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CARDIO-RESPIRATORY PHYSICAL TRAINING
IN WATER AND ON LAND

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Running Head: Physical training in water and on land

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Cardio-respiratory Physical Training
in Water and on Land

ABSTRACT

Fifteen unconditioned young men, who were similar in maximal aerobic power ($\dot{V}O_2$ max), were divided into three groups (n = 5 each) and physically trained for one month on a bicycle ergometer either on land (I) or immersed to the neck in water of either 32° C (II) or 20° C (III) to determine how physical training (PT) in water differs from training in air. PT consisted of one-hour daily exercise bouts, 5 times/wk, with exercise intensity readjusted each week to maintain a constant training stimulus of ~75% $\dot{V}O_2$ max (determined on land). Throughout the training period, heart rates (HR) of III averaged 20 and 10 beats • min^{-1} less than I and II, respectively, despite working at the same $\dot{V}O_2$ and % $\dot{V}O_2$ max. Following PT, plasma volume was not increased over the pre-training values ($p > 0.05$) in any group. Hemoglobin concentration and hematocrit significantly increased in all three groups. Training elicited a 16% increase in $\dot{V}O_2$ max in I compared to increases of 13 and 15% for II and III, respectively. It was concluded that PT in water produces similar physiological adaptations as does training on land. In cold water, $\dot{V}O_2$ max is improved despite training with HR's significantly lower than those on land.

Key words: physical training, water immersion, body temperature, maximal aerobic power, exercise

Physical exercise in water may be expected to produce different physiological responses than exercise in air due both to the hydrostatic effect of water on the cardio-respiratory systems, as well as to the enhanced heat-dissipating quality of water compared to air. While the increased pressure of the water may (9) or may not (5) affect an increase in the work of breathing during rest and exercise, it is generally agreed that increasing pressure in the lower body regions while resting in water produces a displacement of the peripheral blood volume to the central core area (1, 2), thereby increasing venous return and subsequently increasing stroke volume (11, 19). During exercise, the effect of the hydrostatic pressure on stroke volume may be overridden by the muscular activity, particularly if the exercise takes place in thermoneutral water (11, 19). Thus, the extent of the increased stroke volume appears to depend upon the temperature of the water. In water temperatures lower than 20°C, stroke volume is greatly increased over those values obtained at the same oxygen uptake ($\dot{V}O_2$) on land (11, 19). In thermoneutral water temperatures (~32°C), however, stroke volume at the same $\dot{V}O_2$ is equal to that on land (11). Hence, the heat-dissipating effect of the water appears to be a contributing factor to the magnitude of the increase in stroke volume during exercise in water of varying temperatures. That is, when blood is displaced centrally from the vasoconstricted peripheral areas during cold water exercise, venous return and stroke volume are further increased over that resulting from the hydrostatic displacement of the peripheral blood volume. Since cardiac output is the same in water and on land at the same $\dot{V}O_2$ (11, 19), individuals exercising in cold water would accomplish the same work output as those on land with significantly lower heart rates (HR). Hence, the relationship between $\dot{V}O_2$ and HR is modified somewhat with exercise in cold water so that the HR/$\dot{V}O_2$ response curve is shifted to the right (5, 11, 14).

It has been shown that performing upright exercise with subnormal body temperatures does not yield as high values of maximal oxygen uptake ($\dot{V}O_2$ max) as does exercising on land or in thermoneutral water (3, 6, 18). The mechanism for this reduction in $\dot{V}O_2$ max is unknown, although it may be a consequence of the lower maximum HR during cold water exercise (3, 6, 7, 11, 18) which would thus limit the maximally attainable cardiac output and hence effect a decrease in $\dot{V}O_2$ max.

The lower $\dot{V}O_2$ max values and lower HR at the same $\dot{V}O_2$ during exercise in cold water presents a unique situation for physical training. Since $\dot{V}O_2$ max is reduced in cold water, individuals exercising at the same $\dot{V}O_2$ in cold water as those on land would, in effect, be exercising at higher relative intensities. This should present a greater training stimulus to the cardio-respiratory systems; and a greater improvement in $\dot{V}O_2$ max with training might be expected. If, in addition, training can take place despite the lower HR with exercise in cold water, individuals may be able to train at high exercise intensities with lower cardiovascular strain, as indicated by lower HR and similar blood pressure (4), than would be possible with identical exercise intensities on land.

This study was therefore undertaken to compare the effects of physical training on land and in water. Two water temperatures were selected to help distinguish the physiological effects of exercising in thermoneutral water (32°C) from those found during exercise in cold water (20°C). It was hoped that by having the individuals exercising at the same % $\dot{V}O_2$ max (as determined on land), both on land and in water, the cold-water trained group would have a higher training stimulus and hence show a greater training effect.

METHODS AND PROCEDURES

Subjects: Fifteen unconditioned young men were selected for participation in this study. After having the procedures and nature of the potential risks explained, they gave their written consent to participate. Following a preliminary qualifying physical examination, the subjects were divided into three equal groups (n = 5, each) which were matched on the basis of $\dot{V}O_2$ max, body surface area and percentage body fat. Group I exercised in a neutral environment (22° C) on land while groups II and III trained while immersed to the neck in water of either 32° C or 20° C, respectively.

Procedures: Maximal oxygen uptake was determined at a neutral temperature (22° C) on land both on the bicycle ergometer (10) and on the treadmill (22) before and after the four weeks of training. Physical training consisted of pedaling a Monark bicycle ergometer at 75% of the cycling $\dot{V}O_2$ max for one hour per day, 5 days per week, for four weeks. Each week the exercise intensity was readjusted to maintain the same relative intensity of exercise as training progressed. For the land group, this weekly readjustment was accomplished by increasing the tension on the flywheel so that a HR of ~170 beats • min^{-1} was achieved. In the two groups exercising in water, however, HR did not appear to be a reliable indicator of exercise intensity (see RESULTS). Hence, the exercise intensity was readjusted each week by increasing the percentage of the initial $\dot{V}O_2$ max at which the subjects were exercising. Assuming the individuals would improve their aerobic capacity by 10-15% over the course of the intensive four-week program, the projected % $\dot{V}O_2$ max was increased by 5% each week. Therefore, during week 1, the subjects exercised at 75% $\dot{V}O_2$ max; week 2, at 80% $\dot{V}O_2$ max; week 3 at 85% $\dot{V}O_2$ max; and week 4 at 90% $\dot{V}O_2$ max. Measurements of $\dot{V}O_2$ were made at least once each day during the land training and twice each day during the water training. In addition, HR was measured every 10 min from the ECG tracing to assure that the individual was maintaining the appropriate exercise intensity.

The ergometer which was used for the training in water was a simple modification of the Monark bicycle ergometer which is described in detail elsewhere (21). The friction belt was first removed and then equal lengths of standard angle iron (fins) were attached by bolts to the flywheel (Fig. 1). Up to six pieces of angle iron - three on each side - could be fastened to the flywheel. By varying both the number of fins from 0 to 6 and the pedal frequency from 30 to 40 rpm, a range of $\dot{V}O_2$ between 0.5 and 4.5 liters • min^{-1} could be achieved.

INSERT FIGURE 1

Measurements: During all maximal testing and for all training days, $\dot{V}O_2$ was determined by the open circuit technique by collecting one-minute expired air samples into Douglas bags. The expired air was subsequently analyzed for O_2 (Applied Electrochemistry O_2 Analyzer) and CO_2 (Beckman LB II CO_2 Analyzer) content. The volume of air was then measured in a Tissot spirometer and converted to STPD to calculate $\dot{V}O_2$ values.

Heart rate was continuously monitored with an ECG for individuals exercising on land and in water. Rectal temperature (T_{re}) was measured with a thermistor probe inserted 10 cm beyond the anal sphincter.

Prior to and following the training program, plasma volume was measured with Evans Blue dye in all subjects. Hematocrit was determined in triplicate by microcentrifugation. Hemoglobin was measured by the cyanmethemoglobin method. Blood samples were drawn from the antecubital vein after the subject had been sitting quietly for 30 min at a room temperature of 22°C.

All variables were analyzed with a mixed factorial analysis of variance. Tukey's multiple comparison procedure was used as a follow-up if significant ($p < 0.05$) F-values were found.

RESULTS

The physical characteristics of the three groups of subjects who participated in the training program are presented in Table 1. No significant differences among the groups were found in the initial measurements of percentage body fat, body surface area, or $\dot{V}O_2$ max as determined either on the bicycle ergometer or on the treadmill (see Table 3).

INSERT TABLE 1

Both in groups I and II, one individual trained for only 18 out of the 19 training sessions; the rest trained for all 19 days. Four of the five subjects in group III missed one day of training while one subject only completed 17 of the possible 19 training days.

Figure 2 presents the mean weekly values of $\dot{V}O_2$, HR and % $\dot{V}O_2$ max at which each group exercised. The land group exercised at 79% $\dot{V}O_2$ max for week 1 and increased to 93% of initial $\dot{V}O_2$ max by week 4. These relative exercise levels corresponded to average oxygen uptakes of 2.35 to 2.85 liters $\cdot$ min^{-1}. The heart rate was fairly constant over the four weeks at ~170 beats $\cdot$ min^{-1}.

INSERT FIGURE 2

As seen in Figure 2, HR was not as good an indicator of exercise level in the two groups exercising in water. For week 1, groups II and III exercised at levels corresponding to 70 and 75% of their land $\dot{V}O_2$ max, respectively. Although the $\dot{V}O_2$ averaged 2.17 and 2.23 liters • min^{-1} for week 1 for the warm and cold water groups, respectively, and was no different from the land group ($p > 0.05$), HR values were significantly lower in the subjects exercising in water (155 and 145 beats • min^{-1}, for groups II and III, respectively). This trend of lower HR's for the same $\dot{V}O_2$ was maintained in the two water groups throughout the four weeks of training. However, for each week of training, HR was significantly lower than the land group only in the cold water group.

Both groups exercising in water worked at similarly increasing levels of % $\dot{V}O_2$ max (from 69 to 91% $\dot{V}O_2$ max for group II and from 75 to 97% $\dot{V}O_2$ max for group III) and actual $\dot{V}O_2$ (from 2.17 to 2.82 liters • min^{-1} for group II and from 2.23 to 2.88 liters • min^{-1} for group III) over the month-long training period. The $\dot{V}O_2$ and % $\dot{V}O_2$ max at which the water groups exercised each week were not different from the intensity levels of group I.

The oxygen pulse for each week of training was calculated to obtain a relative index of stroke volume (Table 2). All groups showed an increase ($p < 0.05$) in oxygen pulse from week 1 to week 4 of training. For all four weeks, group III had higher values of oxygen pulse than did group I but this was not a statistically significant difference.

INSERT TABLE 2

During the hour-long training sessions, the individuals exercising on land experienced an average rise in T_{re} of 1.1° C. The T_{re} of the warm water group increased ~0.6° C per hour while that of the cold water group showed a steady decline averaging about 0.9°C per hour of exercise. Although the absolute levels of body temperature depended upon the ambient or water temperature, groups I and II each maintained the same value during each week of exercise despite the steadily increasing exercise levels (weekly mean values of 38.35°C and 38.20°C, respectively). With group III, however, the T_{re} showed the greatest variation and did not appear to depend upon the relative exercise intensity. For week 1, when the individuals were exercising at a $\dot{V}O_2$ of 2.2 liters • min^{-1}, the decline in core temperature over the hour of exercise averaged 1.1° C. By week 4, core temperature decreased only 0.6° C with a $\dot{V}O_2$ of 2.9 liters • min^{-1}.

The improvement in $\dot{V}O_2$ max, as measured on the bicycle ergometer on land, is presented in Figure 3. All three groups significantly increased their $\dot{V}O_2$ max as a result of the training on land (15.9%) or in warm (12.6%) or cold (15.0%) water. Post-training values of $\dot{V}O_2$ max did not differ among the three groups ($p > 0.05$).

INSERT FIGURE 3

It was thought that groups II and III may have involved more of a muscle mass while pedaling the ergometer in the water. Therefore, a $\dot{V}O_2$ max determination on the treadmill was made on all subjects before and after the training period. Pre-training $\dot{V}O_2$ max values on the treadmill were similar for all three groups (52.6, 51.2 and 53.8 ml • kg^{-1} • min^{-1} for groups I, II and III respectively). Following training, the $\dot{V}O_2$ max values in $ml \cdot kg^{-1} \cdot min^{-1}$ were significantly increased by 6, 9 and 10% in groups I, II and III, respectively (Table 3). Compared to the cycling max test, all groups demonstrated a significantly lower improvement in $\dot{V}O_2$ max on the treadmill. Other significant differences between the treadmill and bicycle ergometer max tests included a significantly lower maximum HR and a higher maximum respiratory exchange ratio (R) on the bicycle ergometer compared to the treadmill in all groups. The maximum minute ventilation ($\dot{V}_E$) was significantly lower during maximum cycling in group III only. No significant differences among the groups were noted in HR_{max} or R_{max} either before or after training on the bicycle ergometer or on the treadmill. $\dot{V}_E$ max on the treadmill was significantly lower in group II than in groups I and II before training while no differences were found after training. On the bicycle ergometer, $\dot{V}_E$ max was significantly higher in group I compared to groups II and III both before and after training.

INSERT TABLE 3

Figure 4 indicates the changes in plasma volume, hematocrit and hemoglobin concentration occurring in the three groups as a result of training. Plasma volume, as measured with Evans Blue dye, did not change significantly in any of the groups following the training program ($p > 0.05$). Both hematocrit and hemoglobin concentration were significantly increased following training in all three groups. The cold water group tended to demonstrate a greater percentage increase in both hematocrit (7% compared to 5 and 2% for groups I and II, respectively) and hemoglobin (8% compared to 3 and 6% for groups I and II, respectively) as a result of training, but these were not statistically significant.

INSERT FIGURE 4

DISCUSSION

In the present study, individuals were physically trained on a bicycle ergometer either on land or in warm or cold water in which the added burden of metabolic heat dissipation is not as pronounced as that which occurs on land (15, 16). All three groups were initially matched with regard to $\dot{V}O_2$ max since it is well-known that the extent of the improvement in $\dot{V}O_2$ max depends upon the initial physical fitness of the individuals. From Figure 3, it is obvious that the different training programs all were successful in inducing similar improvements in $\dot{V}O_2$ max.

It had been hoped that by having all three groups training at the same % $\dot{V}O_2$ max as determined on land, the cold water group would actually be exercising at a higher relative intensity since previous investigations have demonstrated a reduction in $\dot{V}O_2$ max during cold water exercise (3, 6, 18). Our results, however, showed no greater increase in $\dot{V}O_2$ max resulting from cold water exercise than was evident during exercise on land or in warm water (Figure 3, Table 3). Since $\dot{V}O_2$ max in water was not measured in this study, it is unknown if the individuals were indeed training at greater relative intensities. However, exercise at higher relative intensities during cold water training may be necessary to elicit similar improvements in $\dot{V}O_2$ max as those on land due to the peripheral modifications resulting from both the intense vasoconstriction (19) as well as the decreased blood and muscle temperatures (3) experienced during cold water immersion. Even if higher relative exercise intensities were required, however, heavy exercise in cold water subjectively appears to be easier to maintain than comparable levels on land since few complaints - other than those regarding the temperature of the water - were voiced by the five subjects training in the 20°C water.

The $\dot{V}O_2$ max determinations on both the bicycle ergometer and the treadmill (Table 3) suggested no further specificity of training in water compared to on land other than the established specificity of bicycle training on $\dot{V}O_2$ max (17). That is, while no differences in physiological parameters were evident as a result of exercise media, the mode of $\dot{V}O_2$ max testing - either treadmill or bicycle ergometer - resulted in significant differences in $\dot{V}O_2$ max, HR_{max}, and R_{max}, similar to what has been demonstrated previously by Pechar et al. (17). Significant improvements in both the treadmill and bicycle $\dot{V}O_2$ max were evident for all groups. However, the extent of the increase in $\dot{V}O_2$ max was significantly greater in all groups when measured on the bicycle ergometer. Thus, a reduction in the difference in $\dot{V}O_2$ max between the bicycle and treadmill determinations was evident following training. Since all groups had similar initial and final treadmill and bicycle $\dot{V}O_2$ max values, they all demonstrated a similar decrease in the $\dot{V}O_2$ max difference between the bicycle and treadmill tests as a result of training.

It was found that the HR was not a good indicator of absolute exercise intensity for the individuals training in water. For the land group, the projected training stimulus of 75% $\dot{V}O_2$ max was adequately represented by a HR of ~170 beats • min^{-1}. In groups II and III, however, HR was lower (160 and 150 beats • min^{-1}, respectively) than the land group during all four weeks of training.

The reason for the lower HR at a given $\dot{V}O_2$ during exercise in cold water is not clear. Administration of atropine to individuals exercising with subnormal body temperatures did not change HR; hence the decrease is not due to increased parasympathetic activity (6). It also is apparently not a consequence of diminished sympathetic activity since plasma norepinephrine levels are higher during hypothermia (4). Beta-receptor activity, however, may be reduced since HR is not lowered with propranolol administration during exercise with low (esophageal temperature $< 37.0^\circ$C) body temperatures (6). Possibly, the reduction in core temperature may directly affect the heart's ability to produce tension. The performance of the heart, as measured by contractility and peak pressures during isovolumic contraction, is enhanced by hypothermia (13). But, since mechanical properties of the heart, such as the rate of tension development per unit time and the time required to peak tension and relaxation, are impaired by hypothermia (8), the overall contractility of the heart may be diminished.

It has been postulated that the mechanism responsible for the lowered HR in water is the redistribution of the blood volume from the peripheral cutaneous bed to the central area (5, 11). The increased hydrostatic pressure of the water, coupled with the peripheral vasoconstriction to diminish heat loss, would force blood from the periphery into the thorax (1, 2, 19) resulting in enhanced venous return and increased stroke volume. Since cardiac output at the same $\dot{V}O_2$ is identical when exercising in either water or air (11, 19), exercise could be accomplished with lower HR. A higher stroke volume for group III is suggested by the higher oxygen pulse for this group during all weeks of training (Table 2).

Heart rate may also be lowered as a consequence of baroreceptor activity. That is, the increased stroke volume resulting from peripheral vasoconstriction would produce an increase in blood pressure if cardiac output remained the same. Pressor-receptor activity would thus be increased with the reflex response of lowering HR to normalize blood pressure. This theory is substantiated by the finding that blood pressure during submaximal exercise is lower in relation to $\dot{V}O_2$ and HR at subnormal body temperature (4).

The higher HR in the warm water group than in the cold water may be a consequence of the thermoregulatory requirement for a higher skin blood flow in the warmer water. Since body temperature rose approximately 0.6°C over the course of the hour-long training session, the 32°C water apparently was not cool enough to provide adequate heat dissipation via convection and conduction to maintain thermoneutrality. Hence vasomotor effects were called into play, so that the tissue conductance could be increased (12, 16) via peripheral vasodilatation. Therefore, some of the centrally located blood volume would be shifted back to the periphery to increase heat dissipation. Heart rate would then increase somewhat due to the reduced venous return producing a lowered central blood volume which would effect a decrease in stroke volume (20). Since the metabolic heat dissipation in air is considerably less than that of water, further dilatation of the cutaneous beds would be necessary for adequate heat dissipation in the land-trained group. Hence, venous return and stroke volume would decline further producing a reciprocal increase in HR.

A significant observation in this study was the fact that individuals training in cold water were able to achieve as great an improvement in maximal aerobic power as did those individuals exercising on land with HR's some 20 beats$\cdot$min^{-1} higher. Since all groups were exercising at the same $\dot{V}O_2$ and % $\dot{V}O_2$ max during each week of training, it appears that the stimuli to the cardio-respiratory systems were similar in all three groups despite the inequities in HR. As cardiac output at the same $\dot{V}O_2$ is identical in water and on land (11, 19), training in cold water therefore takes place more efficiently with an enhanced stroke volume and lowered HR. In addition, blood pressure has not been shown to be elevated during exercise with subnormal body temperatures (4). Thus, cold water can be considered a medium in which aerobic power can be increased with less cardiovascular strain, as measured by HR and blood pressure, than would occur with similar training on land.

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FIGURE LEGENDS

Figure 1.	Photograph of modified Monark bicycle with three fins attached to the flywheel.
Figure 2.	Week-by-week values of oxygen uptake, heart rate and % $\dot{V}O_2$ max at which each group trained.
Figure 3.	Values of maximal aerobic power as determined on the bicycle ergometer, for each group before and after training.
Figure 4.	Changes in plasma volume, hematocrit and hemoglobin concentration resulting from training in the three groups.

Table 1. Physical characteristics of the subjects. Values are mean ± S.D.

Group	n	Age	Height	Weight 1 *	Weight 2 **	Body Fat	S.A.
		yr	cm	kg	kg	%	m^2
I	5	23.2	177.2	68.8	68.6	17.1	1.85
(Land)		±4.7	± 8.3	±13.9	±11.3	±4.1	±0.21
II	5	20.8	170.5	72.3	71.5	15.6	1.83
(T_w=32° C)		±1.8	± 9.4	±14.7	±15.5	±4.1	±0.23
III	5	23.0	177.3	66.0	65.5	13.2	1.81
(T_w=20° C)		±4.1	± 6.2	±5.7	±5.5	±4.1	±0.05

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* Represents pre-training body weight

** Represents post-training body weight

Table 2. Oxygen pulse ($ml \cdot beat^{-1}$) during each week of training for groups exercising on land (I) or in water of 32°C (II) or 20°C (III). Values are mean ± S.E.

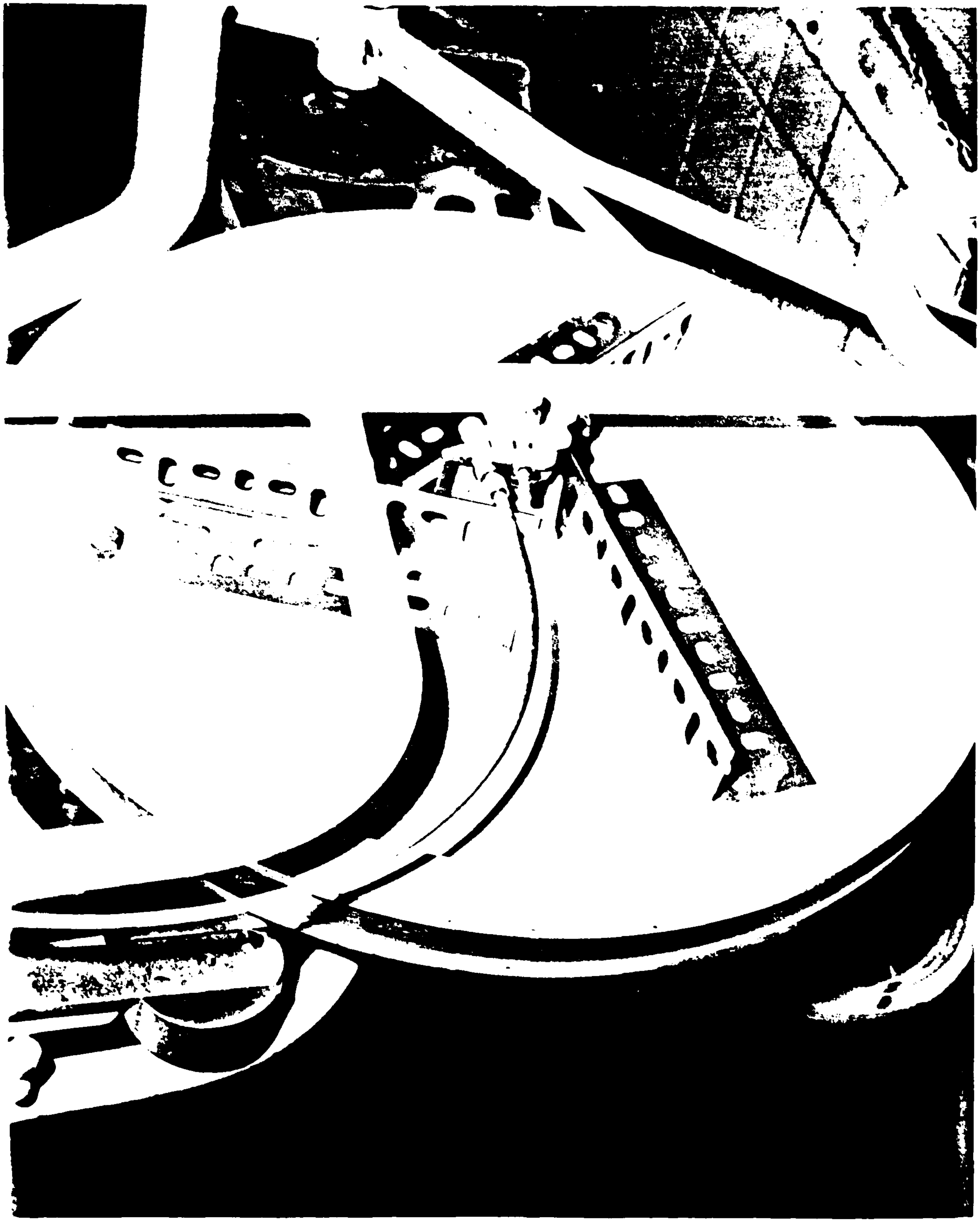
	Week 1	Week 2	Week 3	Week 4
Group I	13.91 ± 0.87	15.26 ± 0.99	16.21 ± 1.11	16.87 ± 1.22
II	14.81 ± 1.21	16.39 ± 1.51	16.84 ± 1.14	17.57 ± 1.49
III	16.10 ± 0.74	17.63 ± 1.16	18.29 ± 1.08	19.00 ± 1.15

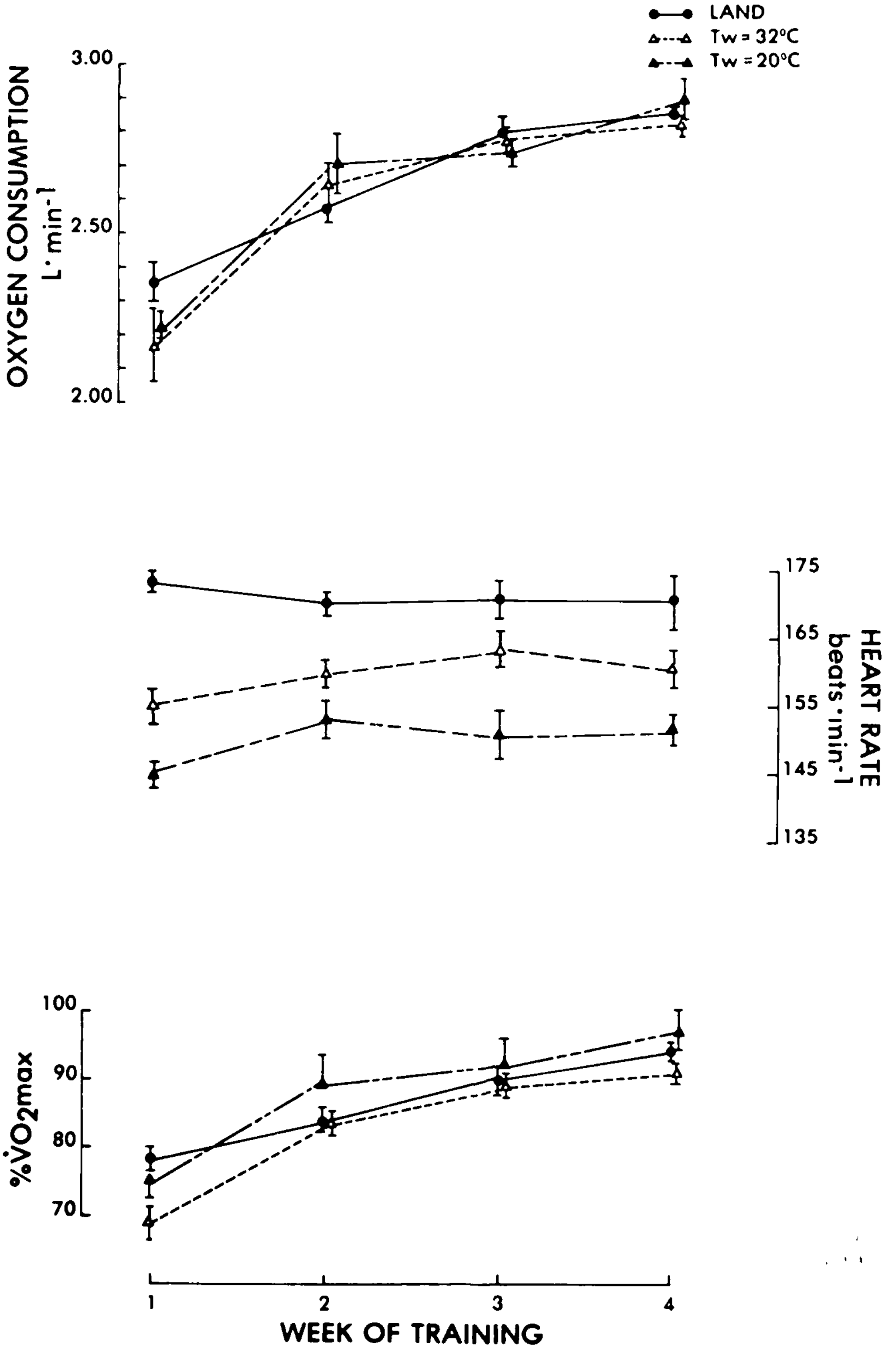
Table 3. Comparison of $\dot{V}O_2$ max determinations on the bicycle ergometer and treadmill before and after training. Values are mean ± S.E.

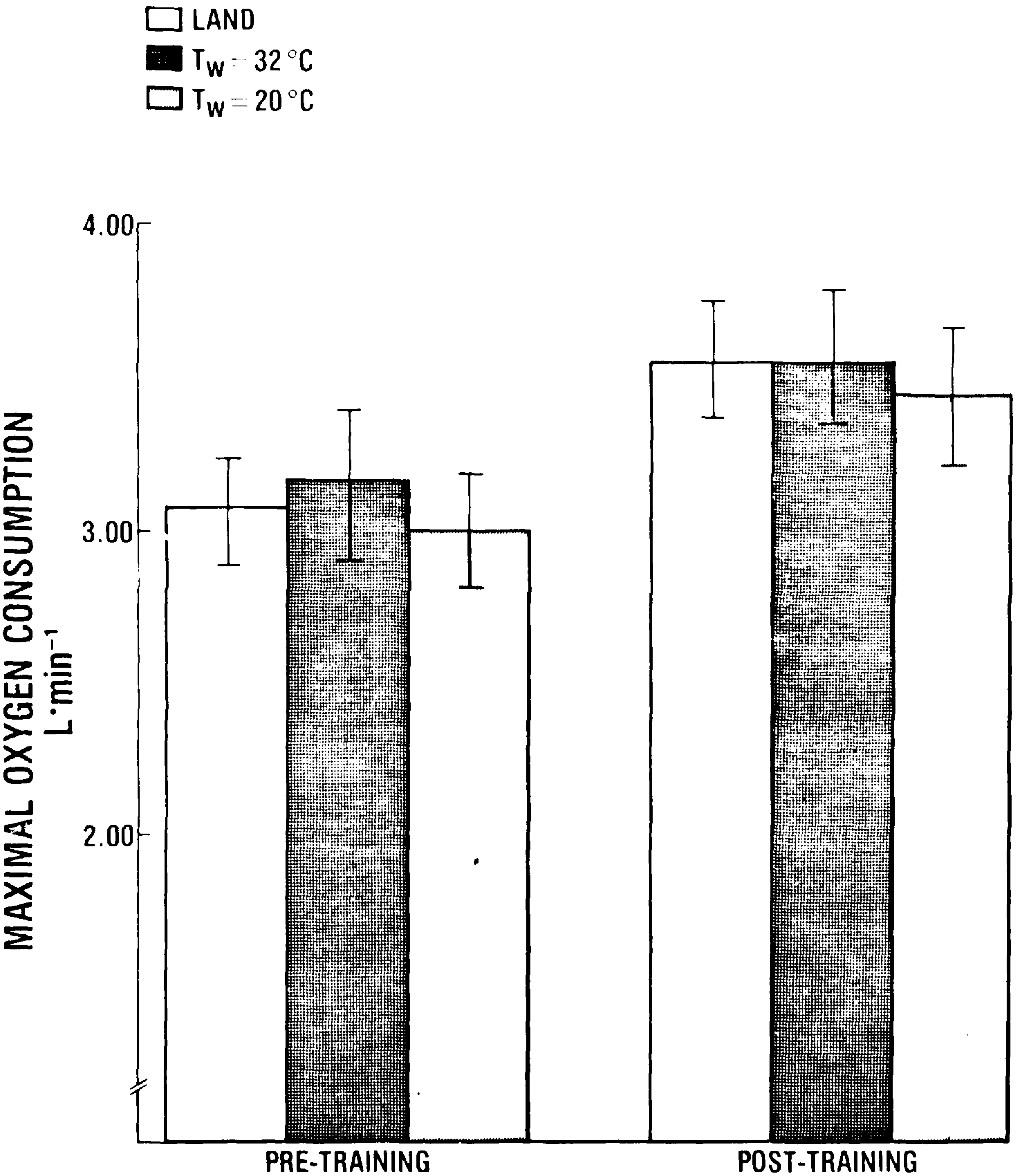
Group	Variable	Bicycle Ergometer			Treadmill Running		
		Pre-training	Post-training	diff	Pre-training	Post-training	diff
I Land	$^{+}\dot{V}O_2$ max, L • min^{-1}	3.08 ± 0.15	3.57 ± 0.19*	0.49	3.58 ± 0.21	3.83 ± 0.22*	0.25
	$^{+}\dot{V}O_2$ max, ml • kg^{-1} • min^{-1}	45.5 ± 2.1	52.0 + 2.3*	6.5	52.6 ± 1.6	55.7 ± 2.2*	3.1
	$\dot{V}_E$ max, L • min^{-1},BTPS	145.2 ± 19.8	160.3 ± 16.3*	15.1	140.0 ± 12.3	148.5 ± 11.5	8.5
	$^{+}HR_{max}$, beats • min^{-1}	193 ± 4	192 ± 3	-1	204 ± 3	197 ± 3*	-7
	+R_{max}	1.27 ± 0.04	1.27 ± 0.04	0	1.19 ± 0.03	1.22 ± 0.04*	0.03
II $T_w = 32^\circ$ C	$^{+}\dot{V}O_2$ max, L • min^{-1}	3.17 ± 0.23	3.57 ± 0.22*	0.40	3.66 ± 0.25	3.91 ± 0.03*	0.25
	$^{+}\dot{V}O_2$ max, ml • kg^{-1} • min^{-1}	44.1 + 1.0	51.0 ± 2.0	6.9	51.2 ± 1.9	55.7 ± 2.8*	4.5
	$\dot{V}_E$ max, L • min^{-1},BTPS	132.0 ± 9.7	142.7 ± 7.9	10.7	132.8 ± 5.3	147.6 ± 8.4*	15.0
	$^{+}HR_{max}$, beats • min^{-1}	183 ± 3	187 ± 3	+4	195 ± 2	192 ± 2*	-3
	+R_{max}	1.27 ± 0.02	1.25 ± 0.03	-0.02	1.18 ± 0.02	1.23 ± 0.02*	0.05
III $T_w = 20^\circ$ C	$^{+}\dot{V}O_2$ max, L • min^{-1}	3.00 ± 0.19	3.45 ± 0.23*	0.45	3.55 ± 0.19	3.88 + 0.17	0.33
	$^{+}\dot{V}O_2$ max, ml • kg^{-1} • min^{-1}	45.3 ± 1.2	52.5 ± 1.7*	7.2	53.8 ± 1.8	59.2 ± 0.9*	5.4
	$^{+}\dot{V}_E$ max, L • min^{-1},BTPS	117.2 ± 12.5	147.3 ± 6.9*	30.1	149.0 ± 7.6	158.2 ± 8.3	9.2
	$^{+}HR_{max}$, beats • min^{-1}	187 ± 6	185 ± 3	-2	197 ± 4	191 ± 3*	-6
	+R_{max}	1.26 ± 0.03	1.30 ± 0.02	0.04	1.21 ± 0.01	1.26 ± 0.03*	0.05

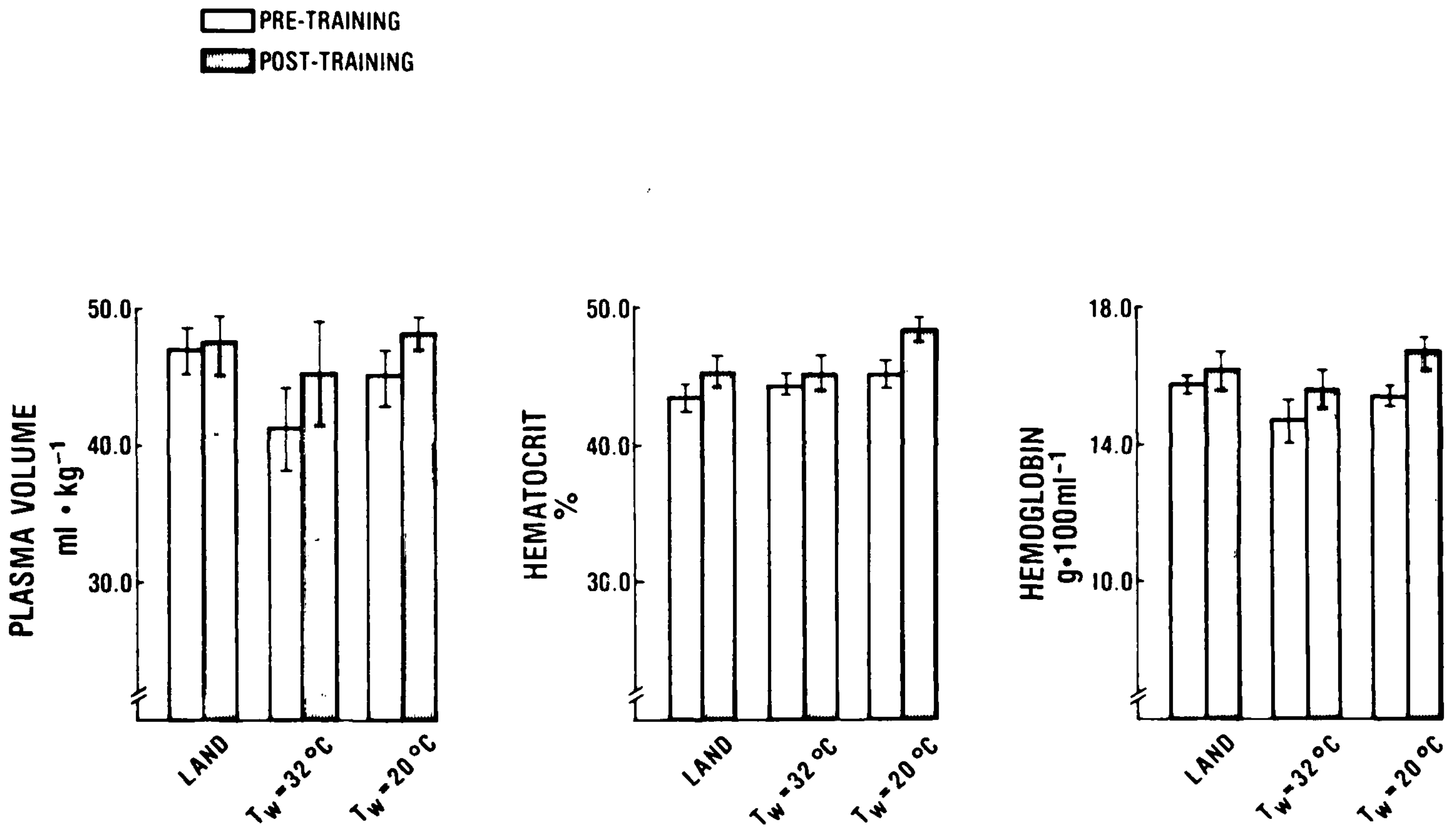
+ Significant difference between bicycle ergometer and treadmill tests ($p < 0.05$).

* Significantly different from pre-training tests ($p < 0.05$).




LAND
Tw = 32°C
Tw = 20°C
OXYGEN CONSUMPTION
L·min-1
3.00
2.50
2.00
HEART RATE
beats·min-1
175
165
155
145
135
%V̇O2max
100
90
80
70
1
2
3
4
WEEK OF TRAINING


LAND
$T_W = 32\,^\circ C$
$T_W = 20\,^\circ C$
MAXIMAL OXYGEN CONSUMPTION
L·min⁻¹
4.00
3.00
2.00
PRE-TRAINING
POST-TRAINING


PRE-TRAINING
POST-TRAINING
PLASMA VOLUME
ml • kg^{-1}
50.0
40.0
30.0
LAND
T_w=32 °C
T_w=20 °C
HEMATOCRIT
%
50.0
40.0
30.0
LAND
T_w=32 °C
T_w=20 °C
HEMOGLOBIN
g•100ml^{-1}
18.0
14.0
10.0
LAND
T_w=32 °C
T_w=20 °C

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Fifteen unconditioned young men, who were similar in maximal aerobic power (VO_2max), were divided into three groups (n = 5 each) and physically trained for one month on a bicycle ergometer either on land (I) or immersed to the neck in water of either 32°C (II) or 20°C (III) to determine how physical training (PT) in water differs from training in air. PT consisted of one-hour daily exercise bouts, 5 times/wk, with exercise intensity readjusted each week to maintain a constant training stimulus of ∿75% VO_2max (determined on land). Throughout the training period, heart rates (HR) of III averaged 20 and 10 beats·min^{-1} less than I and II, respectively, despite working at the same $\dot{V}O_2$ and % $\dot{V}O_2$max. Following PT, plasma volume was not increased over the pre-training values ($p > 0.05$) in any group. Hemoglobin concentration and hematocrit significantly increased in all three groups. Training elicited a 16% increase in $\dot{V}O_2$max in I compared to increases of 13 and 15% for II and III, respectively. It was concluded that PT in water produces similar physiological adaptations as does training on land. In cold water, $\dot{V}O_2$max is improved despite training with HR's significantly lower than those on land.