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Cardiovascular Function during Work in Water as a Criterion for Adaptability to Cold

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Five young male subjects with different individual $\dot{V}O_2max$ and similar fat % were examined their thermal and cardiovascular responses to work in water (27 and 31°C) and air. During head out immersion, three submaximal work ($\dot{V}O_2$ = 1, 1.5 and 2 l/min) for 30 min on a cycle ergometer were performed to examine the adaptability to cold in water compared to air. The submaximal $\dot{V}O_2$ during light work in 27°C water was higher than that in 31°C water and air due to shivering. The bradycardia in colder water (27°C) shown during work was compensated by increased stroke volume since the $\dot{Q}$ during work was the same in air and water. The skin temperature ($\overline{T}s$) in water was almost same as temperature of water and much lower than $\overline{T}s$ in air. Despite the linear relationship between the rectal temperature (Tr) and $\dot{V}O_2$ in air and water, lower Tr in 27°C water was observed in a given $\dot{V}O_2$ due to larger heat loss. Although the Tr-% $\dot{V}O_2max$ was linear both in air and water, the slope of the line in colder water was reduced. The present study suggests some interactions between aerobic and cardiovascular capacity on thermal balance in water although the precise relationship is still unknown.

INTRODUCTION

It is known that work in water induces different physiological responses from work on land, due to effects of buoyancy, pressure, and temperature of water. Studies on cold adaptability during work require evaluation of interactions between thermal and cardiovascular adjustments both in air and in water.

During work in air, core temperature increases to higher level depending on the intensity of the work. Also, the core temperature during work in air is increased in proportion to the relative work load of the subject (% $\dot{V}O_2$ max). Therefore, it is indicated that the relationship between aerobic function and temperature regulation is modified by individual peripheral vasomotor adjustment and sweating capacity. In water, the range of water temperature which one can maintain the thermal balance at work is much smaller than in air, primarily due to the heat transfer mechanism in water. Since heat loss during work in water mainly depends on convective and conductive heat exchange with the inhibition of evaporative heat loss, cardiovascular function is important for heat exchanges in water.

In water, venous return is increased by pressure gradient between the extra-and intrathoracic regions of the lung, and by the peripheral vasoconstriction that occurs in less than thermally neutral water temperature (35.0°C). Also, observations of bradycardia during water immersion at rest and during work have been made by Craig *et al.* (1968) and Rennie *et al.* (1971).

Rennie *et al.* (1971) suggested that during immersion in cold water a smaller fraction of the cardiac output ($\dot{Q}$) is shunted to the skin for the purpose of heat dissipation. Therefore, bradycardia in cold water would be balanced by the increase in stroke volume (S.V.).

Actually, McArdle *et al.* (1976) found that during exercise, $\dot{Q}$ was the same in water $<$ 34°C as in air, while the heart rate (HR) remained 20~25% lower and the SV was higher. Both HR and SV equaled air values only during heavy work.

Although the central circulation during work in water has been studied extensively, still the peripheral circulation is not known clearly.

In water which the evaporative heat loss is inhibited, heat loss due to both skin and muscle blood flow might be affected to a certain extent by the individual aerobic function which regulates the blood flow distribution to the local regions during work. On the contray, because the heat transfer between the working muscle and the skin surface would be facilitated by the surrounding water, the thermal regulation during work in water would be related to rather the tissue composition of the body and their thermal conductivities.

The purpose of this study is to examine the relationship between the thermal balance and the cardiovascular function during work with reference to aerobic work capacity in water compared to in air.

METHODS

Five young male students who own different $\dot{V}O_2$max were the subjects. For the purpose of studying on cardiovascular regulation per se in water, the body fat % was controlled equally over the range of 13–15% of the body weight.

The subjects were studied during an electronic controled cycle ergometer work at the $\dot{V}O_2$ cost of 1, 1.5, and 2 l/min.

All subjects were worked for 30 minutes at each work load separated by one week both in air (20±1°C) and water (27 and 31°C) immersed to the neck, pedaling at 40 rpm to avoid causing the effects of buoyancy and resistance of water.

In an attempt to measure $\dot{V}O_2$max in air and in water, 2-min progressive test was administered.

The expired ventilation ($\dot{V}E$), $\dot{V}O_2$, HR, $\dot{Q}$, rectal temperature (Tr), and mean skin temperature ($\overline{T}s$) were determined each 10 minutes during a 30 minutes work. Immediately following collection of expired air during work period, $\dot{Q}$ was determined by the CO_2 rebreathing method.

Statistical evaluation of differences in mean cardiovascular and metabolic measures during work in air and water were carried out.

RESULTS

$\dot{V}O_2$max both in air and in water (31°C and 27°C) were almost identical among all subjects in the present study. Therefore, the magnitudes of the absolute and the relative work loads in water were comparable to those in air, while the submaximal $\dot{V}O_2$ was tested. The $\dot{V}O_2$ during submaximal work under all conditions was in proportion to external work load, although the $\dot{V}O_2$ during light work in 27°C water was significantly higher than that in 31°C water and in air (Fig. 1). There was no significant difference between the $\dot{V}O_2$ in 31°C water and air at all work loads. In 27°C water, toward the end of each work duration, all subjects tended to shiver during light submaximal work. However, during moderate and heavy work loads, no subject showed shivering response in 27°C water.

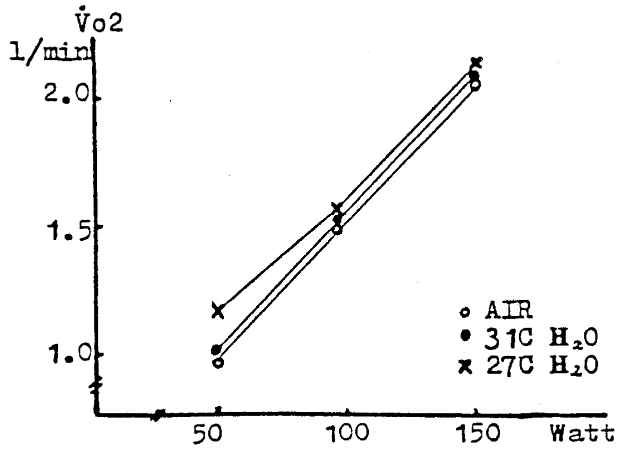

Fig. 1 $\dot{V}O_2$ as function of work load in air and water.

Heart rate and $\dot{V}O_2$ relationship was plotted in Fig. 2, and HR values in air and warmer water (31°C) was the same at any work loads. However, the bradycardia in colder water (27°C) was shown during work and statistical significance was ap-

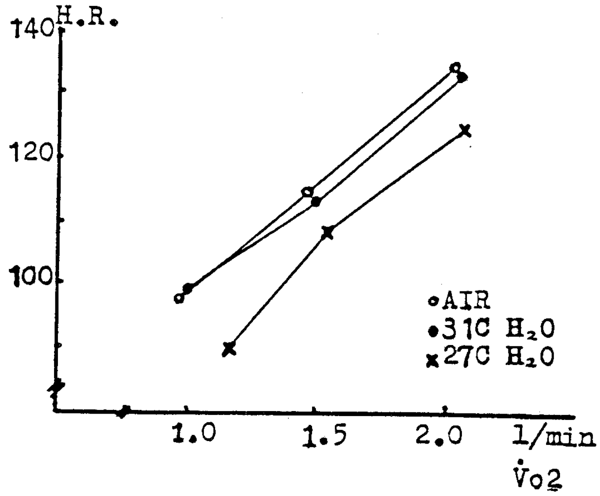

Fig. 2 Heart rate as function of $\dot{V}0_2$ in air and water.

parent at moderate and heavy work loads when compared to air and 31°C water.

The relationship between $\dot{Q}$ and $\dot{V}0_2$ was shown in Fig. 3 with linearity throughout the entire range of work in air and water without effect of water or temperature.

Since the $\dot{Q}$ during work was the same in air and water, reduction in heart rate in colder water was compensated by means of an increase in the stroke volume. This is demonstrated in Fig. 4 which S.V. was increased linearly with the $\dot{V}0_2$ during light and moderate work while S.V. at heavy load was not higher than those at moderate work.

The skin temperature ($\bar{T}s$) during work in water was much lower than $\bar{T}s$ in air as shown in Fig. 5.

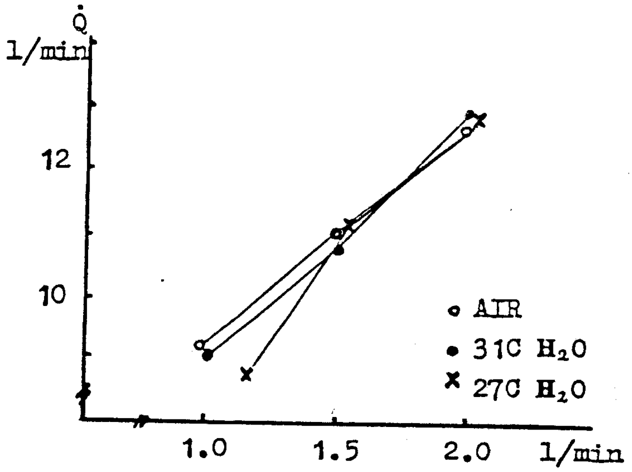

Fig. 3 Cardiac output as function of $\dot{V}0_2$ in air and water.

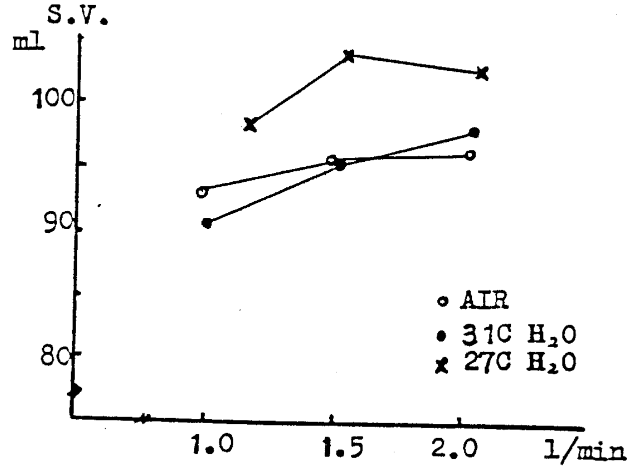

Fig. 4 Stroke volume as function of $\dot{V}0_2$ in air and water.

$\bar{T}s$ in water was approximately equal to temperature of water during each work load.

Rectal temperature (Tr) had proportional relationship to the $\dot{V}0_2$ both in air and water (Fig. 6). However, lower Tr in colder water was observed compared with Tr in warmer water and air, in a given $\dot{V}0_2$ which implied a given heat production if assumed equal mechanical efficiency of the cycle work in air and water. In air when Tr was plotted as a function of the relative work load which expressed as $\%\dot{V}0_2$max, the rise in Tr was related to the $\%\dot{V}0_2$max (Fig. 7). Although the Tr$-\%\dot{V}0_2$max relationship was linear even in water, the slope of Tr$-\%\dot{V}0_2$max was reduced compared to the line in air. Particularly in colder water, Tr was not risen so much when the individual relative cardiovascular load was increased compared with in air.

DISCUSSION

The higher $\dot{V}0_2$ during light work in 27°C water can probably be attributed to shivering thermogenesis produced by the colder water and it is agreed with observations of Craig *et al.* (1968). Also, Nadel (1974) and Holmer *et al.* (1974) demonstrated the increased metabolic rate in 25°C water during submaximal work. In the present study, 27°C water was a thermoneutral water temperature during moderate work ($\dot{V}0_2$ = c.a.

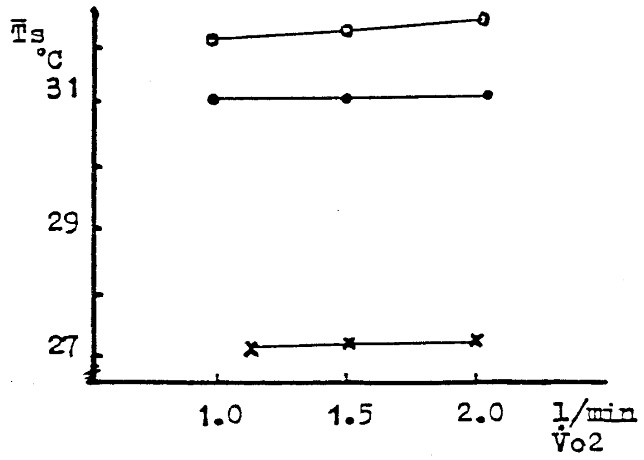

Fig. 5 Skin temperature as function of $\dot{V}O_2$ in air and water.

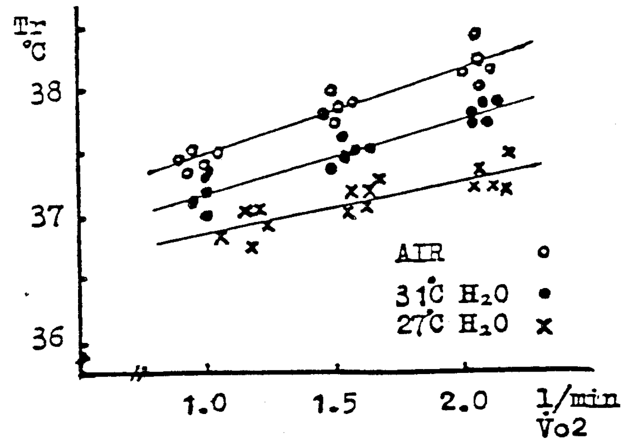

Fig. 6 Rectal temperature as function of $\dot{V}O_2$ in air and water.

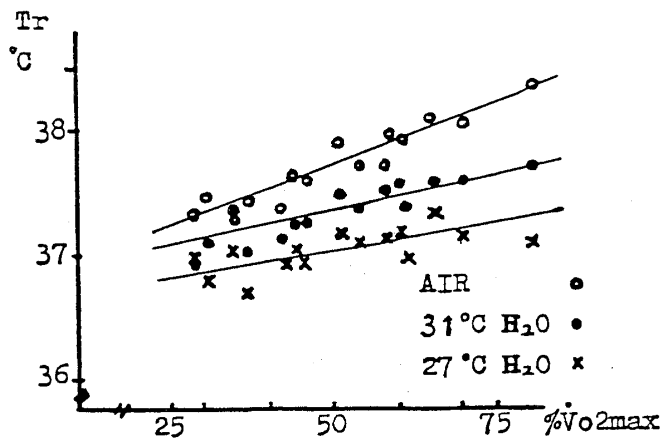

Fig. 7 Rectal temperature as funtion of % $\dot{V}O_2$max in air and water.

1.5 l/min), where subjects could maintain their core temperature and the metabolic rate. However, during light work, the core temperature was decreased since the heat loss in 27°C water exceeded the heat production by light work. As the heat loss in cold water depends on the insulatory effects of body fat and the skin blood flow, the skin blood flow must be regulated when the body fat percentage and heat production of the subjects were constant.

Lower heart rate has been demonstrated during work in colder water by McArdle *et al.* (1976) and their results were similar to our results. Since HR in air and 31°C water were almost same, the bradycardia in colder water reflects a response to water temperature, not a water effect per se.

Similar values for $\dot{Q}$ during work in air and 31°C water in the present study are in agreement with the results of McArdle (1976), Denison *et al.* (1972) and Rennie *et al.* (1971) who concluded that the cardiovascular response to work during immersion in water of thermoneutral temperature (33~35°C) was identical with that in air.

Besides, the bradycardia observed during work in cold water and its compensation met by means of the increased stroke volume in order to maintain the $\dot{Q}$ constant were agreed with the finding of McArdle (1976) and Rennie *et al.* (1971).

McArdle *et al.* (1976) suggested that the increased stroke volume may be the result of an increased peripheral and cutaneous vasoconstriction as the body cools. In addition, it is possible that the hydrostatic effect of immersion increase cardiac filling and maintain $\dot{Q}$. They also suggested that during exercise the higher rate of blood flow through working muscles might cause reduction of the limb vasoconstriction. Increased muscle blood flow may increase conductive heat transfer across the muscle-skin gradient and therefore increase whole body conductance at all water temperatures. Since the above factors combine to increase heat loss by an amount proportional to the thermal gradient between the body core and the water, it would cause a much greater increase in heat loss in cold water. Fig. 5 and Fig. 6 reflect this speculation with the lower Tr in cold water. Nielsen *et al.* (1976) suggested that the reduced sweating and skin circulation would cause the reduction of the slope of Tr-% $\dot{V}O_2$max relationship.

Since $\dot{V}O_2$ and $\dot{Q}$ are closely related, the skin blood flow and the working muscle blood flow are determind by the individuals' cardiovascular capacity. As it is known that a person with a larger $\dot{V}O_2$max is capable of increasing the working muscle blood flow than an unfit subject, the trained one may cause higher heat loss and reduction of Tr in cold water. On the other hand, since the effects of the physical training on the cold tolerance have been reported by LeBlanc *et al.* (1978) who suggested a positive effect on vasoactivity to cold, a higher aerobic and cardiovascular capacity would induce the benefit on thermal balance to cold water.

Due to the above conflict, the present study does not explain how the peripheral vasoactivity during work in water is adjusted for the prevention of the heat loss, relating to aerobic work capacity. However, it is suggested that the exercise heat production matching the heat loss in water requires steady aerobic and circulatory functions which lead to a greater exercise stress on the relatively unfit person. In water, since heat production in the body is changed to heat loss to the external environment much quicker than in air and the forced heat loss by convection and conduction overcomes the heat storage by the physiological responses, a steady heat supply by muscle contraction is required.

It is concluded that in water the thermal balance during work is not related so clearly to the % $\dot{V}O_2$max, due to suppressed sweating and blood flow competition while the central circulation is steady at different temperatures.

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