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Characteristic of foot surface temperature variety during continual low-intensity exercise

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ABSTRACT

Foot thermography information is very important to the footwear's functional design. The purpose of this study is to investigate the distribution and change character of foot skin temperature variety during low-intensity movement. Totally 19 subjects participated in this testing, skin surface temperature monitor was using high-precision Infrared Thermal Imager. The average foot skin temperature existed a significant difference at rest condition. After 30min persistent low-intensity exercise, each area of the foot was increased, and the increasing trend was quite similar. This study could provide the basis of foot physiological function understanding.

KEYWORDS

Foot;
Skin temperature;
Continual exercise;
Youth.

INTRODUCTION

The skin temperature (ST) is an important index of physiological activity to analyze thermoregulation. Thermography as a non-destructive, touch-less and fast temperature measurement method can scan the whole body point by point within a few seconds, and provide comprehensive information of ST. Thermal infrared imager was widely applied in the fields of sports science[1,2,5,8,11,18]. such as diagnosis and forecast of injury, assessment of training quality, investigate of sports equipment etc. Feldman et al.[3] took the thermal images of cervical vertebra and upper body in healthy people, which positively promoted the application and development of thermal infrared imager, and found that it was normal that the temperature difference on both sides of trunk was no more than 0.62 °C

However, due to the limitations of the experimental conditions, measurement site was properly limited[15]. established the information of the whole body ST through dividing the whole body into 40 sites and measuring mean temperature respectively[10]. visualize the human body anterior cutaneous temperature variations in well-trained runners during graded exercise using high-resolution thermal imaging equipment. They found that at the exercise interruption, cutaneous temperature values were in average 3–5 °C lower than at baseline. Cutaneous temperature increased during recovery from exercise. During moderate intensity and high-intensity exercise, ST presented three phases of decrease – increase – balance [6,7]. During submaximal exercise, participants showed significant changes of core temperature and marked decrease of skin temperature in forehead[17].

Besides these studies on the whole body, there was local ST. After 10min typing, opisthenar ST of office worker was went up[4]. What's more, someone[6,7]. observed that hand ST was persistently increasing followed by decrease with exercise progressed[12]. did a vibration test with 40 subjects and found that small temperature changes significantly influence vibration sensitivity of healthy subjects and should be controlled during collection of foot sensitivity data. Sawa*et al.* (2013) considered that reducing plantar skin temperature induces gait variability among healthy young adults.

Therefore, monitoring ST provides very useful information concerning thermolysis modalities and peripheral vasoregulation during exercise. Furthermore, this was the first time to study on ST of different foot anatomic sites using high-precision thermal infrared imager during continual low-intensity exercise. The aim of this study was to observe different foot anatomic sites temperature changing as exercise progressed, which could help understanding foot physiological function and supply important evidence for footwear company.

METHODS

Participants

Nineteen young healthy male volunteers (26.3±1.2 years; 171.7±2.7cm; 65.4±6.5kg) participated in this test without any disease and pedopathy. All participants had no strenuous exercise 24 hours before the experiment. They were in good condition and no-float in the experiment.

Instruments

The high-precision thermal infrared imager (DaLi, type DL700, China) was used in the test, with spatial resolution of 1.13mrad, image pixels of 384×288 and temperature range of -20°C~+500°C. The instrument coming with the thermal images analysis and processing software needed to be calibrated before test. And other equipment including a treadmill, stopwatch, temperature and humidity tester were also used.

Experimental environment

The test was completed in an airtight laboratory commanding the relative humidity in the range of 60% to 70% with air-conditioning and heating. And the room temperature was controlled at 26 °C with fluctuation range of no more than 1 °C. Indoor air flow was stable and no strong infrared radiation source around during the test.

Regions

The foot surface was divided into three regions and ten sub-regions (Figure 1) to understand the foot ST in detail. Medial foot (MF): medial forefoot (N1), medial mid-foot (N2), medial hind-foot (N3) and medial ankle (N4). Instep (B): fore instep (B1), hind instep (B2). Lateral foot (LF): lateral forefoot (W1), lateral mid-foot (W2), lateral hind-foot (W3) and lateral ankle (W4).

Procedures

This study used a low-intensity jogging as a continual exercise, and treadmill has been controlled very well, treadmill speed: 8km / h; slope: 0 °C; total time: 30min. ST has been scanned every five minutes during jogging.

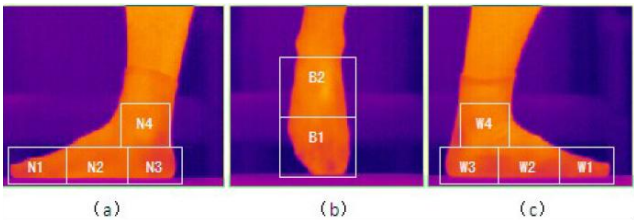

Figure 1 : The regions of foot surface, (a) medial foot, (b) instep, (c) lateral foot

Statistical analyses

Thermography was analyzed with the analysis software of thermal infrared imager. All data were presented as means and SD and statistical analyses were carried out using SPSS11.5 statistical analysis software. Independent-samples T test and paired–samples T test were employed to study the distribution of ST, and repetitive measure ANOVA was used for ST changes comparison with the level of statistical significance was set at the 5% level.

RESULTS

The foot ST in ten sub-regions at rest was shown in TABLE 1. In medial foot region, the mean ST in N2 and N4 was higher than that in N1 and N3, so was in lateral foot region. For instep region, the mean

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ST in B2 was higher than that in B1. Compared with all sub-regions, the maximum ST was in N4 and B2 and the values were 31.6±0.8°C and 31.5±0.9°C, respectively; the minimum ST was in W1 and W4 and the values were 29.2±1.5°C and 29.6±1.4°C, respectively.

TABLE 1: The distribution of ST in 10 subregions at rest ($\bar{X}$±s)

Sub-regions	ST max℃	ST min℃	Mean ST℃
N1	31.3±0.9	28.5±1.5	30.0±1.2
N2	32.6±0.7	29.8±1.2	31.1±0.8
N3	31.7±0.7	29.2±1.3	30.3±1.0
N4	33.0±0.8	29.9±0.7	31.6±0.8
W1	30.5±1.1	28.0±1.8	29.2±1.5
W2	32.2±0.9	28.4±1.4	30.2±1.1
W3	30.9±1.3	28.4±1.7	29.6±1.4
W4	32.6±1.1	29.3±1.1	31.0±1.0
B1	32.1±1.0	28.3±1.6	30.3±1.1
B2	32.8±1.0	29.7±0.9	31.5±0.9

The ST between regions showed a marked difference at rest ($p<0.01$, TABLE 2). We found similar mean ST of 30.8±0.9° C and 30.9±1.0° C in medial foot region and instep region, respectively. And the minimum ST of 30.0±1.2°C was in lateral foot. Moreover, the difference of STmax and STmin between regions appeared the same trend of mean ST.

TABLE 2 : The ST values in three regions at rest ($\bar{X}$±s)

Regions	ST max℃	ST min℃	Mean ST℃
MF	32.2±0.7	29.4±1.1	30.8±0.9
LF	31.5±1.0**	28.5±1.5**	30.0±1.2**
B	32.5±1.0	29.0±1.1	30.9±1.0
Regions	ST max℃	ST min℃	Mean ST℃
MF	32.2±0.7	29.4±1.1	30.8±0.9
LF	31.5±1.0**	28.5±1.5**	30.0±1.2**
B	32.5±1.0	29.0±1.1	30.9±1.0

Note: compared with MF, ** $p<0.01$

The foot ST in three regions and ten sub-regions after 30min exercise was shown in TABLE 3 and TABLE 4. From the tables, value of mean temperature, maximum temperature and minimum temperature did not show significant difference neither in ten sub-regions nor in three regions ($p>0.05$). It illustrated that the whole foot ST would tend to consistent after a certain time continual exercise.

The foot ST in three regions during 30min exercise was shown in TABLE 5. From the table, as the exercise progressed, the foot ST increased. At the fifth minute, the ST in the lateral foot and instep region was close to the temperature at rest, while that was lower in medial foot region. In general, the ST was decreased at the onset of exercise. What's more, we found that the mean ST in medial foot and instep region after 15min exercise was higher than the counterpart before 10min exercise (including 10min); meanwhile it occurred at the 20th minute in lateral foot region. This suggested that the time 15min of sustained low-intensity sports was a turning

TABLE 3 : The distribution of ST in 10 subregions after 30min exercise ($\bar{X}$±s)

	ST max℃	ST min℃	Mean ST℃
N1	34.4±1.0	32.3±1.1	33.5±1.0
N2	34.7±1.1	31.9±1.5	33.4±1.3
N3	33.9±1.3	31.3±1.2	32.6±1.2
N4	34.8±1.0	30.8±3.0	33.4±1.1
W1	33.5±1.2	31.1±1.1	32.5±1.2
W2	34.1±0.9	31.3±0.9	32.8±1.0
W3	34.0±1.2	31.1±1.3	32.7±1.2
W4	34.6±0.6	31.7±0.9	33.2±0.8
B1	34.3±1.1	31.4±1.2	33.0±1.2
B2	34.7±1.0	32.0±1.2	33.4±1.1
F	1.101	0.792	0.787
P	0.376	0.624	0.630

TABLE 4 : The distribution of ST in 3 regions after 30min exercise ($\bar{X}$±s)

Regions	ST max° C	ST min° C	Mean ST° C
N	34.5±1.0	31.6±1.6	33.2±1.1
W	34.0±0.9	31.3±1.0	32.8±1.0
B	34.5±1.0	31.7±1.2	33.2±1.1
F	0.422	0.190	0.361
P	0.662	0.828	0.702

TABLE 5 : The variation of mean ST in three regions during exercise ($\bar{X}$±s)

Mean ST° C	Medial foot	Lateral foot	Instep
rest	30.8±0.9	30.0±1.2	30.9±1.0
10min	31.2±2.2	30.6±1.3	31.5±1.5
15min	32.2±1.3*	31.3±1.1	32.4±1.2*
20min	32.5±1.6*	31.7±1.4*	32.6±1.3*
25min	32.9±1.0**	32.3±0.8**	32.8±0.6**
30min	33.2±1.1**	32.8±1.0**	33.2±1.1**

Note: compared with the values measured before 10min, * $p<0.05$, ** $p<0.01$

point of changing foot ST for the whole foot. It could be seen visually in the Figure 2.

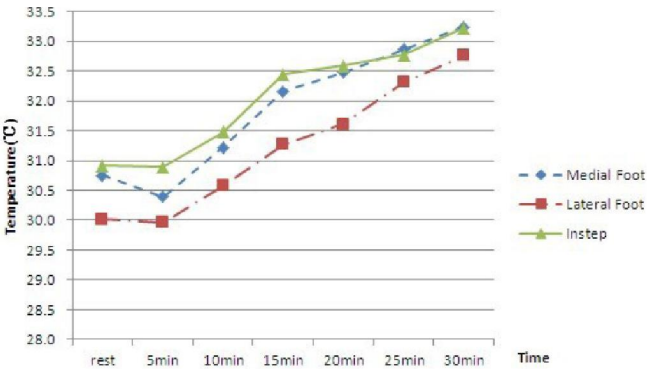

Figure 2 : The variation of mean ST in three regions during exercise

DISCUSSION

The human body is a spontaneous source of infrared radiation, emitting infrared radiation continually to the surrounding. The body's infrared radiation owning its special physiological mechanism and structural basis has a close relationship with energy metabolism, heat balance and organization structure. Skin is the most important place of the body heat transfer. The structural characteristics of the skin blood circulation determine that skin blood flow can change in a wide range[9]. ST changes by a variety of factors, mainly related to the skin microcirculation blood flow, sympathetic nervous excitability level as well as metabolic activity of local organizations. Furthermore, it may be affected by the ambient temperature, air flow, the human spirit state and secretory activity of sweat glands[19]. Therefore, the related condition exercised strict control over the same level to ensure objective and accurate test data in this study.

The results of this study indicated that the foot ST values were effectively different between these regions at rest. It was most likely due to the differences in the distribution of innervation and cutaneous/tissue vascularization between peripheral and central regions[14]. As previous literatures report, the ST was distinct from various parts of body which was the more close to the trunk and head the higher, otherwise, the limbs ST was relatively lower[9]. Therefore, temperature needed to be considered when making shoes.

And we found another result that the ST dropped after the start the exercise. As the exercise progressed, the ST was increased in all three regions and presented to be consistent. These findings of the present study were supported by many researchers[7]. Exercise is associated with large hemodynamic changes involving multiple regulatory processes. Blood circulation is fundamental for heat removal from deep regions of the body and heat transportation to cutaneous layers. At the beginning of the exercise, the ST was fallen. A cutaneous vasoconstrictor response attributable to an increase in catecholamine and other vasoconstrictor hormones released in order to satisfy the supply of blood for activated muscles[16]. However, as time going, exercise caused more heat generation within the body resulting in vasodilation and invoked cutaneous thermo-regulatory processes.

CONCLUSION

In this study, the temperature of foot cutaneous surface was monitored using thermal infrared imaging system during continual low-intensity exercise yielding a specific time evolution of cutaneous temperature modifications. Generally, foot ST was shown to be increased during low-intensity movement, but different regions exists temperature difference. It seems 15 minutes like turning point after which the temperature increasing slowly. The results in our study provide the basis of understanding foot physiological function and supply objective evidence for producing shoes functional property especially like footwear comfort.

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