Effects of Two Kinds of Sports Shoes with Different Structure on Thermoregulatory Responses

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The present experiments were carried out to clarify the effects of two different kinds of shoes, i.e., the standard shoes and the mesh shoes, on thermophysiological responses and clothing microclimates (temperature and humidity) in five female students during rest and walking in the field conditions. Main results were summarized as follows: 1) Skin temperatures in instep, sole and leg were kept lower in the mesh shoes than in the standard shoes. 2) Rectal temperature and heart rates were also kept lower in the mesh shoes than in the standard shoes. 3) Questionnaires disclosed that the subjects wearing the mesh shoes felt less damp.

These findings were discussed in terms of thermal physiology. The mesh shoes seemed to be more effective for both the dry and wet heat loss from the feet to the surroundings, resulting in the inhibition of increase in the core temperature.


Key words: Mesh shoes, Standard shoes, Clothing microclimate, Thermoregulatory responses, Dry and wet heat loss

Recently, people are very interested in keeping their bodies healthy and are trying to improve their health in various ways. Running and walking are especially popular among them. The sports shoes could play a significant role in enjoying sports. Whether they feel comfortable or not during and after sports might depend partly on how the sports shoes they wear fit them. Furthermore, the shoes can contribute an improvement of the race record and a relief of the fatigue sensation.

Although there are some papers having dealt with the studies of sport shoes (Yokoyama 1989, Hirazuka 1955), however, these studies have focussed themselves only on the materials of sports shoes and have not investigated how the sport shoes with different structure and materials could influence the whole bodily thermoregulatory responses. Feet could play an important role for heat loss control (Aschoff 1958, Day 1968). Therefore, how to cover feet might exert different influences for heat loss mechanisms. In present experiment two kinds of shoes were used as experimental shoes: the stan-

Fig. 1 Two kinds of shoes: the standard shoes (top) and the mesh shoes (bottom).
standard shoes and mesh shoes (Fig. 1). As seen in the figure, the small poles are abundant in the mesh shoes, which enables air ventilation occur more effectively. Thus, the clothing microclimate might be different between the standard shoes and mesh shoes, resulting in different influences on heat loss from feet to surroundings.

With these in mind, the experiments were carried out in order to elucidate how two kinds of sport shoes with different structure could influence differently the whole bodily thermoregulatory responses during walking and rest.

**MATERIALS AND METHODS**

Five healthy female students aged 19 yrs volunteered as subjects. The reason why the general students were selected as subjects is that the sports shoes used in present experiments are widely worn not only in athletes, but also in general students both during every day life and sports activity. Field experiments were conducted from May to July 1991. They wore training T-shirts (cotton/polyester blend) with long sleeves (weight: 230 g), training full trousers (cotton/polyester blend) (weight: 255 g) and shorts as underwears. Rectal and skin temperatures (instep, sole, leg, forearm, chest), heart rate and clothing microclimate (temperature, humidity) between skin and clothing at level of trunk, leg and sole were continuously measured throughout the experimental periods. Rectal and skin temperatures were measured with thermistor sensor. They walked on the flat roof of university building according to the rhythm of metronome (allegro assai 138) for 15 min and took a rest in the shade for 10 min in the field. These schedules were repeated three times in a trial. Each subject repeated the trial twice in each kind of shoes. The data obtained from two trials with one kind of shoes in each subject were averaged and the averaged values were used as representative ones of one kind of shoes in each subject. The order the subjects wore either the mesh shoes or the standard shoes was randomized. Air temperature when the field experiments were carried out ranged from 26°C to 32°C under sunny sky and from 24°C to 29°C in shade, relative humidity from 50 to 80%RH, wind velocity from 0.6 to 3.3 m/sec and glove temperature from 33.0°C to 43.0°C. The two kinds of shoes used weighed 270 g (mesh shoes) and 304 g (standard shoes), respectively. They were rubber-soled. The insteps of both shoes were made of synthetic leather and genuine leather. Fig. 1 shows two kinds of shoes: the standard shoes (top) and the mesh shoes (bottom). Table 1 shows the physical characteristics of the subjects.

**RESULTS**

Fig. 2 showed a comparison of the skin temperatures of frontal leg (top), instep (middle) and soles (bottom). Skin temperatures of frontal leg, instep and sole were mostly higher in the standard shoes than in the mesh shoes.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (yrs)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Surface area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>19</td>
<td>161.3</td>
<td>52.0</td>
<td>1.54</td>
</tr>
<tr>
<td>S2</td>
<td>19</td>
<td>166.5</td>
<td>48.5</td>
<td>1.53</td>
</tr>
<tr>
<td>S3</td>
<td>19</td>
<td>168.2</td>
<td>57.0</td>
<td>1.65</td>
</tr>
<tr>
<td>S4</td>
<td>19</td>
<td>158.0</td>
<td>47.0</td>
<td>1.45</td>
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<tr>
<td>S5</td>
<td>19</td>
<td>153.6</td>
<td>44.0</td>
<td>1.39</td>
</tr>
</tbody>
</table>

* Body surface area was calculated by the formula of Takahira (1925)
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Fig. 2 A comparison of average leg skin temperature (top), instep skin temperature (middle) and sole skin temperature (bottom) during three repeated schedules of 15 min walk and 10 min rest between two kinds of shoes. Closed circles: standard shoes. Open circles: mesh shoes. Mean ± S.E.M. (n = 5). *: P<0.05, **: P<0.01.

Fig. 3 showed a comparison of the skin temperatures of chest (top) and forearm (bottom). Skin temperatures of chest and forearm were significantly or apt to be higher in the standard shoes than in the mesh shoes.

Fig. 4 showed a comparison of the clothing microclimate temperatures of near frontal chest (top), near frontal leg (middle) and near sole (bottom). As seen in the figure, the clothing microclimate temperatures of near frontal leg and near sole were significantly higher in the standard shoes than in the mesh shoes mostly. The clothing microclimate temperatures of near frontal leg fell while walking and rose while resting in both shoes. The clothing microclimate temperatures of near sole continued to rise gradually throughout the experimental period.

Fig. 5 showed a comparison of the clothing microclimate humidity of near frontal chest (top), near frontal leg (middle) and near sole (bottom) between two kinds of shoes. Cyclic changes of the clothing microclimate humidity were observed in near frontal chest and near frontal leg in both shoes, corresponding nearly to walking and rest. The values tended to be lower in the mesh shoes throughout the experimental period, although significantly different partly. On the contrary to these, the clothing microclimate humidity of near sole was mostly higher significantly in the standard shoes. It was kept lower in the mesh shoes during the walking and rest.

Fig. 6 showed a comparison of the rectal temperature between two kinds of shoes during the whole experimental periods. Although there did not exist any differences till the end of first rest, the values became significantly higher in the standard shoes during the middle and the latter periods.

Fig. 7 showed a comparison of the heart rate between two kinds of shoes. The heart rate increased abruptly to 120 and 130 beats/min as soon as the subjects started to walk and slowed down to 80 and 90 beats/min as soon as they took a rest. Close observations demonstrated that the values tended to be higher and were significantly higher in the standard shoes during the walking. During the beginning of rest the value seemed to fall more sharply in the mesh shoes.

Fig. 8 showed a comparison of the damp sensation felt by the subjects while wearing the sports shoes. It is clearly seen in the figure that the damp sensa-
tion was greater in the standard shoes in three parts of the body: instep, sole and around toes. There were some subjects wearing the mesh shoes who never felt damp in instep, sole and around toes, while the subjects wearing the standard shoes felt damp slightly or considerably.

**DISCUSSION**

Most interesting findings are that rectal temperatures were higher in the standard shoes than in the mesh shoes. This means that how feet are covered differently could influence the whole bodily thermoregulatory responses. Higher levels of heart rates in the standard shoes might be closely related with the higher levels of the core temperatures in the standard shoes. Although the differences of core temperatures between two kinds of shoes were small, they might be of importance for the maintenance of homeothermy, since even such small differences of core temperature could have a significance as a signal on autonomic regulation such as sweating, forearm blood flow and shivering through central mechanism (Nakayama 1987, Aschoff et al., 1971).

What physiological mechanisms are responsible for the findings that the level of core temperature was different between these two kinds of shoes? Feet could play an important role for heat loss mechanisms (Aschoff 1958, Day 1968). As seen in Figs. 2 and 4, the sole skin temperatures and the clothing microclimate temperatures near the sole were slightly higher in the standard shoes. These higher temperatures would reflect the higher thermal insulation in the standard shoes. Lower temperatures in sole skin and the clothing microclimate near the sole in the mesh shoes were probably in-
Fig. 4 A comparison of average clothing microclimate temperatures near frontal chest (top), clothing microclimate temperatures near frontal leg (middle) and clothing microclimate temperatures near sole (bottom) during three repeated schedules of 15 min walk and 10 min rest between two kinds of shoes. Closed circles: standard shoes. Open circles: mesh shoes. Mean ± S.E.M. (n = 5). * : P < 0.05, ** : P < 0.01.

Fig. 5 A comparison of average clothing microclimate humidity near frontal chest (top), clothing microclimate humidity near frontal leg (middle) and clothing microclimate humidity near sole (bottom) during three repeated schedules of 15 min walk and 10 min rest between two kinds of shoes. Closed circles: standard shoes. Open circles: mesh shoes. Mean ± S.E.M. (n = 5). * : P < 0.05, ** : P < 0.01.
Fig. 6  A comparison of average rectal temperature during three repeated schedules of 15 min walk and 10 min rest between two kinds of shoes. Closed circles: standard shoes. Open circles: mesh shoes. Mean ± S.E.M. (n = 5). * : P < 0.05, ** : P < 0.01.

Fig. 7  A comparison of average heart rate during three repeated schedules of 15 min walk and 10 min rest between two kinds of shoes. Closed circles: standard shoes. Open circles: mesh shoes. Mean ± S.E. M. (n = 5). * : P < 0.05, ** : P < 0.01.

duced by the effective ventilation between sole and mesh shoes, resulting in more efficient and greater convective heat loss.

As the instep was covered by the mesh, the heat from the instep could be easily lost in the mesh shoes. As seen in Fig. 5 (bottom), the clothing microclimate humidity near the sole was lower in the mesh shoes both during walking and rest. This means that the evaporation is presumed to occur more efficiently in the mesh shoes, since the lower
humidity near sole in the mesh shoes could make the evaporation from the feet occur more easily. Thus, the mesh shoes seemed to be more effective for both the dry and wet heat loss from the feet to the surroundings in warm environments, resulting in the inhibition of increase in the core temperature and heart rate.

Our present results suggest how appropriate it is to select sports shoes which could help to accelerate dry and wet heat loss from feet to surroundings.

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REFERENCES

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