Journal of Ergonomics

Satsumoto et al., J Ergonomics 2016, 6:4
DOI: 10.4172/2165-7556.1000171

Research Article Open Access

Effects of Shoe Fit and Moisture Permeability of a Leather Shoe on Shoe Microclimate and Air Exchange

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Abstract

The purpose of this study was to investigate effects of shoe fit and moisture permeability of a leather shoe on shoe microclimate and air exchange Three kinds of leather shoe with different fit were compared, whose ball girth were tight fitted: 1E, medium fitted: 2E, loose fitted: 3E. It was also examined the effect of water vapor permeability of a leather shoe which would affect water vapor transfer in a shoe. We compared the artificial leather with the natural leather. Subject trials were carried out with above shoes in a climatic chamber under the condition of 30℃, 65%RH. The shoe microclimate of the foot and the velocity over the opening the shoe were measured. The subject walked on a tread-mill for 20 minutes after 10 minutes' rest and repeated twice. The experimental results showed that the absolute humidity in a shoe microclimate of the natural leather was lower than one of artificial leather at all part of a foot. It indicated that the water vapor transfer of the natural leather was larger than the artificial leather. The smaller the ball girth of shoe was, the larger the magnitudes of velocity near the opening, especially at the arch of the foot. The decrease of absolute humidity during walking in the arch was larger for tight fitted 1E than for the medium fitted 2E. It seemed the bellows action during walking. This fit effect was supported by our earlier study of the bellows action [1-3].

Keywords: Bellows action; Thermal comfort; Shoe microclimate; Heat and water vapor transfer

Introduction

Shoes have an important role to keep the feet from damaging by the environment and to make a person being comfortable during walking. However the modern fashions for young women's shoes are rather tight fitted and the toe shape of shoes is narrow, shoes itself sometimes make their feet injured and get sweaty. At that time comfortable shoes microclimate must be done by speedy heat and moisture exchange from the foot to the environment. There are three factors which affects the shoe microclimate. One is human factor, the second is human environmental factor and the third is a shoe factor.

About human factor, in a hot environment, during vasodilation venous blood returns near to the skin hence increasing the availability of heat loss from the skin to the environment. Arterio-venous anastomoses (called AVA for short) in feet region makes a role to increase heat transfer from the body to keep core temperature constant. In a hot environment, to increase heat loss, the AVA deep to the skin capillaries can open and reduce the fall in temperature along the length of the artery, hence increasing arterial temperature, raising skin temperature, and increasing heat loss [4]. The increase of skin temperature will make the shoe microclimate hot.

The human body has two types of sweat gland, eccrine and apocrine sweat glands. Apocrine glands are found in the armpits and pubic regions and eccrine glands are distributed on the other part of the body. Eccrine glands performs the thermoregulatory function. Soles of feet are one of the maximum distribution sites of average density of eccrine sweat glands [5]. The density of sweat gland at the plantar surface was compared with one of the dorsal surface within the foot. There were 420 glands/cm^2 on the plantar one and 250 glands/cm^2 on the dorsal one by Szabo [6] for European subjects and 320 glands/cm^2 on the plantar one and 144 glands/cm^2 on the dorsal one for the Asian subjects by Hwang and Bail [7] respectively measured by the anatomical method. The glands density is at least two times higher on the plantar surface than one on the dorsal surface for both results. Park and Tamura showed that during thermos-neutral conditions, the sweat evaporation on the plantar surfaces was significantly greater than other regions [8]. It is generally regarded the sweat rate is not proportional to the density of the glands, because the number of active sweat glands is not uniform [9]. It is shown that the local and total sweating rate of the body is proportional to core temperature [10]. However, as the sweat glands of the plantar surfaces are influenced by the emotional and anxiety states [11] and friction between the skin and the contact surfaces [12], it is not clear the sweating contribution of the plantar surface on thermoregulation under the thermal stress. It is commonly believed that the skin of the plantar does not participate in thermoregulatory sweating [13-15]. But Taylor et al. [16] indicated the sweat secretion from the plantar surface slightly increased during thermal stress and exercise loading. As the sweat increased more remarkably on the dorsal surface, about 70% of the sweat flow emanated from the upper skin surfaces and only 30% was from the plantar surface. Smith et al. [17] measured the body sweat distribution during running measured with technical absorbents and showed the sweating of plantar was.

In case of putting on shoes, in addition to thermal influence, as there are emotional and frictional influences, the sweat secretion of the plantar surfaces are likely to be higher than any other regions of the body. It will make a shoe microclimate higher.

About human environmental factor, as the increase of woman's participation in business and the latest fashion of long boot, they will feel very uncomfortable with stickiness because the moisture transfer was disturbed. After one had been wearing shoes for one day, it is better

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Received June 24, 2016; **Accepted** July 11, 2016; **Published** July 18, 2016

Citation: Satsumoto Y, Piao S, Takeuchi M (2016) Effects of Shoe Fit and Moisture Permeability of a Leather Shoe on Shoe Microclimate and Air Exchange. J Ergonomics 6: 171. doi:10.4172/2165-7556.1000171

shoes are rest two or three days. But the business men often had been putting on same shoes for some days. Because it makes the shoes sweaty and unhygienic, there are many "athlete's foot" among business men.

About a shoe factor, the water vapor permeability of the leather material of a shoe is about 1/200 of clothes. In addition, because it is easier to walk that the fitting of a shoe is tight, the shoe microclimate will tend to become sweaty.

It is well known that the bellows action during walking keep one's foot from being sweaty to some degree by increasing heat and water vapor transfer in shoes [18]. But it is not sure how the size factor and material property affect on bellows action. So in this study to improve the thermal comfort due to the microclimate in the leather shoe, it was evaluated by the wear trial that the effect of size factor and material property of the leather shoe on heat and water vapor transfer in the shoe.

Methods

Subject

This study aims to make clear the effect of the gap amount in the shoe on the shoe micro climate temperature-humidity in walking. So to set the gap amount strictly, a subject was set to one person. A healthy female student, aged 31 years old, volunteered as a subject. The characteristics of the subject are shown in Table 1.

Body surface area was calculated by Takahira's equation [19]. She was informed about the purpose of this study and experimental procedure and she gave her consent to participate in the experiments.

The size of a subject's foot was measured by the professional shoe fitter who works for Yoshinoya CO., LTD The foot length was 218mm and foot measurement (ball girth) was 229mm respectively for the average value of each foot as shown in Figure 1a. The comfortable size of shoes was checked by fitting. The favorite size of the subject was 2E for ball girth of shoe.

Variation of shoes

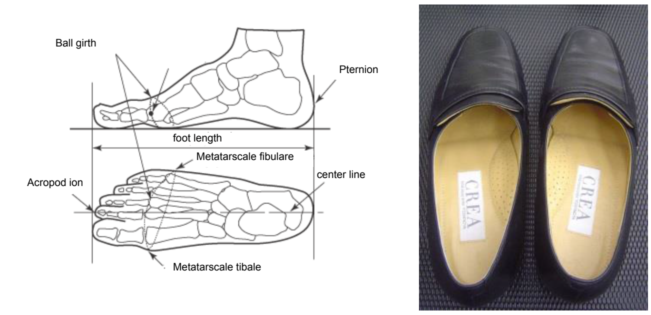
Size variation of shoes: As we usually put on brogue as a casual leather shoes, we chose brogue as the shape of sample shoes as shown in Figure 1b. We studied the effect of fitting of foot measurement (ball girth) as one of the size factor. Variation of shoes is shown in Table 2.

As the subject feel comfortable in putting on 2E for foot measurement (ball girth), we let the shoe maker try to make three kinds of shoes for foot measurement, tight fitted: 1E, medium fitted: 2E, loose fitted: 3E. Their size of foot measurement differs from each other 6mm pitch. Materials of them are natural leather both for surface leather and back one.

Material variation of shoes: We also examined the effect of water vapor permeability as one of the material property of leather shoes which would affect water vapor transfer in shoes. So we also let the shoe maker try to make the shoes of artificial leather, whose size was 2E for foot measurement (ball girth). We named it 2E-s.

To infer the shoe's garment property from the sheet's property of the shoe, test specimen, each of whose size was 0.2×0.2 m^2, was made and a laboratory experiment was done by using KES-FB system even though this method does not account for shoe garment design or fit. Characteristics of two leathers, which are used for shoe material, are shown in Table 3.

We measured the water vapor resistance by CH_3COOK method. The elastic property of two leathers is similar. The shearing property G for natural leather is 1.4 times as large as one for artificial leather. 2HG for natural one is smaller. Those means the natural leather is harder to shear and easier to return. Though the surface friction coefficients of natural leather is larger than one of artificial, surface smoothness of natural one is about 1.6 times as smooth as one for artificial leather. For compression property, artificial leather is easier to compress. For thermal property, the thermal conductivity of each leather is almost same, but water vapor resistance of artificial leather is about 1.12 times as large as one of natural one.



a) Measured point of foot b) Photograph of sample shoes

Figure 1: Schematic illustration of measured point of foot and photograph of examined type of shoes.

Age (years old)	Height (cm)	Body mass (kg)	Surface area (m2)	Foot length (mm)	Foot measurement (mm)
31	150	42	1.34	Right217 Left219	Right233 Left225

Table 1: Characteristics of a subject.

Examined shoe	1E	2E	3E	2E-s
Ball birth (mm)	225	231	237	231
Foot length (mm)	225	225	225	225
Material of leather	natural	natural	natural	artificial

Table 2: Variation of trial shoes.

Material property	Symbol /unit	Natural Calf skin	Artificial leather
Elongation	EM (%)	6.44	6.11
	LT (−)	0.779	0.874
	WT (g・cm/cm²)	12.8	13.5
	RT (%)	43	50.8
Shearing	G (g/cm・deg)	8.06	5.87
	2HG (g/cm)	16.7	19.3
Surface	MIU (−)	0.435	0.379
	MMD (−)	0.0192	0.0145
	SMD (μm)	0.79	1.24
Compression	LC (−)	0.315	0.491
	WC (g･cm/cm²)	0.122	0.157
	RC (%)	53.4	52.7
Thickness (mm)		1.13	1.31
Thermal conductivity (W/m/K)		0.82	0.83
Water vapor resistance (s/m)		15277	17116.5
Bending and air permeability property cannot be measured because of hardness of leather.			

Table 3: Physical characteristics of materials.

Procedures

The subject was dressed in a 100 % cotton two-piece wear with long sleeves and short trouser, panty and a pair of knee length stockings and put on each type of shoes Subject trial was carried out in an artificial climatic chamber under the condition of 30℃, 65%RH and lower than 0.2 m/s.

Experimental procedure was shown in Figure 2. Thirty minutes before the experiment, we made a subject enter and stay in the climatic chamber to acclimatize a subject to the chamber and to attach the sensor elements to the subjects' body. After sensors were attached, the subject sat on chair. Then the experiment started. It took sixty minutes. After the subject had been sitting on the chair for 10 minutes, she had been walking for 20 minutes with treadmill (O_2ROAD21:made by Takei industrial corp.) at the speed of 4km/hr and she had been sitting on the chair for 20 minutes and she had been walking at the same speed for 10 minutes again. For four shoes subjective experiments were tested. To confirm the reproducibility, for each shoes experiments were repeated three times for evaluation.

Shoe microclimate: The microclimate of shoe was measured by using temperature-humidity sensors (Vaisara CO., LTD) at 5 points of the foot once a second during a test. The positions of sensors are an instep, an arch, a big toe, a little toe and under an ankle as shown in Figure 3.

Velocity near the opening of shoe: To clarify the effect of a fit of shoes on bellows action, the following experiments were conducted. The velocity was measured once a second with 8 anemometers at the ankle part of leg which was surrounded opening of shoe as shown in Figure 3 as an index of ventilation by the bellows action during three kinds of shoes with a different fit were worn. Walking was done for 120 seconds, and the velocity data was collected to the data logger once a second respectively. The anemometers comprised a pair of temperature of hot wire ball and voltage sensor (QB-5, Tohnic CO., LTD) as shown in Figure 4.

Bottom pressure during gait motion: When the person is standing in standing posture, it is said that weight is supported 50% by the heel, 25% by the first toe, and 25% by the other four toes [20]. However it is not clear what distribution the pressure of the plantar region becomes when shoes were worn and walking. Therefore the walking on the treadmill was done under the four-speed condition for each shoes sample. It was 2 km/hr (slow walking rate), 4 km/hr (normal walking rate), 6 km/hr (slow running rate), and 8 km/hr (normal running rate) respectively as for the speed. Walking was done for 120 seconds, and the pressure data was collected to the data logger once a second respectively. Bottom pressure during walking was measured by using air pack pressure sensor (AMI 3037, AMI CO., LTD) at a heel and a base of toe in back of foot as shown in Figure 5. The first 20 seconds and the last 20 seconds were rounded down among the data that had been taken for 120 seconds, and the maximum value was taken for 80 seconds.

Results

Micro climate in shoe environment

The absolute humidity in microclimate of shoe was shown in Figure 6. They were different from one another among the size of shoe. When the size of foot measurement was 3E, the absolute humidity was smallest almost at the all positions and any time even at rest. It seems due to free convection because there were enough gaps for 3E. Second one was 1E. The maximum humidity was when size was 2E, which means sweaty in microclimate.

The difference of microclimate by positions was remarkable as shown in Figure 6. The maximum humidity at the big toe reached over 25 g/m^3 in any sizes of shoe. It was most sweaty around the big toe and around the little toe, it was secondary sweaty in the all cases. These results are reasonably understood because the toe part is located most distant from the opening as the shoe structure. The third sweaty part was instep. The humidity at instep was low in the first rest and increased in the first exercise remarkably. It was because instep is one of the skins which had the thermal sweat gland. In opposite to other positions, the humidity at the arch decreased in the first exercise and increased slowly in the second rest and decreased again in the second exercise. This was due to the effect of ventilation from the shoe to the environment by the bellows effect of shoe. The bellows effect was most remarkable when the size was 1E.

The absolute humidity in microclimate of shoe made of natural leather, 2E was lower than one of artificial leather 2E-s almost at all part of foot. It is consistent with the study of Mitsui et al. (1999) [21].

Figure 7 shows the average value of temperature in the microclimate during the first exercise. The order of temperature was 2E-s > 2E > 1E > 3E.

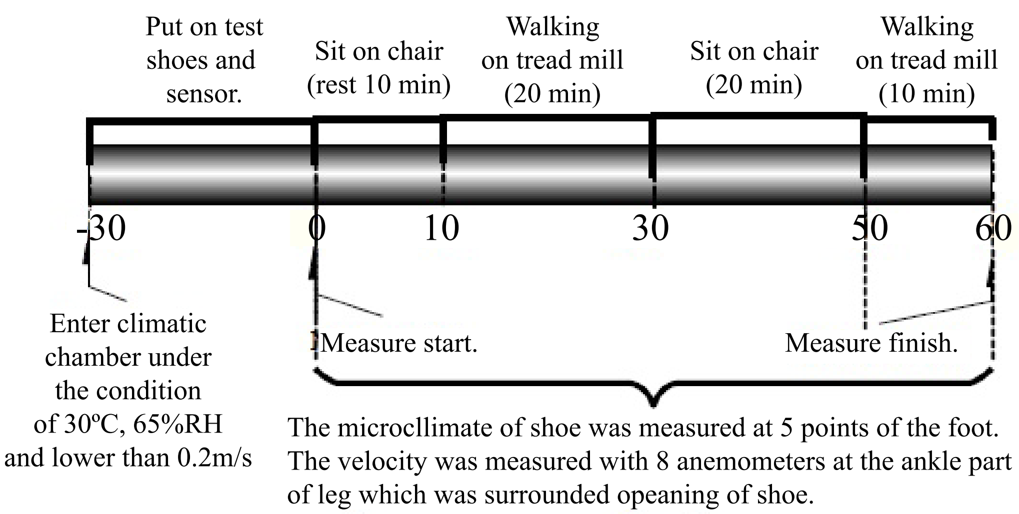


Figure 2: Experimental procedure.

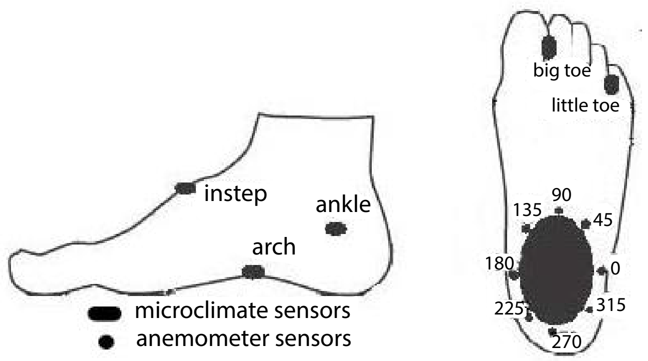


Figure 3 Positions of sensors.

a) a foot with sensors. b) a pair of sensors.

Figure 4: Photograph of anemometers attached to ankle part of foot.

Figure 5: Photograph of bottom pressure sensor attached to heel part of foot.

So it was found that the heat and water vapor transfer occurred harder above order. The reason that temperature of 2E-s was higher than one of 2E was that the water vapor permeability of natural leather was larger than artificial leather as shown in Table 3. Nowadays the permeability of artificial leather is improved. But the natural one is still more comfortable than artificial one.

Because the environmental condition was hot and humid, it had hardly occurred heat and water vapor transfer after exercise. So the absolute humidity in the microclimate was almost higher than environmental one after exercise. Only few conditions were opposite tendency as follows. The absolute humidity of 3E was lower than environmental one in the second rest at the instep, under the ankle, and at the arch. Absolute humidity of 1E became lower than environmental one both in the first and the second walking.

Velocity near the opening of shoe affected by bellows action

Figure 8 shows the velocity of the right shoe's exchanged air in the by bellows function in case of wearing shoes of three level of tightness.

The air velocity with the tightest-fit (1E) was the highest among the three sizes of the shoe. The second was that of proper fit (2E), and the velocity of the one-size larger (3E) shoe was the smallest. The figure also shows that the velocity at toe and at heel were the smallest. The velocity at "front-left" and "rear-left" was the largest. The velocity in right side of foot was larger than that in left side.

The previous study of our laboratory (Satsumoto et al., 2000, 2003) [1-3] demonstrated that the narrower the space between foot and shoe, the higher velocity of exchanged air. The velocity in microclimate was calculated by the theoretical analysis as shown in equation (1).

$$u=-1/s \; ds/dt \; x \qquad (1)$$

Where: x: space coordinates along the plate

(Zero point is bottom of the space)

u: velocity of x axis, s: air gap between skin and plate; t: time

The results in this study can be understood as the narrower space between foot and shoe makes large the pressure difference between in the shoe and the environment. And this leads to the effective the bellows function and to the large rate of air exchange. This signifies that higher fittingness for shoe to foot is better to obtain good ventilation and not to make foot sweaty in shoes.

Bottom pressure during walking

Figure 9 shows the bottom pressure at heel. In the heel bottom pressure, one of proper size (2E) was largest, and, one of pitch size (1E) was middle and one of the loose (3E) was smallest as shown in Figure 9. It is shown that for a proper size, braking by the heel and the promotion operation in the toe root are smoothly done and the gait performance is high.

Conclusion

To improve the thermal comfort due to the microclimate in leather shoes, it was evaluated the effect of size factor and material property of leather shoes on heat and water vapor transfer in shoes. We studied the effect of fitting of foot measurement as one of the size factor. We compared three sizes, tight fitted: 1E, medium fitted: 2E, loose fitted: The smaller the foot measurement was the larger the magnitude of velocity near opening of shoe, especially at the arch of the foot. Therefore it was shown that the fitting affected the bellows action during walking. Because the air except the arch stagnated and became sweaty even though during walking, As the absolute humidity in microclimate of shoe made of natural leather, 2E was lower than one of artificial leather 2E-s almost at all part of foot. However, the natural leather use in shoes development goes against the more recent world claim for preserving the animal habit and reducing human consumption of animal resources. Therefore, considerations about the development of artificial materials, with better performance, must be taken.

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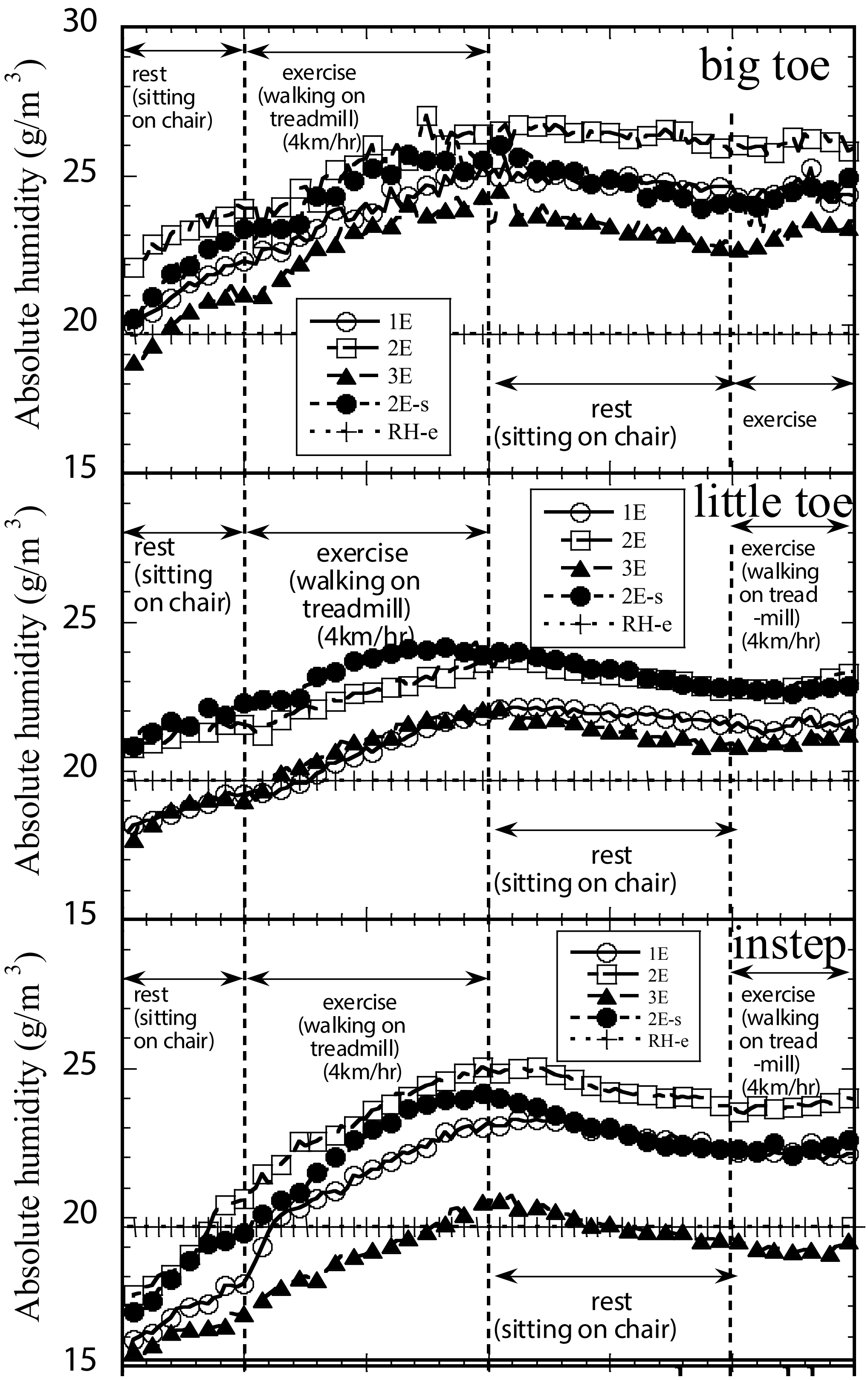

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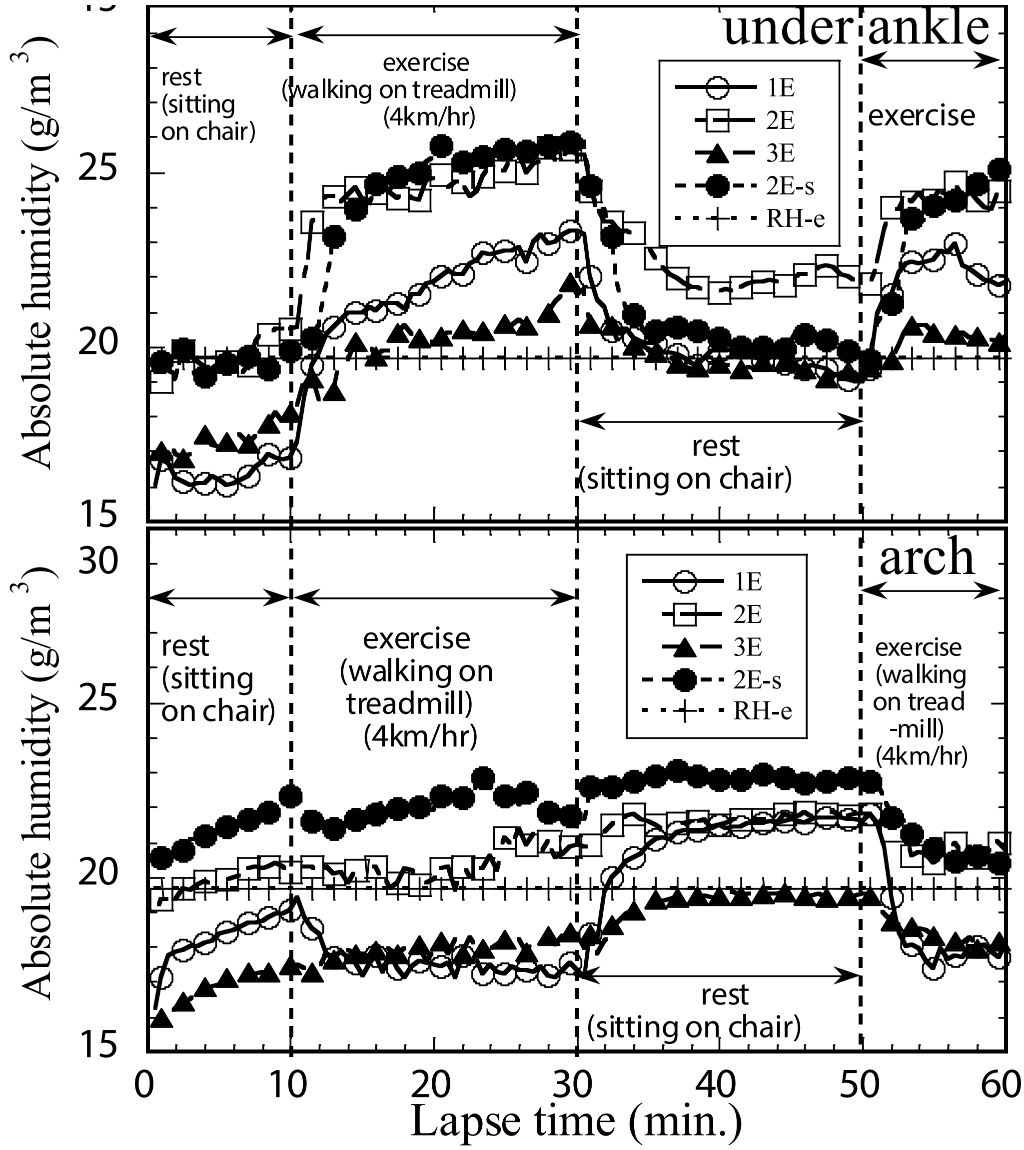

Figure 6: Absolute humidity in shoe environment.

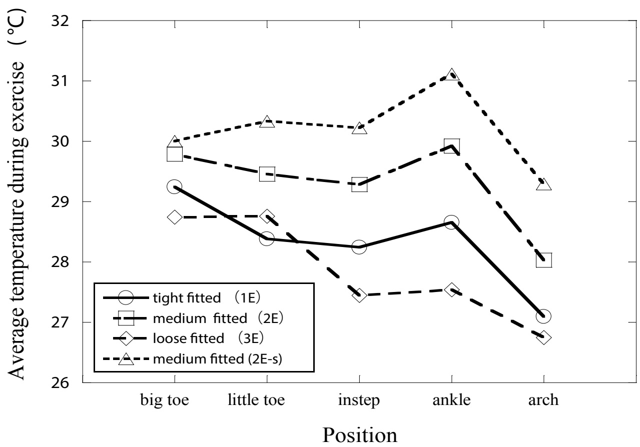

Figure 7: Average temperature in shoe environment during first exercise.

wearing shoes of three level of tightness.

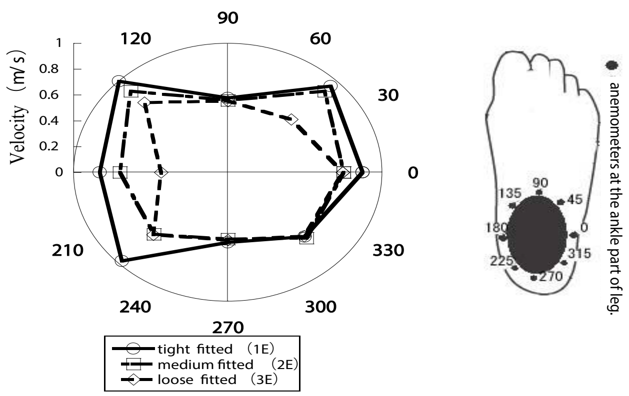

Figure 8: Velocity at near the opening of right shoe.

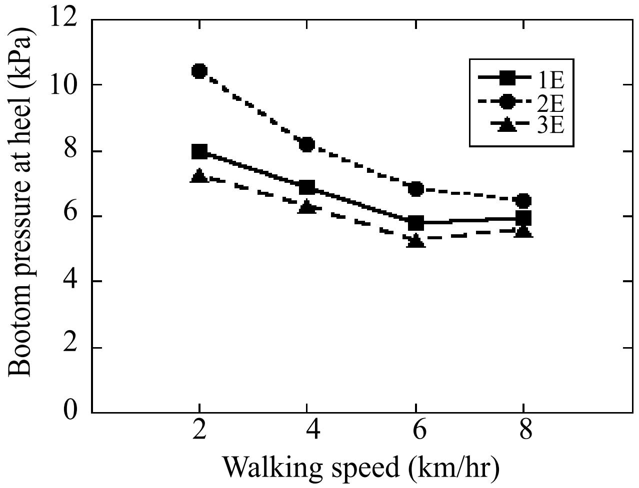

Figure 9: Bottom pressure at heel during walking.

Acknowledgements

This study was partially supported by a grant-in aid for scientific research (B) from the Ministry of Education and Culture, Japan, from 2003 to 2004. We thank subject who participated in this study.

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