Insulation and Body Temperature of Prepubescent Children Wearing a Thermal Swimsuit During Moderate-Intensity Water Exercise

Hitoshi Wakabayashi, Koichi Kaneda, Masashi Okura and Takeo Nomura

Institute of Comprehensive Human Sciences, University of Tsukuba

Abstract This study investigated thermal swimsuits (TSS) effects on body temperature and thermal insulation of prepubescent children during moderate-intensity water exercise. Nine prepubescent children (11.0 ± 0.7 yrs) were immersed in water (23°C) and pedalled on an underwater cycle-ergometer for 30 min with TSS or normal swimsuits (NSS). The rectal temperature (T_{re}) was maintained slightly higher with TSS than with NSS. The total insulation (I_{total}) was significantly higher with TSS. The ΔT_{re} , Δ mean body temperature ($\bar{T}_b$), and tissue insulation (I_{tissue}) in the NSS condition were correlated with % body fat, which indicated that the insulation layer of subjects with low body fat was thinner than that of obese subjects, and tended to decrease body temperature. Wearing TSS increased I_{total} , thereby reducing heat loss from subjects' skin to the water. Consequently, subjects with TSS were able to maintain higher body temperatures. In addition, TSS is especially advantageous for subjects with low body fat to compensate for the smaller I_{tissue} . *J Physiol Anthropol* 26(2): 179–183, 2007 <http://www.jstage.jst.go.jp/browse/jpa2>
[DOI: 10.2114/jpa2.26.179]

Keywords: prepubescent children, thermal insulation, body temperature, thermal swimsuit, water exercise

Introduction

The thermal conductance of water is approximately 25 times greater than that of air. During cold water immersion, body heat is rapidly conducted away from human skin to the water. Several studies have reported that moderate exercise facilitates overall heat loss during cold water immersion (McArdle et al., 1992; Keatinge and Evanse, 1961; Sloan and Keatinge, 1973) because the increased blood circulation to muscle tissues raises the conductive heat transfer from the body core to the skin, thereby reducing tissue insulation (Veicsteinas et al., 1982). Furthermore, in moderate exercise conditions, body movements through the water accelerate convective heat loss

from the skin surface to the water. Children are especially likely to be affected by a cold water environment, because they have a larger surface area/mass ratio (Inoue et al., 1996; Sloan and Keatinge, 1973) and thinner subcutaneous fat layer in the trunk region compared to adults (Martin and Ward, 1996).

In the elementary schools of Japan, the recommended water temperature (T_w) during swimming class is set approximately above 23°C . However, there has been no evaluation of the lowest T_w during swimming class based on experimental data. A T_w of 23°C appears not to be sufficient to maintain children's core body temperature, because of their physical characteristics as described above and the moderate exercise intensity during swimming class. Therefore, it is necessary to develop some way to maintain the core body temperature. Wearing an additional insulation layer on the skin surface is beneficial to reduce convective heat loss. Thermal swimsuits (TSS), which are partial-coverage wetsuits, were developed to use in a cool water environment for improving physical fitness or learning swimming techniques. The effects of wearing TSS have been evaluated with male adults during water immersion at rest and during low- to moderate-intensity water exercise (Wakabayashi et al., 2006b; Wakabayashi et al., 2006a). They reported that TSS could increase total insulation and maintain body temperatures, and suggested that subjects with lower body fat might receive more benefit from TSS. However, it is not clear whether prepubescent subjects can benefit from the thermal effects of wearing TSS in the same way as the adult subjects. Further evaluation of TSS with prepubescent subjects is required before introducing the TSS into elementary school swimming classes. This study investigated TSS effects on body temperature and the thermal insulation of prepubescent children during moderate-intensity water exercise at a T_w of 23°C .

Methods

Nine male prepubescent subjects (age: 11.0 ± 0.7 yrs, height: 144.8 ± 6.4 cm, weight: 37.2 ± 5.5 kg, %fat: $15.1 \pm 4.9\%$, surface area: 1.23 ± 0.11 m²) volunteered for this study. Both

the subjects and their parents gave written informed consent. The Human Subjects Committee of the University of Tsukuba approved this study design. Their body-fat percentages (%fat) were measured using bioelectrical impedance analysis (BC-118; Tanita, Japan). The body surface area (SA) was estimated by the DuBois equation ($SA = 0.007184 \cdot BW^{0.425} \cdot H^{0.725}$), where BW is the body weight and H represents height.

After subjects sat in room air (23–24°C) for 5 min, they were immersed in water (23°C) up to their chest on an underwater cycle-ergometer for 5 min. They then pedalled at 50 rpm for 30 min. Each subject carried out the protocol twice with a normal swimsuit (NSS) and with a TSS (JCW-24100; Zipathong Co. Ltd., Japan) at submaximal exercise intensity based on pre-test HR data measured in the elementary swimming classes ($HR = 130\text{--}140$ bpm, $\dot{V}_{O_2} = 25\text{--}28$ ml·min⁻¹·kg⁻¹). The TSS used in this study was made of nylon-faced neoprene (1.5 mm thick), covering the thighs, trunk, upper arms, and neck.

During experiments, rectal temperature (T_{re}) and 6 skin temperature regions were measured using thermistor sensors. The mean skin temperature ($\bar{T}_{sk}$) and mean body temperature ($\bar{T}_b$) were calculated using the following equations.

$$\bar{T}_{sk} = 0.07T_{head} + 0.35T_{chest} + 0.07T_{upperarm} + 0.12T_{forearm} + 0.19T_{thigh} + 0.20T_{calf}$$

$$\bar{T}_b = 0.67T_{re} + 0.33\bar{T}_{sk}$$

Expired gases were continuously assessed using a mass spectrometer (WEMS2000; Westron Corp., Japan). Values of the minute ventilation ($\dot{V}_E$), oxygen uptake ($\dot{V}_{O_2}$), carbon dioxide elimination ($\dot{V}_{CO_2}$), and respiratory exchange ratio (RER) were averaged every 1 min.

Total metabolic heat production (M) was calculated from $\dot{V}_{O_2}$ and RER . Metabolic heat production from the unit skin surface (M_s) was calculated using the following formula:

$$M_s = 0.92 \cdot M / SA \quad [W \cdot m^{-2}],$$

where the respiratory heat loss was assumed to be 8% of M .

Body heat storage (S_s) was calculated from $\Delta\bar{T}_b$, BW , and the human body specific heat capacity (C_b) using the following formula.

$$S_s = C_b \cdot \Delta\bar{T}_b \cdot BW / SA \quad [W \cdot m^{-2}]$$

Heat loss from the skin to the water (H_s) was calculated as

$$H_s = M_s - S_s \quad [W \cdot m^{-2}].$$

Total insulation (I_{total}) and tissue insulation (I_{tissue}) were calculated using the following formulae, according to Rennie et al. (1962).

$$I_{total} = (T_{re} - T_w) / H_s \quad [^{\circ}C \cdot m^2 \cdot W^{-1}]$$

$$I_{tissue} = (T_{re} - \bar{T}_{sk}) / H_s \quad [^{\circ}C \cdot m^2 \cdot W^{-1}]$$

Suit insulation (I_{suit}) was calculated using the following formulae, according to Shiraki et al. (1986).

$$I_{suit} = I_{total} - I_{tissue} \quad [^{\circ}C \cdot m^2 \cdot W^{-1}]$$

Comparisons of body temperature datasets were performed using two-way analysis of variance and further tested using a paired t-test at various time points between experimental conditions. All other data were compared using paired t-tests between experimental conditions. Pearson's product moment correlation coefficients were used to determine the degree of association between subjects' %fat and ΔT_{re} , $\Delta\bar{T}_b$, I_{tissue} . Statistical significances ($p < 0.05$) between TSS and NSS are shown with an asterisk (*) in the Figures and Tables.

Results

Average values of $\dot{V}_{O_2}$, $\dot{V}_E$, HR, and RPE during water exercise are shown in Table 1. Values of $\dot{V}_{O_2}$, HR, and RPE showed no differences between TSS and NSS conditions. The $\dot{V}_E$ was significantly lower with TSS than with NSS ($p < 0.05$).

Changes in T_{re} and $\bar{T}_{sk}$ are shown in Fig. 1. At the beginning of water immersion, $\bar{T}_{sk}$ dropped rapidly with NSS; however, a

Table 1 Cardiovascular responses during exercise in 23°C water

Swimsuit	NSS mean SE	TSS mean SE
$\dot{V}_{O_2}$ (ml·min ⁻¹ ·kg ⁻¹)	27.6 (1.7)	25.5 (1.5)
$\dot{V}_E$ (l·min ⁻¹)	32.4 (1.4)	28.7 (1.3)*
HR (bpm)	138.1 (5.2)	135.4 (5.0)
RPE	12.0 (0.7)	12.1 (0.5)

Fig. 1 Body temperature change during immersion and exercise in water (mean ± SE)

Fig. 2 The relationship between subjects' %fat and ΔT_{re} , ΔT_b .

slower decrease was found with TSS. After the onset of water exercise, $\bar{T}_{sk}$ decreased gradually for approximately 10 min, then remained stable until the end of immersion in both conditions. $\bar{T}_{sk}$ was significantly higher with TSS than with NSS throughout the exercise ($p < 0.05$). During exercise, T_{re} decreased slightly from the pre-immersion baseline with NSS, but increased slightly with TSS; T_{re} was significantly higher with TSS than with NSS from 10 min to 15 min ($p < 0.05$).

Figure 2 shows the relationship between subjects' %fat and ΔT_{re} , ΔT_b at the end of exercise. The ΔT_{re} and ΔT_b of each subject in the NSS condition were positively correlated with their %fat ($r = 0.65$, $p = 0.06$; $r = 0.71$, $p < 0.05$). However, in the TSS condition subjects maintained their T_{re} , and no correlation was observed between subjects' %fat and the ΔT_{re} and ΔT_b of each subject.

The M_s , S_s , and H_s during the 30 min water exercise are shown in Fig. 3. The M_s showed no differences between the TSS and NSS conditions. The S_s were significantly lower in TSS than in NSS ($p < 0.05$). TSS showed significantly lower H_s than in the NSS condition ($p < 0.05$).

The results of I_{total} , I_{tissue} and I_{suit} during the water exercise are shown in Fig. 4. The I_{total} was significantly higher in the TSS than in the NSS condition ($p < 0.05$). The I_{tissue} showed no differences between the TSS and NSS conditions.

Figure 5 shows the relationship between subjects' %fat and the I_{tissue} in the NSS condition. The I_{tissue} in the NSS condition correlated significantly with subjects' %fat ($r = 0.79$, $p < 0.05$).

Fig. 3 Metabolic heat production, heat storage, and heat loss from the skin surface during 30 min water exercise (mean $\pm$ SE).

Fig. 4 Insulation of tissue, suit, and total insulation during 30 min water exercise (mean $\pm$ SE).

Fig. 5 The relationship between subjects' %fat and I_{tissue} during water exercise with NSS.

Discussion

Body temperature

At the beginning of water immersion, $\bar{T}_{sk}$ decreased rapidly in the NSS condition. On the other hand, the TSS condition showed a slower decrement of $\bar{T}_{sk}$ (Fig. 1). Kang et al. (1983) and Shiraki et al. (1986) reported a slower and smaller decrement of $\bar{T}_{sk}$ in wetsuit-protected divers compared with the

naked condition, similar to the findings of the present study. Since the TSS used in the present study was made of neoprene, similar to the wetsuits, the TSS was able to reduce water inflow to the clothed body parts and attenuate the convective and conductive heat loss, thus maintaining a higher $\bar{T}_{sk}$.

From the present results, wearing TSS enabled subjects to maintain a higher T_{re} than with NSS. However, the decrement of T_{re} during water exercise with NSS was small, and above 37°C. It seemed to be sufficient to allow the swimming class to proceed without TSS. However, there were large individual differences in body temperature change during water exercise; in particular, subjects with the lowest % fat decreased T_{re} more than 1°C. A positive correlation was observed between subjects' %fat and the ΔT_{re} and $\Delta \bar{T}_b$ of each subject in the NSS condition. Sloan and Keatinge (1973) investigated the oral temperature (T_{oral}) of boys and girls aged 8–20 years during 40 min submaximal swimming in water at 20.3°C, and reported a significant correlation between individual's skinfold thickness and the rate of T_{oral} fall similar to the present result. Holmer and Bergh (1974) investigated the esophagus temperature (T_{es}) changes of male adults during 20 min submaximal swimming in water at 18, 26 and 34°C. They reported that large individual differences and a significant correlation between a subject's mean skinfold thickness and ΔT_{es} were observed at 18°C. The individual differences became smaller at 26°C, and, finally, no individual differences or correlations were observed at 34°C. A similar thermal effect reducing individual differences was observed in the present study by wearing TSS.

Thermal insulation

The additional insulation layer of the TSS increased I_{total} in the TSS condition. The increment of I_{total} might have engendered the lower H_s during water exercise in the TSS condition compared with that in the NSS condition. Consequently, subjects with TSS were able to maintain higher body temperatures than those same subjects with NSS. The I_{tissue} showed no differences between the TSS and NSS conditions, which suggested that the peripheral blood flow during water exercise was similar in both conditions. Similar results were observed in the previous study evaluating the effect of TSS during water exercise with male adult subjects (Wakabayashi et al., 2006a). They suggested that wearing TSS has no effect on the peripheral blood flow, based on the results of similar I_{tissue} and cardiovascular responses between suit conditions.

The significant correlation between %fat and I_{tissue} in the NSS condition indicated that the insulation layer of subjects with low body fat was thinner than that of obese subjects (Hayward and Keatinge, 1981). Wakabayashi et al. (2006a) reported a correlation between the male adult subjects' skinfold thickness and their I_{tissue} during moderate-intensity water exercise with NSS, similar to the findings of the present study. The present result suggests that wearing TSS is advantageous for prepubescent subjects with low body fat to

compensate for the smaller I_{tissue} . None of the previous wetsuit studies have assessed suit-attributable differences among subjects' physical characteristics using the I_{tissue} parameter. We can suggest the greater usefulness of wearing TSS for subjects with low body fat by indicating the positive correlation between %fat and I_{tissue} .

Conclusion

During exercise in 23°C water, wearing TSS served to increase I_{total} by adding I_{suit} , thereby reducing heat loss from prepubescent subjects' skin to the water. Consequently, subjects with TSS were able to maintain higher body temperatures than those same subjects with NSS. In addition, it was suggested that TSS was especially advantageous for subjects with low body fat to compensate for the smaller I_{tissue} . The prepubescent subjects with low body fat can maintain their core body temperature at the same level as the obese subjects by wearing TSS.

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Physiological Anthropology, 2006 (ICPA 2006), in Kamakura, Japan

Received: September 28, 2006

Accepted: November 28, 2006

Correspondence to: Hitoshi Wakabayashi, Institute of Comprehensive Human Sciences, University of Tsukuba, 1–1–1, Tennoudai, Tsukuba, Ibaraki, Japan

Phone: +81–29–853–6338

Fax: +81–29–853–6338

e-mail: waka_swim@hotmail.com

This article was presented at the 8th International Congress of