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Effect of Shoe Type on the Thermoregulatory Response and Clothing Microclimate in Women during Walking and Resting

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Experiments were carried out to clarify the effects of two different types of shoe, *i.e.*, zori (Japanese sandals) and half-length boots, on the thermophysiological response in six adult women during rest and walking outside and under laboratory conditions. Main results were summarized as follows:

1) The rectal temperature remained higher when wearing the half-length boots than with zori both outside and in the laboratory.

2) Sole and instep skin temperatures were significantly higher when wearing the half-length boots than with zori.

3) The clothing microclimate temperature and humidity near the sole were significantly higher with the half-length boots than with zori.

These findings are discussed in terms of thermal physiology. Zori seem to have been more effective for both dry and wet heat loss from the feet to surroundings, which inhibited an increase in the core temperature.

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Keywords: thermoregulatory response, clothing microclimate, half-length boots, zori, heat rate.

INTRODUCTION

Although many types of shoes of different material and design are available, their physiological influence has not been systematically studied. There are some reported studies on foot wear,[1)–6)] although these studies have been focussed only on shoes and feet. To study the effect of shoes in more detail, experiments were carried out to elucidate how different types of shoes could influence the thermoregulatory response of the whole body. Zori and half-length boots were used to clarify the role of shoes in the whole bodily thermoregulatory response and clothing microclimate of resting and walking subjects, these two types of shoes providing contrasting cover to the feet. Feet are known to play an important role in the heat-dissipating mechanism.[7)–9)] Therefore, whether or not the feet are covered by shoes might have a significant influence on the heat-loss mechanism, resulting in different behaviour of the core temperature.

MATERIALS AND METHODS

Six female students, aged 19–20 yrs, volunteered as subjects, their physical characteristics being summarized in Table 1. They wore cotton training T-shirts with long sleeves (weight, 230 g) and full-length cotton training trousers (weight, 255 g). The subjects were made to walk at a speed of 30 m/min for 20 min in the sun and then to take a rest in the shade for 10 min for the outside experiments. This schedule was run three times in one trial. The rectal and skin temperatures (instep, sole, leg, forearm and chest), heart rate, and clothing microclimate (temperature and humidity) between the skin and clothing at levels of the trunk, leg and sole were continuously measured throughout the experimental periods. Clothing microclimate humidity was measured by resistance hygrometry, using a high molecular weight substance, and its value is expressed as absolute humidity in g/m^3. The two types of shoes used were zori (Japanese sandals, 420 g in weight) and half-length boots (420 g in weight) shown in Fig. 1. The outside experiments were carried out from May to June 1990, in an air temperature ranged from 23°C to 28°C in the sun and from 18°C to 23°C in the shade. The relative humidity ranged from

Table 1. Physical characteristics of the subjects

Subject	Age (yrs)	Height (cm)	Weight (kg)	Surface* area (m^2)
S1	20	165.0	50.0	1.54
S2	20	149.5	42.5	1.32
S3	20	158.0	55.5	1.53
S4	20	160.5	47.0	1.47
S5	19	161.0	51.0	1.54
S6	19	163.0	58.0	1.61

* Body surface area was calculated by the formula of Takahira (1925).

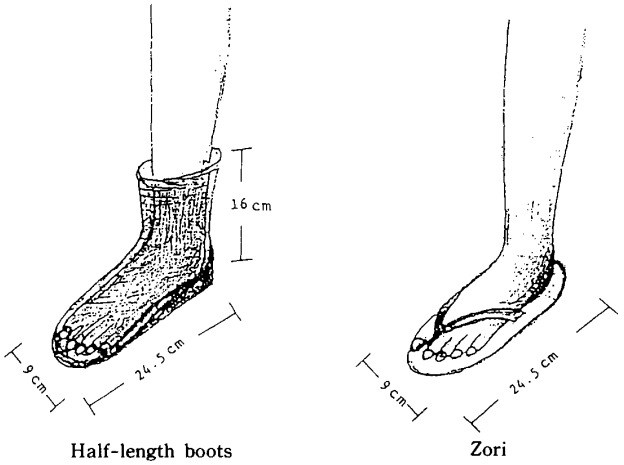

Fig. 1. Two types of shoes used in the experiment.
Left: half-length boots. Right: zori (Japanese sandals). Both shoes had the same weight of 420 g. Zori were made from rush matting with a rubber sole, and the half-length boots were made from rubber lined with cloth.

55% to 65%, and glove temperature from 28°C to 37°C. Similar experiments were also conducted in the laboratory in order to accurately measure the effects of the two kinds of shoes on the thermophysiological response and clothing microclimate. The ambient temperature and relative humidity in the laboratory were 28±1°C and 55±5%, respectively. The six young female adults who participated in the outside experiments also served as subjects in the laboratory experiments. They were made to walk on a treadmill at a speed of 30 m/min for 20 min and then to rest for 10 min, this schedule being run three times. All data obtained were analyzed by ANOVA and a paired *t*-test between the two types of shoes.

RESULTS

Figure 2 shows a comparison of the average

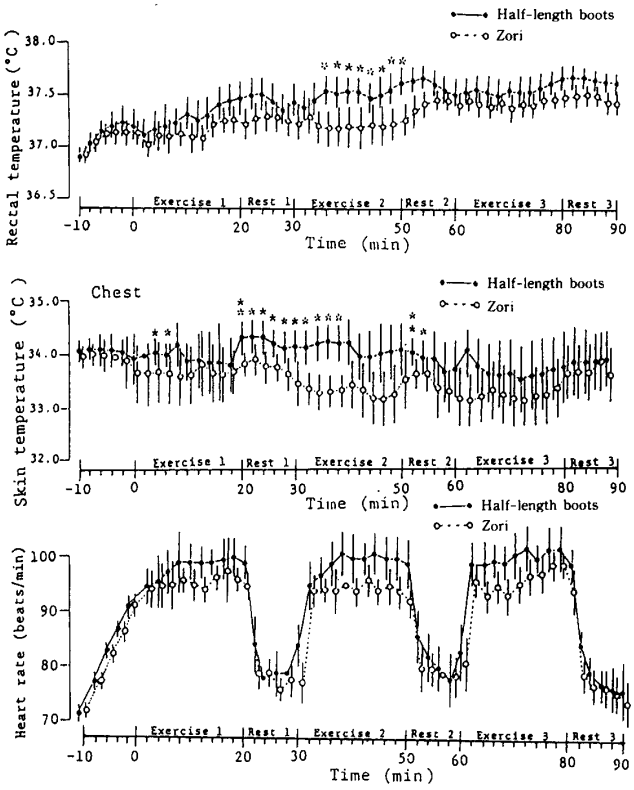

Fig. 2. Comparison of the average rectal temperature (top), chest skin temperature and heart rate (bottom) during three repeated schedules of 20 min walking and 10 min resting between the two types of shoes in the outside experiment.
Closed circles: half-length boots; open circles: zori (Japanese sandals). Results are mean±S.E.M. (n=6). * $p<0.05$, ** $p<0.01$.

rectal temperature (top), chest skin temperature (middle) and heart rate (bottom) during three repeated schedules of 20 min walking and 10 min resting between the two types of shoes in the outside experiments. As can be seen in the figure, the rectal temperature progressively increased and were higher for the half-length boots than for zori

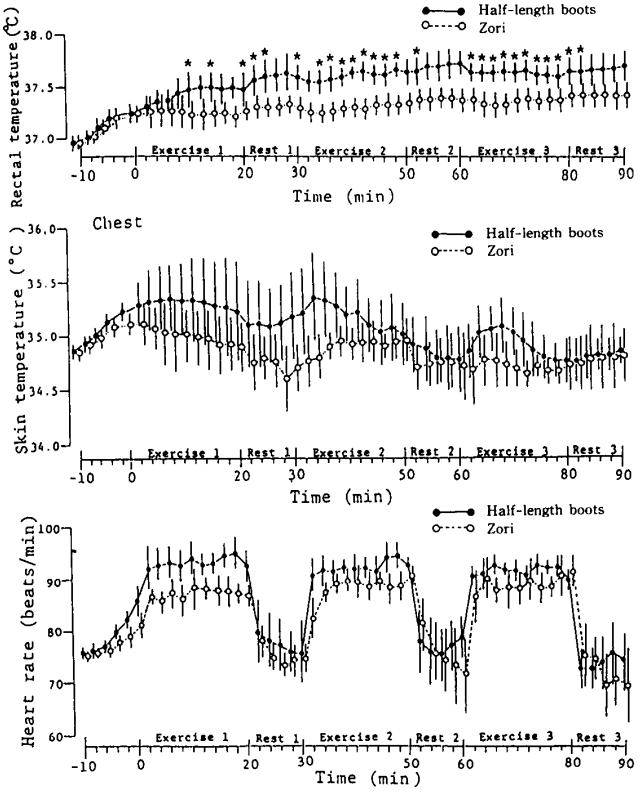

Fig. 3. Comparison of the average rectal temperature (top), chest skin temperature and heart rate (bottom) during three repeated schedules of 20 min walking and 10 min resting between the two types of shoes in the laboratory experiment.

Closed circles: half-length boots; open circles: zori (Japanese sandals). Results are mean±S.E.M. (n=6).

(ANOVA $p<0.01$). The heart rate tended to be higher with the half-length boots during the 20-min walk, but was no different during resting.

Figure 3 shows a comparison of the average rectal temperature (top), chest skin temperature (middle) and heart rate (bottom) between the two types of shoes in the laboratory experiment. As can be seen in this figure, the rectal temperature was also significantly higher with the half-length boots during most of the experimental period. Similar results to those from the outside experiment were obtained from the laboratory experiment.

Figure 4 presents a comparison of the average sole skin temperature (top), clothing microclimate temperature under the sole (middle) and clothing microclimate humidity under the sole (bottom) during three repeated schedules of 20 min walking and 10 min resting between the two types of shoes in the outside experiment. It is clearly apparent that

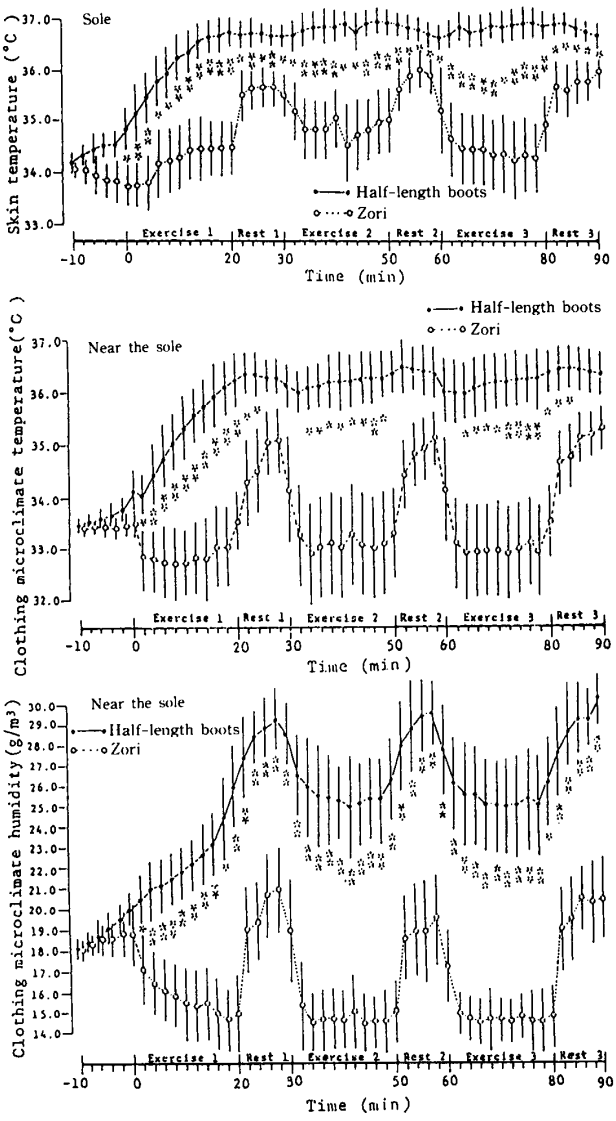

Fig. 4. Comparison of the average sole skin temperature (top), clothing microclimate temperature near the sole (middle) and clothing microclimate humidity near the sole (bottom) during three repeated schedules of 20 min walking and 10 min resting between the two types of shoes in the outside experiment.

Closed circle: half-length boots; open circles: zori (Japanese sandals). Results are mean±S.E.M. (n=6).

the sole skin temperature, clothing microclimate temperature near the sole and clothing microclimate humidity near the sole were significantly higher with the half-length boots. Similar results were again obtained from the laboratory experiment (Fig. 5). It is interesting that the clothing microclimate humidity was lower during walking than during resting. Furthermore, the sole skin

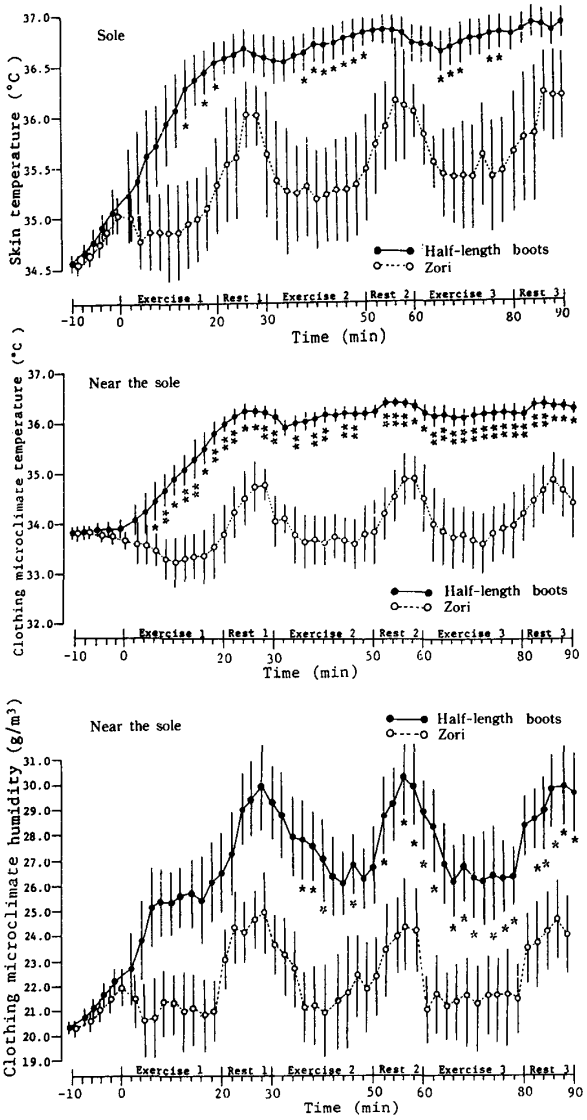

Fig. 5. Comparison of the average sole skin temperature (top), clothing microclimate temperature near the sole (middle) and clothing microclimate humidity near the sole (bottom) during three repeated schedules of 20 min walking and 10 min resting between the two types of shoes in the laboratory experiment.

Closed circles: half-length boots; open circles: zori (Japanese sandals). Results are mean±S.E.M. (n=6).

temperature and clothing microclimate temperature under the sole were lower during walking than during resting. It is noteworthy that a quicker and greater decrease in these values was observed during both walking and resting when wearing zori. These results indicate that the sole skin temperature and clothing microclimate temperature under the sole varied to a greater extent when wearing zori.

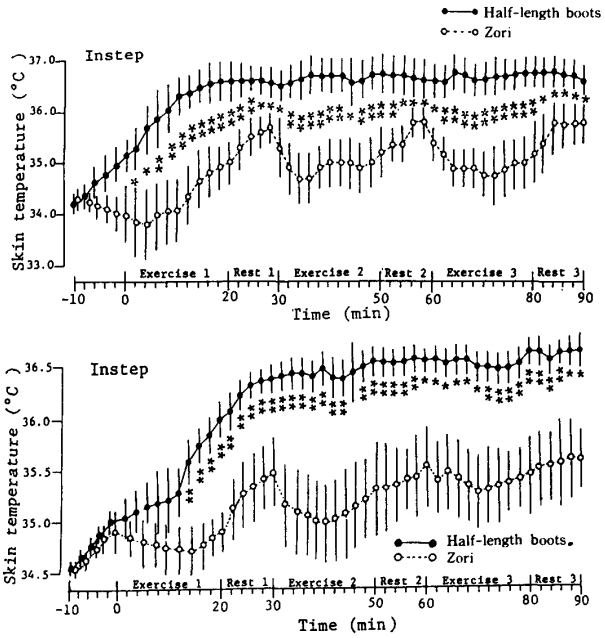

Fig. 6. Comparison of the average instep skin temperature between the two types of shoes in the outside (top) and laboratory experiments (bottom) during three repeated schedules of 20 min walking and 10 min resting.

Closed circles: half-length boots; open circles: zori (Japanese sandals). Results are mean±S.E.M. (n=6).

Figure 6 shows a comparison of average instep skin temperature between two types of shoes in the outside (top) and laboratory (bottom) experiments. It can be clearly seen that the skin temperature rose from 35°C to 36.5°C with the half-length boots, while it remained significantly lower with zori throughout the experimental period, dropping during walking and increasing during resting.

Figure 7 shows the leg skin temperature (top), clothing microclimate temperature near the front of the leg (middle) and clothing microclimate humidity near the front of the leg (bottom) in the outside experiments. The leg skin temperature rose from 34°C to 35°C with the half-length boots, but remained at 33°C to 34°C with zori. The clothing microclimate temperature near the front of the leg ranged from 33°C to 34.2°C with the half-length boots, and from 32.5°C to 33.8°C with zori. The clothing microclimate humidity near the front of the leg with the half-length boots rose to 27 g/m³ 20 min after the start of the experiment, and slightly dropped with subsequent walking to around 26 g/m³. With zori, the humidity rose to

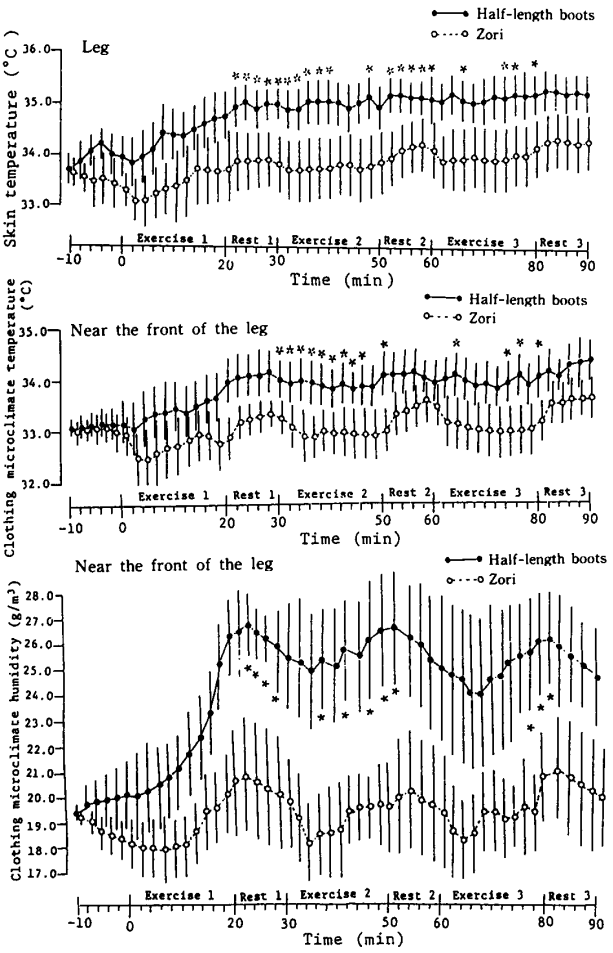

Fig. 7. Comparison of the average leg skin temperature (top), clothing microclimate temperature near the front of the leg (middle) and clothing microclimate humidity near the front of the leg (bottom) during three repeated schedules of 20 min walking and 10 min resting between the two types of shoes in the outside experiment.

Closed circles: half-length boots; open circles: zori (Japanese sandals). Results are mean±S.E.M. (n=6).

21 g/m³ during the first rest period, but dropped to 18 and 19.8 g/m³ with subsequent walking. Quite similar results to those shown in Fig. 7 were obtained in the laboratory experiment. There was no significant difference in clothing microclimate humidity at the level of the trunk between the two types of shoes in both the outside and laboratory experiments.

DISCUSSION

The most interesting findings are that the rectal temperature and chest skin temperature, both reflecting the core temperature, were higher when wearing half-length boots than with zori (Japanese sandals). These results are similar to those in our previous preliminary report.[10] This means that how feet are covered by different types of shoes could influence the thermoregulatory response of the whole body. The higher heart rate with the half-length boots might be closely related to the higher core temperature with the half-length boots. Although the difference in core temperature between the two types of shoes was small, this might be significant to homeothermy in warm and cold ambient conditions, since even such a small difference in core temperature could influence autonomic regulation such as sweating, forearm blood flow and shivering differently through the central control mechanism.[11][12] These effects are closely related to clothing comfort and health maintenance.

We can speculate on the physiological mechanism that is responsible for the core temperature being different with these two types of shoes (Figs. 2 and 3). Feet could play an important role in the heat-dissipating mechanism.[7]–[9] As can be seen in Figs. 4 and 5, the sole skin temperature and the clothing microclimate temperature under the sole were much higher with the half-length boots. These higher temperatures would not help dry heat loss from the feet to surroundings since the feet were covered by the shoe material which would inhibit heat flow. Contrary to this, although the sole skin temperature and the clothing microclimate temperature under the sole were lower with zori, ventilation between the sole and zori would probably be more effective, resulting in greater convective heat loss.

As the instep is open to air in zori, the heat from the instep can be easily lost. As shown in Figs. 4 and 5 (bottom), the clothing microclimate humidity under the sole was significantly higher with half-length boots both during walking and resting. This means that evaporation would occur more efficiently with zori. Thus, zori seem to be more effective for both the dry and wet heat loss from the feet to surroundings in a warm environment, resulting in less increase in the core temperature and heart rate. This present paper has dealt with the effects of different types of shoes of identical weight on the thermoregulatory response and clothing microclimate. Further studies remain to be done on the effect of different materials and weight of shoes on human physiology.[11][12]

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歩行時と休息時の体温調節反応と被服気候に与える異なったタイプの靴の影響

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本論文は，二種類の異なった型の靴が歩行時および安静時の温熱生理反応と被服気候にどのように影響するかを，フィールドと実験室での実験によって遂行した．実験条件は，フィールドでは気温 23℃～28℃（炎天下），18℃～23℃（日陰），湿度 55～65% RH，輻射熱 28℃～37℃，実験室では，室温 28±1℃，湿度 55±5% RH であった．主な結果は，1）両条件下における直腸温は，草履よりも半長靴着用時において有意に高く維持された．2）足底と足背の皮膚温は，草履よりも半長靴において有意に高く保たれた．3）被服気候のうち足底の靴の温湿度は草履よりも半長靴において有意に高く保たれた．これらの結果を温熱生理学の視点より論じた．草履は，足から外界へのドライおよびウエットな放熱に対して有利なように思えた．このことが中核温の上昇の抑制を導いたと考察した．

キーワード：体温調節反応，被服気候，半長靴，草履，心拍数．