Increase of Heat Loss by Wearing Gloves and Boots in Wet-suited Subjects Working in Cold Water

Yang Saeng PARK, Jung Sook KIM and Jang Kyu CHOI

Department of Physiology and Diving Science Institute, Kosin Medical College

The effect of wearing protective gloves and boots on thermal exchanges of wet-suited subjects in cold water was evaluated. Four male subjects, clad in 5 mm-thick neoprene wet suits and either with or without neoprene gloves (5 mm-thick) and boots (5 mm-thick) were immersed up to the neck in water at 13 °C while resting for 3 h or exercising for 2 h. Rectal temperature, oxygen consumption and local (chest, back, upper arm, thigh, forearm, calf, hand and foot) skin temperatures, skin heat fluxes and thermal insulations were determined during immersion. The rectal temperature was not different between conditions but the skin temperature was significantly higher with gloves and boots, especially at the distal extremities (forearm, calf, hand and foot). Consequently, the core-to-skin temperature gradient was reduced by wearing gloves and boots, but the skin heat loss was markedly increased. Calculated overall body insulation was significantly lowered by wearing gloves and boots. These results indicate that in wet-suited subjects resting or exercising in cold (13 °C) water, gloves and boots increase the overall rate of body heat loss. Attenuation of cold-induced vasoconstriction is proposed as the mechanism. (Ann. Physiol. Anthropol. 11(4) : 393-400, 1992)

Key words : Cold water immersion, Underwater exercise, Wet suits, Gloves, Boots

Contemporary women divers of Korea wear neoprene wet-suits consisting of pants, jacket, hood and boots, but no neoprene gloves, hence their hands are subjected to cold stress. A previous study (Choi et al., 1988) on these divers has indicated that gloves do not provide additional protection against body heat loss, but rather decrease the efficiency of heat conservation mechanisms during prolonged immersion. In wet-suited divers resting in water of critical temperature (17 °C), the rectal temperature fall was facilitated and the thermal insulation of body was reduced by wearing gloves. Also, Van Someren et al. (1982) have shown that in unprotected subjects immersed in lukewarm (29 °C) water, selective cooling (12 °C) of hands and feet increased heat production, thereby increasing core temperature or halting its fall. Such results suggest that the sensory input

from cold receptors in the distal extremities is particularly important in eliciting adequate thermoregulatory responses during cold water immersion.

The present study was undertaken to examine this hypothesis in wet-suited subjects exercising in cold water (13 °C). Subjects wore gloves and boots in one series and no gloves and boots in another series.

METHODS

Four male subjects volunteered for the experiments. Their anthropometric characteristics are given in Table 1. Mean subcutaneous fat thickness (SFT) was calculated from measurements of skinfold thickness at 10 sites, as described by Allen et al. (1956). Regional and whole body surface areas of each subject were directly measured using non-

Table 1. Anthropometric characteristics of the subjects

Subject	Age (yr)	Height (cm)	Weight (kg)	BSA (m ²)	SFT (mm)
1	36	170.0	80.8	1.966	6.8
2	33	176.6	63.4	1.860	3.2
3	28	176.4	75.8	1.969	6.7
4	21	173.7	68.9	1.822	4.5
Mean	29.5	174.2	72.2	1.904	5.3
SE	3.3	1.5	3.8	0.037	0.9

BSA : Body surface area

SFT : Mean subcutaneous fat thickness determined according to Allen et. al. (1956).

elastic adhesive tape.

The subjects were clad in regular neoprene wet suits (pants and jackets with zipper and lining) of 5 mm thickness and immersed up to the neck in a constant-temperature water bath, vigorously circulated. Subjects wore 5 mm-thick neoprene gloves and boots in one series and no gloves and boots in another series of experiments. To minimize convective heat loss from under the suit, it was taped at the ankles and wrists, and the waist was belted with a weight belt. The water temperature was adjusted to 13 °C.

$\dot{V}O_2$ was measured by collecting expired gas in a Douglas bag for 3-5 min at 30-min intervals. O_2 content of collected gas was analyzed by a blood gas analyzer (Radiometer, model ABL-30), and its volume was measured immediately by passing it through a dry gas meter (Harvard). The rectal (T_{re}) and skin (T_{sk}) temperatures were measured using appropriate thermocouple (copper-constantan) probes. T_{sk} was measured at the chest (above the mamma), back (subscapular), thigh (antero-medial), calf (postero-medial), upper arm (over the triceps muscle), forearm (postero-medial), and the dorsum of hand and foot. The mean skin temperature ($\bar{T}_{sk}$) was calculated using individual weighting factors (Table 2). The skin heat flux (H_{sk} , kcal/m²·h) was measured using a heat flux transducer (Thermometrics, HA-13-18-10) placed and taped (Hogi Van Surgical Tape, Tokyo, Japan) near each skin tem-

Table 2. Regional body surface area

	(m ²)	(% of Immersed Surface Area)
Head	0.153±0.005	*** *
Chest	0.292±0.007	16.69±0.26
Back	0.323±0.014	18.41±0.50
Upper arm	0.151±0.005	8.60±0.26
Forearm	0.115±0.002	6.59±0.11
Hand	0.093±0.001	5.31±0.10
Thigh	0.406±0.011	23.18±0.35
Calf	0.238±0.003	13.60±0.18
Foot	0.133±0.001	7.61±0.17
Total	1.904±0.037	100.00

Values are mean±SE of 4 subjects.

perature probe. Each heat flux transducer was calibrated as described in a previous study (Park et al., 1988). The calibration constant of our 10 transducers were on the average 13 % higher than the factory provided factor. The mean skin heat flux of a specific body segment and the overall skin heat flux ($\bar{H}_{sk}$) were calculated using the area-weighting factors. Body temperatures and heat fluxes were recorded at 5-min intervals using a data logging system (Fluke, model 2280B) and analyzed by a computer. The overall thermal insulation index (I_{body} , °C/(kcal/m²·h)) was calculated using the following formula : $I_{body} = (T_{re} - \bar{T}_{sk}) / \bar{H}_{sk}$

All results are presented as the mean±SE and the statistical evaluation of data was done using Student's t-test (paired comparison).

RESULTS

Heat exchanges at rest

Fig. 1 presents average time courses of metabolic rate (M), rectal temperature (T_{re}) and regional skin temperatures (T_{sk}) of 4 wet-suited subjects while resting in 13 °C water. The subjects wore gloves and boots (solid lines) in one series and no gloves and boots (broken lines) in another series. In both series the M (top panel) rose rapidly by about 40 % during the initial 30-60 min, then remained unchanged during the rest of immersion period. The steady-state M was not significantly different between the two

series, thus the degree of shivering was identical.

The T_{re} (middle panel) declined gradually from about 37.3 °C before immersion to about 36.8 °C at the end of 3-h immersion. The rate of reduction of T_{re} was not different between the two series.

Changes in regional skin temperature (T_{sk}) is depicted in the bottom panel of Fig. 1. For simplicity, the immersed portion of body was divided into 3 segments representing the trunk (chest and back), limbs (arm, forearm, thigh, calf) and hands+feet, and the area-weighted mean value for each segment was presented. Both with and without wearing gloves and boots, the T_{sk} fell significantly during

immersion. However, the change was not uniform over the body: it was most marked on the hand and foot, less on the limb (arm and leg) and least on the trunk. After an initial drop the T_{sk} on the trunk maintained a more or less constant level, but those on the limbs declined progressively during the rest of immersion period. Likewise, the T_{sk} of the hands and feet protected with gloves and boots progressively decreased over the 3-h immersion. Without gloves and boots, however, the T_{sk} dropped quickly to a temperature slightly above the water temperature (13 °C) and remained unchanged. During most of the immersion period the T_{sk} of the trunk was the same between the two situations, but T_{sk} of

Fig. 1. Average time courses of metabolic rate (M), rectal temperature (T_{re}) and regional skin temperatures (T_{sk}) of 4 wet-suited subjects while resting in water at 13 °C with (solid lines) and without (broken lines) wearing gloves and boots. Significant differences ($p < 0.05$ in paired test) from the corresponding value with gloves and boots are indicated by solid symbols.

Fig. 2. Average time courses of overall ($\bar{H}_{sk}$) and regional (H_{sk}) skin heat fluxes of 4 wet-suited subjects while resting in 13 °C water with (solid lines) and without (broken lines) wearing gloves and boots. Significant differences from the corresponding value with gloves and boots are indicated by solid symbols.

extremities was significantly lower without gloves and boots.

Fig. 2 presents average courses of regional ($\bar{H}_{sk}$) and overall ($\bar{H}_{sk}$) skin heat fluxes during immersion. The regional heat flux change (lower panel) showed three distinct patterns. In general, the heat flux from the trunk increased rapidly during the initial 10 min period, then it was reduced quickly and stabilized after 30-40 min in water. The steady-state trunk $\bar{H}_{sk}$ ($\sim 90 \text{ kcal/m}^2 \cdot \text{h}$ with and without gloves and boots) was approximately 3-fold greater than the pre-immersion level ($\sim 35 \text{ kcal/m}^2 \cdot \text{h}$). The heat flux at the limb surface increased rapidly during the first 5 min, then it declined slowly until the end of immersion. However, the value of heat flux was never reduced to below the preimmersion level within 3 h. The heat flux from hands and feet also increased abruptly during the initial period, but then declined rather quickly and became smaller than the pre-immersion value after 30-60 min in water. By wearing gloves and boots, the heat flux from the trunk was not affected; however, surprisingly, the heat flux from the limbs as well as hand and foot was significantly increased, especially during the later phase of immersion. Consequently, the area-weighted mean skin heat flux ($\bar{H}_{sk}$) appeared to be significantly higher with gloves and boots than without gloves and boots (upper panel).

Heat exchanges during exercise

Four wet-suited subjects performed 2-h leg exercise with and without wearing gloves and boots. The work load was adjusted to be approximately 2 (EXER 1) or 3 (EXER II) Met (1 Met = $50 \text{ kcal/m}^2 \cdot \text{h}$).

Fig. 3 depicts the time courses of M (top panel), T_{re} (middle panel) and local T_{sk} (bottom panel) during 3 Met exercise. Unlike at rest in water, the T_{re} did not decrease, but tended to increase slightly during the first one hour and then declined very slowly. The level of T_{re} at any time period was not significantly different between the two conditions.

Fig. 3. Average time courses of metabolic rate (M), rectal temperature (T_{re}) and regional skin temperatures (T_{sk}) of 4 wet-suited subjects during 3-Met exercise in 13°C water with (solid lines) and without (broken lines) wearing gloves and boots. Significant differences from the corresponding value with gloves and boots are indicated by solid symbols.

The general pattern of T_{sk} change in each region was similar to that observed in the resting condition. Furthermore, by wearing gloves and boots the T_{sk} was maintained high not only in the hand and foot but also in the limb, as observed in the resting condition.

Fig. 4 illustrates changes in local ($\bar{H}_{sk}$) and overall ($\bar{H}_{sk}$) skin heat fluxes during 3 Met exercise. The $\bar{H}_{sk}$ in the trunk was not changed, but those in the extremities were significantly increased by wearing gloves and boots (lower panel). The $\bar{H}_{sk}$ (upper panel) was higher with gloves and boots than without during most part of immersion and this was due to increased heat flux at the distal extremities

Fig. 4. Average time courses of overall ($\bar{H}_{sk}$) and regional (H_{sk}) skin heat fluxes of 4 wet-suited subjects while performing 3-Met exercise in 13 °C water with (solid lines) and without (broken lines) wearing gloves and boots. Significant differences from the corresponding value with gloves and boots are indicated by solid symbols.

(forearm, calf, hand and foot).

Figs. 5-6 summarize the final T_{re} , $\bar{T}_{sk}$, H_{sk} and I_{body} determined at the end of 2-h immersion at 13 °C as a function of exercise intensity. The exercise intensity was expressed as the metabolic rate above the resting value (ΔM).

Fig. 5 (upper panel) shows that, regardless of the protection of the hands and feet, the T_{re} increased linearly with work load at a rate of 0.5 °C per ΔM of 100 kcal/m²·hr.

The $\bar{T}_{sk}$ (lower panel) also rose linearly with work load, but in this case, both the absolute value at a given exercise and the rate of rise with exercise

Fig. 5. Average rectal (T_{re}) and mean skin ($\bar{T}_{sk}$) temperatures of 4 wet-suited subjects measured at the end of 2-h immersion in water at 13 °C with (solid lines) and without (broken lines) wearing gloves and boots, plotted as a function of exercise intensity. The exercise intensity is expressed as the metabolic rate above the corresponding resting-immersion value (ΔM). Values are mean $\pm$ SE.

(2.0 and 1.1 °C per ΔM of 100 kcal/m²·h with and without protection) appeared to be significantly higher with protection of the hands and feet than without protection. Thus, the T_{re} - $\bar{T}_{sk}$ gradient was considerably reduced by wearing gloves and boots.

Fig. 6 (upper panel) shows that the $\bar{H}_{sk}$ increased curvilinearly as the work load increased. The pattern of change with exercise was not altered, but the level of $\bar{H}_{sk}$ at a given exercise level was markedly increased by wearing gloves and boots.

Such an increase in $\bar{H}_{sk}$ in the face of reduced T_{re} - $\bar{T}_{sk}$ gradient indicates that the thermal insulation was decreased by wearing gloves and boots. In fact, as depicted in Fig. 6 (lower panel), the calculated overall body insulation (I_{body}) declined exponentially as the exercise intensity increased, both with and without gloves and boots on, but the value of I_{body} was always much lower with gloves and boots than without them.

Fig. 6. Average mean skin heat flux ($\bar{H}_{sk}$) and mean body insulation (I_{body}) of 4 wet-suited subjects, measured at the end of 2-h immersion in water at 13°C with (solid lines) and without (broken lines) wearing gloves and boots, plotted as a function of exercise intensity. The exercise intensity is expressed as the metabolic rate above the corresponding resting-immersion value (ΔM). Values are mean $\pm$ SE.

DISCUSSION

The major purpose of the present study was to examine the effect of wearing gloves and boots on the heat loss of wet-suited subjects during prolonged underwater activities in cold water. The data depicted in Fig. 6 clearly indicate that the overall body heat flux was increased, rather than decreased, by wearing gloves and boots in both resting and exercising subjects. Local heat flux measurements indicated that the increase in heat flux occurred in the extremities, and not in the trunk (Figs. 2 and 4), the effect being progressively greater at more distal compartment as depicted in Fig. 7 for the leg.

Fig. 7. Regional skin heat flux at the trunk and leg, measured at the end of 2-h immersion with (solid lines) and without (broken lines) wearing gloves and boots in resting and exercising (3 Met) subjects. Values are mean of 4 wet-suited subjects.

Such an effect of gloves and boots in the resting subject may be associated with changes in blood convection to the limb. It is well known that resting heat production takes place mainly in the viscera (Burton et al., 1969) and that during cold exposure, reduction of limb blood flow (Barcroft and Edholm, 1943; Burton et al., 1969; Rennie, 1967) and countercurrent heat exchanges in the limb (Bazett et al., 1948) minimize convective heat transfer from trunk to limbs. As a consequence, local heat flux is progressively reduced down the length of the limb, as observed in the present study (Fig. 7, REST). A relatively low heat flux at the trunk as compared with thigh and calf must be attributed to a higher external (suit) insulation at the trunk (most part of the trunk surface is covered by double sheets, i.e., pants and jacket, and the limbs by a single sheet). We, therefore, speculate that blood vessels in the

extremity were more severely constricted by directly exposing hands and feet to cold water. Constriction of limb blood vessels will not only retard convective heat transfer from trunk to limbs but will also increase the local thermal insulation which is determined by the thickness of unperfused tissue layer (See below). A similar conclusion has been made in our previous study (Choi et al., 1988), in which wet-suited women divers were immersed in 17 °C water with and without gloves on.

The changes in limb heat loss induced by wearing gloves and boots in the exercising subjects may involve alterations of local conductive heat transfer. During exercise, the increase in heat production occurs mainly in working muscles in the limb. This heat is mostly conducted away to the limb surface for dissipation and in part transferred to other body regions by blood-borne convection and subsequently lost to the environment (Ferretti et al., 1988). The radial conduction of heat from the limb core to the surface takes place through series insulations provided by poorly perfused muscle, subcutaneous fat and skin (Park et al., 1984; Veicsteinas et al., 1982; Rennie, 1988). According to Veicsteinas et al. (1982), the insulation of superficial tissues (fat and skin) reaches its maximum attainable value as skin temperature is lowered to 32-33 °C and is not further affected by exercise of less than 3 Met. On the other hand, the insulation due to skeletal muscles is gradually diminished in exercise according to work load (Park et al., 1984; Veicsteinas et al., 1982; Rennie, 1988). In the present study, the limb skin temperature of exercising subjects was always maintained at below 30 °C (Fig. 3), assuring the maximal value of superficial insulation. Thus, any changes in limb heat flux at a given exercise (i.e., at a similar muscle temperature) must be attributed to the changes in muscle insulation. We, therefore, presume that blood circulation to muscles in the exercising limb was somewhat diminished by exposing hands and feet to cold water. It may be that strong cold stimuli to receptors in hands and feet evoked vasomotor

response in the limb muscle, partially offsetting exercise-induced hyperemia. In this regard, Rennie et al. (1980) have reported that in nude subjects immersed in cold water the leg muscle blood flow at a steady-state exercise was progressively decreased as the water temperature was lowered.

The effect of gloves and boots on heat loss from hands and feet (see Fig. 7 for foot) was most likely associated with changes in blood convection to these regions. Rennie (1967) has shown that the entire heat loss from hands occurs as a consequence of blood convection. Local circulation declines during cold exposure not only by sympathetic vasoconstriction (Freeman, 1935) but also due to direct effects of cold on the vessels and the viscosity of the blood (Keating, 1969; Keatinge and Harman, 1980). Because of a substantially low skin temperature in the unprotected hands and feet (Fig. 3) we conclude that blood convection to these regions was significantly reduced as compared with those to the protected hands and feet.

Finally, despite an enhanced skin heat loss, the rectal temperature of subjects was not reduced by wearing gloves and boots. Since the metabolic rate was not apparently altered, it is speculated that the loss of body heat storage was increased by wearing gloves and boots. Whether this indeed happened is, however, difficult to ascertain at present.

In summary, the present data indicate that in wet-suited subjects resting or moderately exercising in cold (13 °C) water, overall body heat loss is increased, rather than decreased, by wearing gloves and boots, and this is mostly due to increase in heat flux at the distal extremities (calf, forearm, hands and feet). These results suggest that the heat conservation mechanism in the limbs is not as effective when hands and feet are protected during prolonged cold water activities.

ACKNOWLEDGEMENT

The authors are most grateful to the subjects for their splendid cooperation. We are greatly indebted

to Dr. D.W. Rennie of the State University of New York at Buffalo for the critical reading of the manuscript and for discussion. This work was presented in the Workshop on the Physiology of Deep Breath-Hold Diving held on June 28-30, 1991 in Chieti, Italy.

REFERENCES

- Allen, T. H., Peng, M. T., Chen, K. P., Huang, T. F., Chang, C., and Fang, H. S. 1956: Prediction of total adiposity from skinfold and curvilinear relationship between external and internal adiposity. *Metabolism* 5: 346-352.
- Barcroft, and H., Edholm, O. G. 1943: The effect of temperature on blood flow and deep temperature in the human forearm. *J. Physiol. (London)* 102: 5-20.
- Bazett, H. C., Love, L., Newton, M., Eisenberg, L., Day, L., and Forster, R. 1948: Temperature changes in blood flowing in arteries and veins in man. *J. Appl. Physiol.* 1: 3-19.
- Burton, A. C., and Edholm, O. G. 1969: *Man in Cold Environment*. New York: Hafner Publishing Company.
- Choi, J. K., Park, Y. S., Park, Y. H., Kim, J. S., Yeon, D. S., Kang, D. H., Rennie, D. W., and Hong, S. K. 1988: Effect of wearing gloves on the thermal balance of Korean women wet-suit divers in cold water. *Undersea Biomed. Res.* 15: 155-164.
- Ferretti, G., Veicsteinas, A., and Rennie, D. W. 1988: Regional heat flows of resting and exercising men immersed in cool water. *J. Appl. Physiol.* 64: 1239-1248.
- Freeman, N. E. 1935: The effect of temperature on the rate of blood flow in the normal and in the sympathectomized hand. *Am. J. Physiol.* 113: 384-393.
- Keatinge, W. R. 1969: *Survival in Cold Water*. Oxford, UK: Blackwell.
- Keatinge, W. R., and Harman, M. C. 1980: *Local Mechanism Controlling Blood Vessels*. London, New York, Toronto, Sydney and San Francisco: Academic Press.
- Park, Y. H., Iwamoto, J., Tajima, F., Miki, K., Park, Y. S., and Shiraki, K. 1988: Effect of pressure on thermal insulation in humans wearing wet suits. *J. Appl. Physiol.* 64: 1916-1922.
- Park, Y. S., Pendergast, D. R., and Rennie, D. W. 1984: Decrease in body insulation with exercise in cool water. *Undersea Biomed Res.* 11: 159-168.
- Rennie, D. W. 1967: Body heat loss during immersion in water. In: Yoshimura, H. and Weiner, J. S., Ed, *Human Adaptability and Its Methodology*. Tokyo: Japanese Society for Promotion of Science, p36-41.
- Rennie, D. W. 1988: Tissue heat transfer in water: lessons from the Korean divers. *Med. Sci. Sports Exerc.* 20: S177-S184.
- Rennie, D. W., Park, Y. S., Veicsteinas, A., and Pendergast, D. 1980: Metabolic and circulatory adaptation to cold water stress. In: *Exercise Bioenergetics and Gas Exchange* (Eds. Cerretelli, B. and Whipp, B. J.). Elsevier/North-Holland Biomedical Press, pp315-321.
- Veicsteinas, A., Ferretti, G., and Rennie, D. W. 1982: Superficial shell insulation in resting and exercising men in cold water. *J. Appl. Physiol.* 52: 1557-1564.
- Van Someren, R. N. M., Coleshaw, S. R. K., Mincer, P. J., and Keatinge, W. R. 1982: Restoration of thermoregulatory response to body cooling by cooling hands and feet. *J. Appl. Physiol.* 53: 1228-1233.

(Received February 4, 1992)

Yang Saeng PARK

Department of Physiology, Kosin Medical College, 34 Amnam-dong, Suh-ku, Pusan 602-030 Korea