THE EFFECT OF SIZE FACTOR OF LEATHER SHOES ON VENTILATION RATE IN SHOES

Yayoi Satsumoto[1], Masaaki Takeuchi[2] and George Havenith[3]

[1] *Faculty of Education and Human Sciences, Yokohama National University,*
79-2 Tokiwadai, Hodogaya, Yokohama, 240-8501 JAPAN
[2]*Faculty of culture and sport policy, Toin University of Yokohama,*
1614 Kurogane-cho, Aoba, Yokohama, 225-8503 JAPAN
[3] *Environmental Ergonomics Research Centre*
Loughborough University Design School,
Ashby Road, Loughborough, Leicestershire, LE11 3TU, UK

Contact person: satumoto@ynu.ac.jp

INTRODUCTION

It is well known that bellows action during walking keep one's foot from becoming too sweaty to some degree by increasing heat and water vapor transfer in shoes. But it is unclear how the size factor affects the bellows action. So in our previous study (Satsumoto et al,2006) , the effect of the fit of leather shoes as one of the size factors was evaluated with respect to heat and water vapor transfer in shoes. In that test the microclimate temperature and humidity and air velocity near openings in leather shoes was measured. We compared three sizes, tight fitted: 1E, medium fitted: 2E, loose fitted: 3E.

The results in our previous study showed that the smaller the ball girth circumference of shoe was, the larger the magnitude 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. This fitting effect was supported by our earlier study of the bellows action (Satsumoto et al., 2000, 2003).

This signifies that a higher level of fit for shoe to foot is better to obtain good ventilation and not to make foot sweaty in shoes.

However, the air velocity around the opening does not show ventilation itself; it would be better to check the effect of the fitting factor on ventilation rate.

Satsumoto et al. developed a device to evaluate the ventilation of diapers by using a tracer gas dilution method (transient method) (Satsumoto et al. , 2010).

In the present study, the device designed to evaluate the ventilation of diapers was applied to measure the ventilation of shoes by using the steady state tracer gas method and to allow localized microclimate ventilation measurements in different locations in the shoes. The effect of the fitting of shoes on microclimate air exchange due to ventilation between the interior of the shoes and the ambient atmosphere was studied quantitatively during walking.

METHODS

Subjects

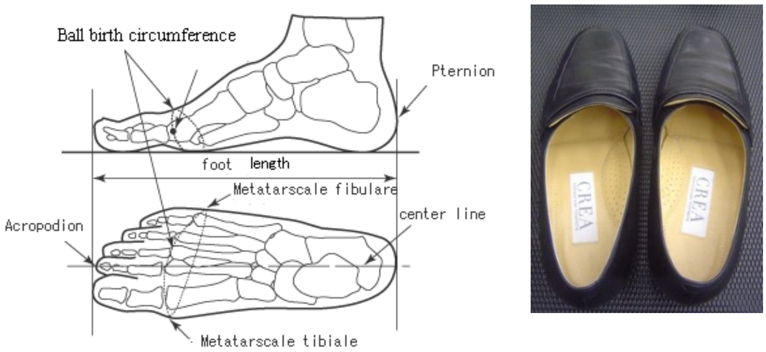
Table 1 Characteristics of subjects.

Height (cm)	Body mass (kg)	Surface area (m^2)	Comfortable Size of shoes	Foot length (mm)	Ball birth circumference (mm)
165.0	50.0	1.55	24.5	Right236	Right237
			2E	Left237	Left240

To evaluate the size fitting property of shoe, a female volunteered as a participant. The characteristics of the participant are shown in Table 1. Body surface area was calculated by Takahira's equation (1925). The comfortable size of shoes was found to be 24.5 (2E) by fitting. The favorite size of the subject was also 2E.

Size Variation of shoes

As we usually put on brogue as a casual leather shoe, we chose brogue as the shape of sample shoes as shown in Fig.1b. We studied the effect of fitting on ball birth circumference as one of the size factor.



a) Measured point of foot b) sample shoes.

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

As the participant felt comfortable in putting on 2E for ball birth circumference, we let the shoe maker, Yoshinoya Ltd., try to make three kinds of shoes for a ball birth circumference, tight fitted: 1E , medium fitted: 2E, loose fitted: 3E. Their ball birth circumferences are 237, 243, 249 respectively as shown in Table2. Their size of ball birth circumference differs from each other 6mm pitch. The foot lengths are same. Materials of them are natural leather both for surface leather and back one.

Table 2 Variation of trial shoes.

Examined shoe	1E	2E	3E
Ball birth circumference (mm)	237	243	249

Tracer gas methods

A steady state tracer gas method was used for measuring air exchange in clothing (Havenith et al., 2000, 2010). In the case of the previously used transient method, a measurement to estimate the air volume under the clothing is needed (Berglund, 1997) to calculate the air ventilation rate. As it is hard to measure air volume during the tracer gas experiment, which is also expensive and time consuming (Havenith & Zhang, 2000), we chose the steady state method to reduce the repetition error caused by variations in air volume. The steady state method does not need the air volume under the garment/shoe to calculate the microclimate ventilation rate.

Steady state tracer gas system

Figure 2 shows the schematic diagram of the ventilation system. The tracer gas (100% CO_2) was mixed with fresh air and a set flow (mass flow controller & meter model MQV, Yamatake CO., LTD) was introduced in the shoes via a gas distribution tubing system. The concentration in the inlet tubes was determined by a CO_2 analyzer (GMP343, Vaisala CO., LTD). The CO_2 concentration of the inlet air was adjusted to about 3500ppm.

Microclimate air samples were taken with an identical tubing system (outlet), and outlet concentration was determined by the fore mentioned gas analyzer (switching [3 way valves] between inlet and outlet with the same analyzer avoids influence of sensor differences).

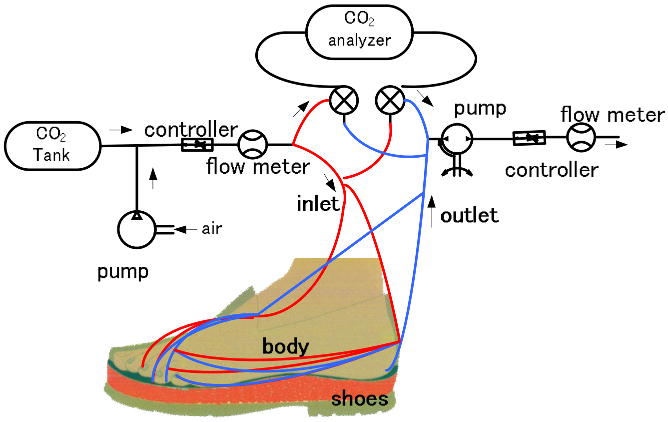


Fig.2 Schematic diagram of ventilation system.

The inlet flow rate (V_{in}) and outlet flow rate (V_{out}) must be controlled to precisely the same value (0.5 l/min) in case of the steady state tracer gas method to avoid introducing forced ventilation. The pump and the flow controller were used to manage the steady state flow.

$$V = V = V \qquad (1)$$

The background concentration in the room was monitored by the CO_2 analyzer.

Tube distribution in the micro space of shoes

The inlet and the outlet tube were branched to 8 or 4 distribution / sampling tubes respectively to make the CO_2 concentration underneath the shoes uniform. The diameter of tubes were 1.25mm outside diameter and 1.0mm inside diameter at the end parts and relatively hard tubes are used not to collapse even if it is placed with the foot and shoes or weight is put on it.

To enhance the uniformity of CO_2 concentration in the micro space, the tube distribution system was revised twice as follows.


Front view Side view Back view (sole)

Fig.3 Photograph of tube locations in case of second experiments.

For first experiments, the amounts of tubes were 8 each for inlet and outlet ones.

In the first revision (second experiment), sixteen holes for each side (totally thirty two holes) were drilled at 1cm pitch from the end of the tubes to 17cm from the end of the tube. As it seems that the sample tubes' location may be very important for the result, we set tubes on the sole position to enhance uniformity more. In the second revision (third experiment), as tubes were too tight in side position, the amounts of tubes were 4 each for inlet and outlet. Figure 3 shows tube locations of second one. In test the tubes are covered with net to keep the position.

Walking effect

To estimate the effect of walking on the ventilation of the shoes, the participant kept walking at 4km/hr on the treadmill during the test.

Measurement procedure

The experiment was carried out in an air conditioned chamber at 26±2.0 ℃, 65±10% relative humidity. After the tracer gas circulation pumps were switched on, the inlet CO_2 concentration was adjusted to about 3500ppm. Then the flow rate of inlet and outlet were equalized and monitored. Then by switching 3 way valves, the CO_2 concentration of inlet and outlet were monitored and recorded until all concentrations reached a steady state. The CO_2 concentration of the environment was monitored and recorded before and after experiments.

Method of Analysis

For the steady state method, the steady state data of CO_2concentration at the inlet (CO_2in), outlet (CO_2out), the atmosphere in the box (CO_2e) and the flow rate (V) in and out of a shoe are needed to calculate the microclimate ventilation rate (VENT) shown in equation (2) .

$$\mathrm{VENT} = \mathrm{V} \times \frac{\quad}{\quad} \qquad (2)$$

Where, CO_2in: the CO_2 concentration of the inlet (ppm), CO_2out: the CO_2 concentration of the outlet (ppm), CO_2e: the CO_2 concentration of the atmosphere in the box (ppm), V: flow rate both inlet and outlet (l/min.).

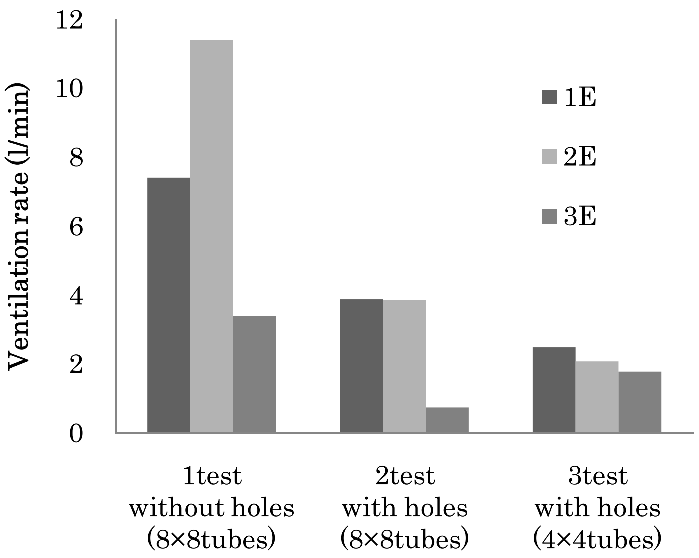


Fig4. Overall microclimate ventilation rate of shoes.

RESULTS

Result of overall ventilation

Effect of the tube distribution on ventilation rate

To enhance the uniformity of CO_2 concentration in the micro space, the tube distribution system was revised twice. As shown in Fig.4, by revision of the tube distribution, the level of ventilation rate (VENT) is reduced and stable. The difference of levels is not a problem for our comparative testing, but it may be if we need absolute data. In comparison the amounts 8×8 tubes each for inlet and outlet, with the amounts of 4×4 tubes, there are too little spaces between tubes especially in side position to measure. It seems that 4×4 tube each inlet and outlet is suitable distribution to measure.

Effect of the fitting factor on ventilation rate

It is seen that the smaller the ball birth circumferences of the shoe, the larger the microclimate ventilation rate is. This agrees with our previous results by measuring microclimate absolute humidity and velocity near openings (Satsumoto et al., 2006).

Results of local microclimate ventilation rate

The local distribution of ventilation rate is shown in Fig.5. The difference of microclimate by positions was remarkable. The maximum ventilation rate was seen in instep and second one is in big toe, third one is in ankle and last one is in an arch. These results are not corresponding to our previous experimental results by microclimate data (Satsumoto et al.,2006). These results are not reasonably understood because the toe part is located most distant from the opening as the shoe structure and the maximum humidity at the big toe reached over 25 g/m^3 in any sizes of shoe in our previous study. It seems that to set too many tubes decrease the spaces between tubes, which leads the un-uniformity of CO_2 concentration in the micro space. So we will try the further experiments in the revised 4×4 tubes condition in the near future.

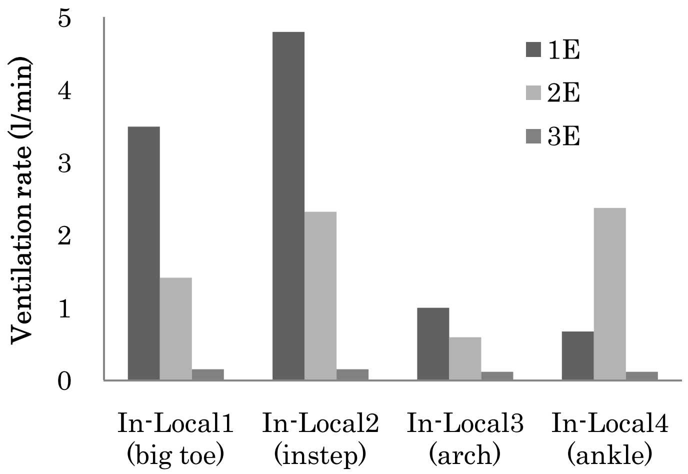


Fig.5 Local distribution of ventilation rate for shoes.

As for effect of fitting factor, it is also seen in almost all local positions that the smaller the ball birth circumferences of the shoe (tighter fit), the larger the local microclimate ventilation rate is.

CONCLUSIONS

A device designed to evaluate the distribution of the ventilation in diapers was applied to measure the ventilation of shoes by using the steady state tracer gas method and to allow localized microclimate ventilation measurements in different locations in the shoes. The effect of the fitting of shoes on microclimate air exchange due to ventilation between the interior of the shoes and the ambient atmosphere was studied quantitatively during walking.

Experimental results indicated that ventilation was affected by the fitting of ball birth circumference, which was one of the size factors of the shoes. It was seen that the smaller the ball birth circumferences, i.e. the tighter the fit, the larger the microclimate ventilation rate was. This agreed to our previous results by measuring microclimate absolute humidity and velocity near openings of shoes (Satsumoto et al., 2006).

As for the local ventilation values, the ventilation of the instep and big toe was larger than one of the arch and ankle. It was not reasonably understood because the toe part was located most distant from the opening as the shoe structure and the maximum humidity at the big toe was shown in any sizes of shoe in our previous study. It seems that to set too many tubes may decrease the spaces between tubes, which leads to an un-uniformity of CO_2 concentration in the micro space. So we will try the further experiments in the revised 4×4 tubes condition in the near future.

Acknowledgments

We give thanks to Unicharm Corporation for their help to this study. We thank the students of Yokohama National University who participated in this study, especially to Mr. Liu Yu for his experimental help, who is a student of Yokohama National University graduate school of education (masters' course).

REFERENCES

1. Berglund, L. G. and Akin, F. J., (1997), Measurement of air exchange in diapers by tracer gas methods, TAPPI J., 80(9), 173–178.
2. Havenith, G. and Zhang, P., (2000), Comparison of Different Tracer Gas Dilution Methods For The Determination of Clothing Vapour Resistance, EPSRC Report on Project GR/N10509/01.
3. Havenith, G., Zhang, P., Hatcher, K., Daanen, H., (2010), Comparison of two tracer gas dilution methods for the determination of clothing ventilation and of vapour resistance, Ergonomics,53(4), 548–558.
4. Satsumoto Y., Havenith. G., (2010), Evaluation of overall and local ventilation in diapers, Textile Research Journal, Vol. 80, No.17, 1859-1871.
5. Satsumoto Y., Ito Y., Hasebe Y., Takeuchi M., (2003), The Effect of Bellows Action on Heat Transfer in Clothing System Part2 The Effect of Opening condition of Clothing. Sen'i Gakkaishi, 59(1), 22-29.
6. Satsumoto Y., Shanhua P., Takeuchi M., (2006), The Effect of Size Factor and Material Property o Leather Shoes on Heat and Water Vapor Transfer relating to Shoes Microclimate, Proceedings of 8th International conference.
7. Satsumoto Y., Wang H, Hasebe Y., Ishikawa K., Takeuchi M., (2000), The Effect of Bellows Action on Heat Transfer in Clothing System Part 1 The Effect of Size of Air Space and Air Permeability of Clothing. Sen'i Gakkaishi, 56(11), 524-536.
8. Takahira H., (1925), Metabolism of Japanese part2, Method of measurement of body surface area of Japanese,1 (1)61.