated the same fundamental principles. Thus, it is suggested that, because the improvements in $\dot{V}O_{2max}$ observed in the two HCT groups were similar, the cummulative metabolic demand of the two programs was also similar. However, in the absence of direct measurements, this contention remains speculative.

With respect to HR, the threshold intensity necessary to produce a training effect on the cardiovascular system has been reported to be approximately 60% of the heart rate reserve (3). On the basis of this calculation using the pre-training GXT, the HCT_{sub} and HCT_{max} groups were required to maintain HRs greater than 134 and 129 beats·min^{-1}, respectively. In these two groups, the respective HR responses during the training sessions averaged 60 and 75% of HR reserve. These findings suggest that the magnitude of the HR responses to the two HCT programs are adequate for improving $\dot{V}O_{2max}$. However, it is necessary to emphasize a note of caution in making extrapolations of this nature. HCT, unlike a continuous dynamic activity such as cycling, involves "non-steady state" exercise. Thus, comparisons of calculated training intensities based upon the cardiovascular responses such as HR are likely to be spurious when fundamentally different forms of exercise are being considered.

The findings of the present study lend support to this view. The HR response to the training sessions involving HCT_{max} met the conventional criteria for the threshold intensity necessary to induce training effects, as did the cycling group. However, unlike the cycling group, which demonstrated a reduction in HR during submaximal exercise, the HCT_{max} group failed to demonstrate a change in HR at submaximal workloads. The HCT_{sub} group (which had a lower HR response during training) responded in a manner similar to the cycle training group with respect to the HR response to submaximal workloads. Clearly, considerations other than HR during training sessions play a role in the cardiovascular adaptation to training.

Present findings may have some practical implications. The fact that the improvement in $\dot{V}O_{2max}$ observed in the HCT_{sub} group was similar to that seen in the HCT_{max} group suggests that HCT at less than the maximal effort can be used to enhance cardiovascular fitness.

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