Thermoregulatory Responses to Low-Intensity Prolonged Swimming in Water at Various Temperatures and Treadmill Walking on Land

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Abstract The purpose of the present study was to examine the effect of water temperature on the human body during low-intensity prolonged swimming. Six male college swimmers participated in this study. The experiments consisted of breast stroke swimming for 120 minutes in 23°C, 28°C and 33°C water at a constant speed of 0.4 m · sec⁻¹ in a swimming flume. The same subjects walked on a treadmill at a rate of approximately 50% of maximal oxygen uptake (VO₂max) at the same relative intensity as the three swimming trials. Rectal temperature (Tre) in 33°C water was unchanged during swimming for 120 minutes. Tre during treadmill walking increased significantly compared to the three different swimming trials. Tre, mean skin temperature (Tsk) and mean body temperature (Tb) in 23°C and 28°C water decreased significantly more than in both the 33°C water and walking on land. VO₂ during swimming in 23°C water increased more than during swimming in the 28°C and 33°C trials; however, there were no significant differences in VO₂ between the 23°C swimming trial and treadmill walking. Heart rate (HR) during treadmill walking on land increased significantly compared with HR during the three swimming trials. Plasma adrenaline concentration at the end of the treadmill walking was higher than that at the end of each of the three swimming trials. Noradrenaline concentrations at the end of swimming in the 23°C water and treadmill walking were higher than those during the other two swimming trials. Blood lactate concentration during swimming in 23°C water was higher than that during the other two swimming trials and walking on land. These results suggest that the balance of heat loss and heat production is maintained in the warm water temperature. Therefore, a relatively warm water temperature may be desirable when prolonged swimming or other water exercise is performed at low intensity. J Physiol Anthropol 20 (3): 199-206, 2001 http://www.jstage.jst.go.jp/en/

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Introduction

The regulation of body temperature during exercise in water is different from that during exercise on land, because sweat evaporation, the primary means of heat dissipation during exercise on land, does not occur in water. In addition, heat loss or gain through convection and conduction is much greater in the water than on land (Nielsen, 1978). Thus, when the water temperature is higher than the skin temperature, heat gain is greater in water, whereas when the water temperature is lower than the skin temperature, heat loss occurs more readily than in air. In Japan, long-distance swimming was introduced into public school education for health promotion. Water temperature is important to the swimmers as the temperature may affect certain body responses.

Thermophysiological studies during swimming have been conducted by many researchers (Costill et al., 1967; Holmér, 1972; Holmér et al., 1974; Holmér and Bergh, 1974; Nadel et al., 1974; Nielsen and Davies, 1976; McArdle et al., 1976; Galbo et al., 1979; Nielsen et al., 1984). Galbo et al. (1979) reported that rectal temperature (Tre) and heart rate (HR) increased in 27°C and 33°C water and decreased in 21°C water during 60 minutes of swimming at approximately 68% of maximal oxygen uptake (VO₂max), and plasma noradrenaline...
concentration was higher in 21°C and 33°C water than that in 27°C water. They concluded that the rise in body temperatures normally observed during exercise enhances the exercise-induced increases in plasma concentrations of noradrenaline and other hormones. Furthermore, their study indicated that decreased body temperatures may elicit catecholamine secretion as a direct consequence of thermoreception. Nadel et al. (1974) showed that core body temperature decreased after 20 minutes of swimming in 18°C and 26°C water at 40% \( \dot{V}\text{O}_2\text{max} \), and it increased in 26°C and 33°C water at 70% \( \dot{V}\text{O}_2\text{max} \).

Thus, although considerable research exists on thermoregulatory responses to swimming, there appears to be a lack of research on the thermophysiological responses to low-intensity prolonged swimming in different water temperatures. The aim of this study was to evaluate the effects of water temperature during prolonged swimming, and to clarify the characteristics of the thermal responses to swimming.

**Methods**

**Subjects**

Six male college swimmers participated in this study after their informed consent for exercise testing was obtained. Their mean age was 19.8 (SD 0.9) years; their mean height was 168.6 (SD 1.9) cm and mean body mass was 66.8 (SD 3.9) kg. The \( \dot{V}\text{O}_2\text{max} \) achieved by the subjects during graded breast stroke swimming at 28 (SD 0.18)°C was 3.63 (SD 0.23) l · min\(^{-1}\), i.e., 53.9 (SD 2.4) ml · min\(^{-1}\) · kg\(^{-1}\). Body fat (13.2 (SD 3.4) %) was determined according to body density, which was calculated by hydrostatic weighing (Tahara et al., 1993), with the formula of Brozek et al. (1963).

**Procedures**

The subjects fasted for 6-10 hours and then had two pieces of bread and 250 ml of skim milk 2 hours before each experiment. The subjects wore swimming trunks and rested in a sitting position for 60 minutes at 27 (SD 1.3)°C room temperature before swimming. The subjects rested for an additional 5 minutes in the swimming flume (SWIMMASTER, Japan Aqua Tech Co., Ltd., Japan). The actual trials consisted of breast stroke swimming for 120 minutes in 23 (SD 0.18)°C, 28 (SD 0.19)°C and 33 (SD 0.18)°C water at a constant speed of 0.4 (SD 0.02) m · sec\(^{-1}\) in the flume. The absolute work load was equal in the three water temperatures. Water was continuously circulated to assure adequate mixing.

The same subjects, again wearing swimming trunks, rested in a sitting position for 60 minutes under environmental conditions: ambient temperature, 25 (SD 1.1)°C; room humidity, 65 (SD 3.1)% and then did on-land walking using a moving belt treadmill (WOODWAY, Sakai Co., Ltd., Japan) for 120 minutes. The relative intensity was the same (approximately 50% \( \dot{V}\text{O}_2\text{max} \)) as the three swimming trials.

**Measurements and instruments**

Rectal temperature (Tre) and skin temperatures of the arm (Tarm), chest (Tchest) and thigh (Tthigh) were measured every minute with thermistor probes beginning with the pre-exercise rest period in air and occurring until the end of all exercise. Tre was measured by inserting the thermistor probe 12 cm deep into the rectum of the subjects. Adiabatic covers for skin (Nihon Koden Co., Ltd., Japan) and transparent tape (3M Co., Ltd., USA) were used to prevent water infiltration into the site of skin temperature measurement during swimming. A portable data recording machine (VMM-67, VINE Co., Ltd., Japan) was used to record temperatures every minute. Mean skin temperature (Tsk) was calculated as 0.25Tarm + 0.43Tchest + 0.32Tthigh (Roberts et al., 1977). Mean body temperature (Tb) was calculated from the equation (Gagge and Nishi, 1977) \( \text{Tb} = 0.67\text{Tre} + 0.33\text{Tsk} \). Oxygen uptake (\( \dot{V}\text{O}_2 \)) was measured every 30 minutes by an automatic breath gas analyzer (AE-10, Minato Medical Science Co., Ltd., Japan). Heart rate (HR) was continuously monitored using a telemetry method (DS-501, Fukuda-denshi Co., Ltd., Japan). A 10-ml blood sample was obtained from an antecubital vein of the subjects every 30 minutes during the exercise. Catecholamines were determined by high-performance liquid chromatography. Lactate concentration was analyzed using the fluorometric enzymatic method.

**Statistical analysis**

Differences in subject response mean values among the three water temperatures were analyzed by one-way repeated-measures ANOVA. A value of P<0.05 was taken as the limit for statistical significance. The difference in mean values between water at three temperatures and air at 25°C was also analyzed by one-way repeated-measures ANOVA.

**Results**

The measurements of body temperature at rest and during exercise for each condition are shown in Table 1. The changes in rectal temperature (Tre) during the swimming and walking trials are shown in Fig. 1. Tre during swimming for 120 minutes in 23°C and 28°C water decreased significantly compared with temperatures recorded at rest in air. In Tre in 33°C water, however, there was no significant change. Tre during treadmill walking increased significantly compared with that before walking. Tre levels during swimming in 23°C and 28°C water were significantly lower (P<0.001-0.05) than that recorded during the 33°C trial.
The changes in mean skin temperature (Tsk) during the swimming and walking trials are shown in Fig. 2. Tsk during swimming for 120 minutes in 23°C and 28°C water decreased significantly compared with temperatures recorded at rest in air. Tsk during swimming for 120 minutes in 33°C water increased compared with that at rest in air. Tsk during treadmill walking increased significantly compared with that before walking. Tsk during swimming in 23°C water was significantly lower (P<0.01) than that in 28°C water.

The changes in mean body temperature (Tb) during the swimming and walking trials are shown in Fig. 3. Tb during swimming for 120 minutes in 23°C and 28°C water decreased significantly compared with temperatures recorded at rest in air. Tb during swimming for 120 minutes in 33°C water increased compared with that at rest in air. Tb during treadmill walking increased significantly compared with that before walking. There were no significant differences (p=0.71) in Tb between the 33°C swimming trial and treadmill walking. Tb during swimming in 23°C water was significantly lower (P<0.05) than that recorded during the 28°C trial.

\( \text{VO}_2 \) for the three swimming trials and the walking trial during the period from 30 minutes after the onset of exercise to the end were 1814 (SD 200) ml·min\(^{-1} \) in 23°C, 1558 (SD 286) ml·min\(^{-1} \) in 28°C, 1519 (SD 198) ml·min\(^{-1} \) in 33°C and 1687 (SD 130) ml·min\(^{-1} \) on land (Fig. 4). The relative exercise intensities (%\( \text{VO}_2 \text{max} \)) at each trial were 50 (SD 5%) in 23°C, 43 (SD 6%) in 28°C, 42 (SD 4%) in 33°C and 46 (SD 3%) on land. \( \text{VO}_2 \) during swimming in 23°C water was significantly higher (P<0.05) than those in 28°C and 33°C water; however, there was no significant difference (p=0.46) in \( \text{VO}_2 \) between the 28°C and 33°C water. \( \text{VO}_2 \) during treadmill walking on land did not differ from those recorded in the three swimming trials (p>0.08-0.40).

HR during the swimming and walking trials increased gradually during the first 30 minutes of each exercise and then kept a steady level (by ANOVA) until the end of exercise. Increases of HR during exercise from 30 minutes after the start of exercise to the end in comparison to pre-exercise measurements were as follows: 29 (SD 11) beats · min\(^{-1} \) in 23°C, 26 (SD 8) beats · min\(^{-1} \) in 28°C, 36 (SD 7) beats · min\(^{-1} \) in 33°C and 72 (SD 11) beats · min\(^{-1} \) on land (Fig. 5). HR during treadmill walking was significantly higher (P<0.05) than the HR recordings during the three swimming trials, although there were no significant differences in HR among the
Fig. 1 Changes in rectal temperature (Tre) before and during the swimming and walking trials. Values at rest show Tre in air (-5th min) and Tre in water (from the -4th min to the -1st min).

Fig. 2 Changes in mean skin temperature (Tsk) before and during the swimming and walking trials. Values at rest show Tsk in air (-5th min) and Tsk in water (from the -4th min to -1st min).
The changes in plasma adrenaline, noradrenaline and lactate concentrations during the swimming and walking trials are shown in Fig. 6. There were no significant differences in adrenaline concentrations among the three swimming trials at rest and during swimming. However, adrenaline concentration at 120 minutes during walking on land was significantly higher (P<0.05) compared with the adrenaline concentrations during the three swimming trials. Noradrenaline concentrations after 90 and 120 minutes of swimming in the 23°C trial were significantly higher (P<0.05) than those in the 28°C and 33°C trials. Noradrenaline concentration at 120 minutes of walking on land was significantly higher than that recorded in the 28°C and 33°C water swimming trials. Blood lactate levels at 30, 60, 90 and 120 minutes of swimming in 23°C water were significantly higher (P<0.05) than those during swimming in 28°C and 33°C water and walking on land.

**Discussion**

In the present study, Tre declined progressively during swimming in 23°C and 28°C water, but not in 33°C water, which suggests that heat loss through convection and conduction in 23°C and 28°C water was larger than that experienced in 33°C water. Similar results have been reported by Craig and Dvorak (1969). Galbo et al. (1979) showed that Tre increased during swimming in 27°C and 33°C water, but the exercise intensity in their trials was
higher than those in the present study. Nadel et al. (1974) showed that after 20 minutes of swimming, core temperature (Tes; esophageal temperature) decreased in 18°C and 26°C water and increased in 33°C water at 40% VO2max, but Tes increased in 26°C and 33°C water at 70% VO2max. Therefore, core temperature during exercise in water may depend on water temperature and exercise intensity. In this study, Tre during treadmill walking on land was significantly higher than those during the three swimming trials. This finding suggests that heat loss during walking is small compared with that experienced during swimming. Craig and Dvorak (1969) indicated that core temperature during exercise on land was higher compared to that during exercise in water.

In the present study, Tsk increased during swimming in 33°C water and treadmill walking and decreased in the 23°C and 28°C swimming trials (Fig. 2). These findings suggest that cutaneous vasodilation was elicited during swimming in 33°C water and walking on the treadmill (in air), and peripheral vasoconstriction occurred in 23°C and 28°C water. Nielsen and Davies (1976) reported similar results. Although the absolute workload was the same in the three water temperatures in this study, VO2 during swimming was higher in cold water (in 23°C) in comparison to 28°C and 33°C water (Fig. 4). VO2 in 23°C water was 296 (SD 83) ml · min⁻¹ higher than that in 33°C water, most likely due to shivering. Shivering has been demonstrated to occur when mean body temperature falls below 35.2–35.4°C (Kruk et al., 1991). In the present study, Tb during swimming trials was below 35.4°C at 2 minutes in 23°C and at 6 minutes in 28°C after the start of swimming, and the average Tb during swimming for 120 minutes in 23°C and 28°C water was 34.1 (SD 0.64) °C and 35.0 (SD 0.33)°C, respectively.

Several studies (Nielsen, 1973; Holmér and Bergh, 1974; Nadel et al., 1974; Houston et al., 1978; Galbo et al., 1979) indicated that VO2 during swimming in cold water increased compared to swimming in warm water. Nadel et al. (1974) found that VO2 was greater in 18°C than in 26°C water at any submaximal swimming speed and likewise greater in 26°C than in 33°C water. They suggested that increased cost of swimming in cold water was largely attributed to shivering. Thus, the high VO2 in 23°C water in this study was probably due to shivering.

HR during treadmill walking was significantly higher than those recorded during the swimming trials (Fig. 5). Lower HR during swimming than during treadmill work on land could be due to a difference in posture, hence the muscle mass activated, and reflex bradycardia elicited by face immersion (Oldridge et al., 1978). In this study,
there were no significant differences in HR recorded during the three swimming trials, the result was inconsistent with other studies in which HR decreased during exercise with decreasing water temperature (Craig and Dvorak, 1969; Holmér and Bergh, 1974; McArdle et al., 1976). In the present study, adrenaline levels during the three swimming trials showed no significant difference, which was probably due to a low intensity of exercise. Noradrenaline levels at 90 and 120 minutes of swimming in 23°C water were significantly higher than those recorded in 28°C and 33°C water (Fig. 6). In general, noradrenaline concentration increases in the cold environment, with a decrease in core (rectal) temperature (Bergh et al., 1979; Therminarias et al., 1989). Johnson et al. (1977) reported that the plasma noradrenaline response to cold water changes with skin temperature rather than rectal temperature. In the present study, Tsk during swimming in 23°C water was significantly lower than that in 28°C water, but the Tre was not. Thus, the relatively high noradrenaline in 23°C water than in 28°C water was accounted for by a low Tsk. The result of the present study suggests that plasma noradrenaline responses to cold water were affected by Tsk rather than Tre.

The blood lactate concentrations were significantly higher in 23°C water than in 28°C and 33°C water, although the swimming speed was the same in all three water temperatures. Galbo et al. (1979) reported that blood lactate concentration was higher in 21°C water than in 27°C and 33°C water during swimming for 60 minutes. In the present study, lactate concentration in 23°C water was higher than that during treadmill walking (Fig. 6), in spite of the same exercise intensity. Svedenhag and Seger (1992) reported that blood lactate concentrations during water running were higher than those during treadmill running on land at the same exercise intensity. In the present study, blood lactate concentrations during swimming in 23°C water reached a maximum value at 30 minutes and then remained steady until the end of swimming. Bergh and Ekblom (1979) indicated that the elimination of blood lactate might have been delayed due to cooling of muscle during cold water exercise. It seems reasonable that lower body temperature may have caused the increase of lactate production in muscles by shivering and the decrease in peripheral blood volume and flow (Therminarias et al., 1989).

In cold water swimming, heat loss was higher than heat production compared to warm water swimming and walking on land. These results suggest that relatively warm water may be desirable when prolonged swimming or other water exercise is performed at low intensity.

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References


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