Study on the Thermal-wet Comfort Property of Socks Based on Infrared Thermal Imaging Technology

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Abstract

Based on infrared thermal imaging device, the temperature distributions of feet surface after rest, jogging under wearing cotton/blended/bamboo fiber socks were measured. And the subjective comfort questionnaire was designed, the hotness and wetness feeling of the feet after rest/jogging under wearing socks with different materials were assessed. Based on the research, the socks that suit for the unevenly distributed heat of feet were designed.

Keywords: Infrared Thermal Imaging Technology; Socks; Thermal-wet Comfort

1. Introduction

Infrared thermal imaging system coordinates the infrared optical lens with infrared sensors, according to the measured radiant illumination of the infrared spectrum, to achieve non-contact optical temperature measurement. The early infrared technology is mainly applied in the fields of military, spectroscopy, non-destructive testing, commercial multi spectral imaging analysis, resource remote sensing, infrared astronomy, traffic, wind cut transformation, medical treatment, public security, etc. Infrared technology has been widely used in other fields, such as military, medical, and meteorological. But its application in the textile and garment industry is relatively short. The application of infrared temperature measurement technology in textile and clothing industry is mainly concentrated on textile fabrics testing. By means of infrared thermal image instrument combined with constant temperature water bath test device, Wang Yunyi et al [1] had studied the heat and moisture transfer performance and its coupling phenomena of the soybean protein composite fiber, modal fiber and blended fabric of products. Chen Yisong and the others' [2] experiments proved that it's more effective to measure the temperature of body and clothing surface with the help of infrared camera. Because it's hard to do contact the rmography in some processes (such as slashing drying and dehydration fabric drying material, fabric heat setting, etc) in the textile industry, therefore, the method of infrared radiation temperature measurement is worthy of extensive promotion and application.

In terms of the influence of three kinds of different conditions, namely, the firing rate of prefabricated specimen, measuring position of prefabricated specimen and the luminance of pattern by infrared radiation on the measurement results of the infrared thermometer, Dong Xia and the others[3] had found out the optimum conditions and methods for the accurate temperature measurement. Gong Xiaozhou ,Xia Yu and the others[4] had respectively tested the heat and moisture conductivity, permeability and heat dissipation of body armor which uses warp knitted spacer fabric as lining, and had discussed the warp knitted spacer fabric`s influence on body armors' comfort performance. What's more, the feasibility of improving bulletproof equipment`s comfort performance by warp knitted spacer fabric had also been tested. With the positive result, the traditional lining (plain woven) is replaced by warp knitted spacer fabric and finally made into garments. Sa Liu, Yunhong Li and the others [5] had calculated and evaluated thermal conductivity of carbon fiber fabric by infrared thermal imaging technology. Firstly, the temperature time curve of carbon fiber fabric is obtained by analyzing and calculating of the thermal image, and the thermal conductivity of the material is deduced. Secondly, the factors that affect the accuracy of measurement are analyzed. The infrared method offers a new way to evaluate the thermal conductivity of carbon fiber fabrics.

However, the infrared technology is rarely used in socks comfort research and temperature measurement. As an indispensable part of people's daily life, socks directly influence people's physical health and psychological comfort. In summer or after taking large amount of exercise, if the socks are not moisture absorbed and ventilated enough, people would feel hot and uncomfortable. In winter, if the socks are not warm enough, uneven temperature distribution will freeze the toes. This project is aimed at analyzing the temperature changes and distribution of the feet when people are at rest and after jogging by thermal imaging technology in order to design a kind of socks that are suitable for hot and wet condition.

2. Experiments

2.1 Experimental Instruments and Materials

The instrument is T250 FLIR infrared thermal imaging system, the thermal imaging sensor is 240, the infrared image resolution is 0.08 pixels X180 pixels, and the temperature range is -20 to +350. The thermal imaging system transforms the infrared radiation quantity into an electronic video signal, and forms the infrared thermal: imaging of the target by the electronic processing [6]. This experiment uses three pairs of socks respectively made of cotton, polyester cotton blended (65% cotton, 35% polyester), and bamboo fiber.

2.2 Experimental Conditions and Methods

The experimental conditions is（25±1）℃ and the relative humidity is 50% ± 5%. The subjects are three young female college students aged 21 years old. The final experimental results are derived from the average value of the results of the 3 tests. During the experiment, the subjects wearing the same socks enter the experimental environment. After adapting to the environment for 30 min in the stationary state, then at a distance of about 50cm, use the infrared thermal imaging instrument to shoot the instep and sole of subjects that have rested/jogged for 10 min (at the speed of 5km/h) to get infrared thermal Image in the moment of the socks were taken off. Thereafter, the temperature distribution of the foot surface is analyzed by infrared thermal imaging system software.

3. Results and Analysis

3.1 Experiment Results

Figure 1 is the thermal image at the moment of the cotton socks were taken off form the subjects' feet after resting for 30min. The brighter the place is, the higher the temperature is, and vice versa.

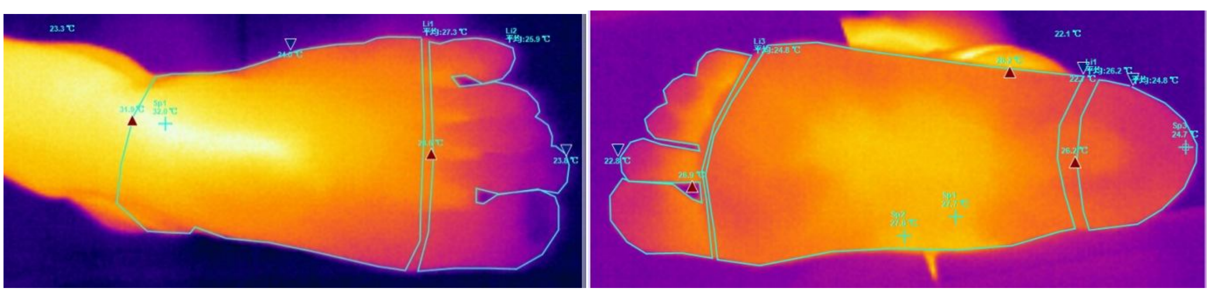

Fig.1: Temperature Distribution of feet Wearing Cotton100% socks at Rest for 30min

Table 1 is the maximum temperature of the instep and sole after wearing cotton, polyester cotton blended yarn, bamboo fiber three material socks for 30 minutes at rest, can be easily sorted out that the descending maximum temperature order of the instep and the sole is: Cotton > polyester / cotton blended > bamboo fiber.

Table 1: The Highest Temperature of the feet under Wearing Three Kinds of Material Socks at rest for 30min (℃)

Materials	max TEMP of instep	max TEMP of feet
cotton	32.0	28.6
P/C blended	30.9	28.1
bamboo fiber	30.6	27.2

Table 2 is the average temperature of each part of the foot in three materials. From table 2, it can be seen that under wearing three material socks at rest 30 minutes, the descending average temperature order of each part of feet is: cotton > polyester / cotton blended > bamboo fiber.

Table 2: The Average Temperature of the Various Parts of Feet under Wearing Three Material Socks at Rest 30min

Materials	instep	toes	feet	toe bottom	heel
cotton	27.3	25.9	26.2	24.8	24.8
P/C blended	25.8	24.4	25.4	24.3	24.5
bamboo fiber	26.2	24.0	24.9	23.7	24.5

Table 3 is the maximum temperature of feet wearing cotton, polyester cotton blended yarn, bamboo fiber three material socks after 10 minutes jogging. It can be seen that the descending maximum temperature order of the instep and the sole is: cotton > polyester / cotton blended > bamboo fiber. The highest temperature of instep is the place between the toes. Under wearing cotton and polyester cotton the highest temperature position of the soles is the bottom of the place between the toes. Under wearing bamboo fiber the highest temperature position of the soles is center.

Table 3: The Highest Temperature & Positions of Them Wearing Three Material Socks after Jogging 10min (℃)

Materials	max TEMP of instep	max TEMP of feet	Position of max TEMP of instep	Position of max TEMP of feet
cotton	36.8	36.8	Between toes	Bottom between toes
P/C blended	36.7	36.6	Between toes	Bottom between toes
bamboo fiber	34.5	33.2	Between toes	Center of instep

Table 4 is the average temperature of each part of the foot in three materials. From table 4 it can be seen that under wearing three material socks after jogging 10 min, the descending average temperature basic order of each part of feet is: ton > polyester / cotton blended > bamboo fiber.

Table 4: The Average Temperature of the Various Parts of Feet under Wearing Three Material Socks after Jogging 10min (℃)

Materials	instep	toes	feet	toe bottom	heel
cotton	33.4	34.6	33.8	33.6	33.3
P/C blended	33.1	34.6	33.7	34.0	32.6
bamboo fiber	28.2	30.9	28.7	29.2	26.9

Figure 2 is the thermal image at the moment of the cotton socks were taken off form the subjects' feet after jogging for 10min. The brighter the place is, the higher the temperature is, and vice versa.

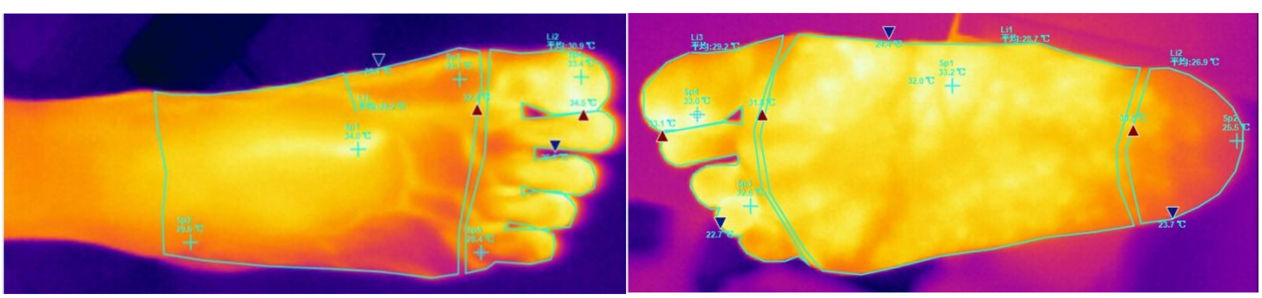

Fig.2: Temperature Distribution of Feet under Wearing Bamboo Fiber Socks after Jogging 10min

For the sweating point and exerting point of human feet are mainly in the soles of the feet, feet skin surface is divided into five regions respectively : the instep (F1), the toe (F2), feet (F3), toe bottom (F4), heel (F5), as shown in figure 3. Figure 4 gives the average temperature changes of the five regions under wearing three kinds of materials of socks at rest 30 minutes. Figure 5gives the average temperature changes of the five regions under wearing three material socks after jogging 10 minutes.

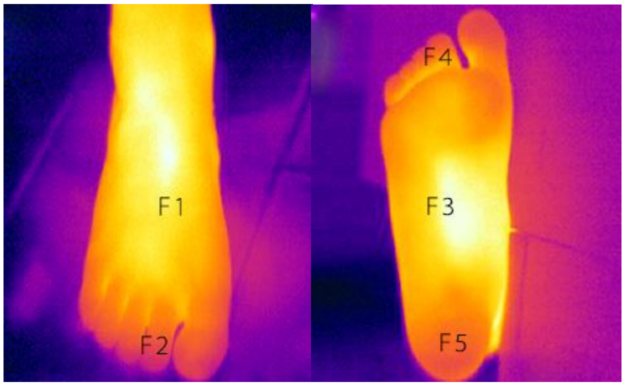

Fig.3: Regional Division

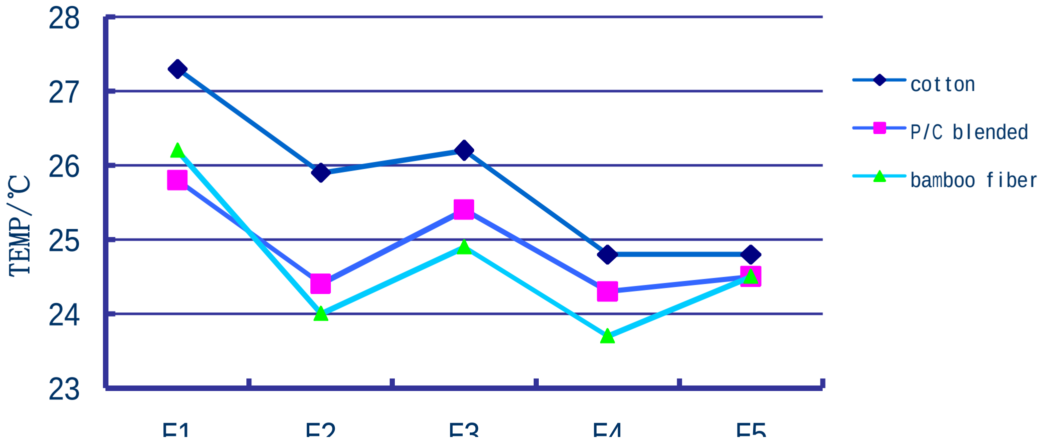

Fig.4: The Average Temperature Changes of the Various Parts of Feet under Wearing Three Material Socks at Rest 30min

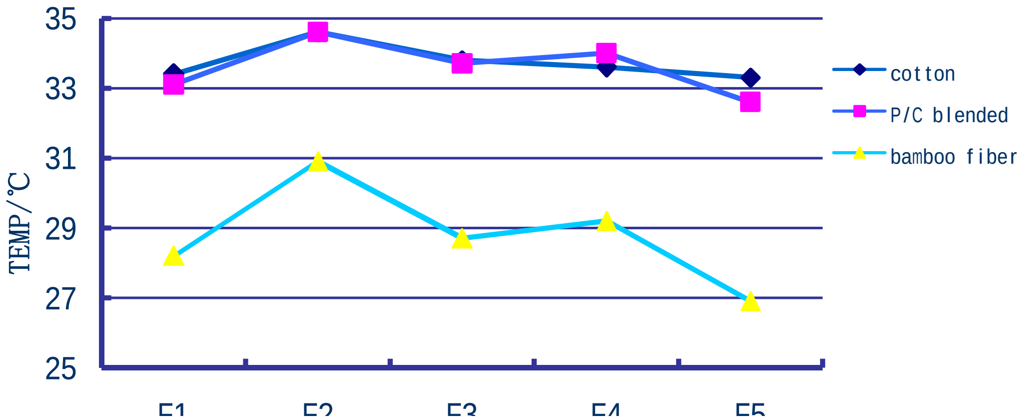

Fig.5: The Average Temperature Changes of the Various Parts of Feet under Wearing Three Material Socks after Jogging 10mim

As for the divided regions, the questionnaire about subjective comfort was designed, and two subjective feeling assessments for the five regions were recorded. Subjective feeling assessment is made up of hotness and wetness. The final result is the average of the two subjects' assessment results. This subjective feeling assessment was in 5 levels, the minimum value is 0, and the maximum value is 4. The higher the value is, the heavier the hotness or wetness is. Related subjective levels can be seen from table 5 and table 6.

Table 5: Scale of Subjective Hot Feeling Assessment

Value	Meanings
0	especially cold
1	cold
2	pat
3	hot
4	especially hot

Table 6: Scale of Subjective Wet Feeling Assessment

Value	Meanings
0	especially dry
1	dry
2	pat
3	wet
4	especially wet

Table7 and 8 give respectively the results of subjective assessment of hot and moisture feeling t after jogging 10 min/at rest 30min.

Table 7: Results of Subjective Assessment for Hotness and Moisture Feeling at Rest 30min

	cotton(H)	P/C blended(H)	bamboo fiber(H)	cotton(W)	P/C blended(W)	bamboo fiber(H)
F1	2	2	2	2	1.5	1.5
F2	2	2	2	2	2	1.5
F3	3	3	2	2.5	2	2
F4	3	3	2	2.5	2	2
F5	2	2	2	2	1.5	1.5

Table 8: Results of Subjective Assessment for Hotness and Moisture Feeling after Jogging 10min

	cotton(H)	P/C blended(H)	bamboo fiber(H)	cotton(W)	P/C blended(W)	bamboo fiber(H)
F1	4	4	3.5	3	3	2.5
F2	3.5	3	3	3.5	3	2.5
F3	4	4	3.5	3.5	3.5	3
F4	4	4	3.5	4	3.5	3
F5	3.5	3.5	3	3	3	2.5

3.2 Analyses and Discussions

According to the experiments, the conclusions were: firstly, when at rest, the maximum temperature of five regions is higher, and the highest temperature is at the instep artery; Compared with the average temperature, the heel and toes is 1 to 2℃ (from table 1, table 1) lower than foot and instep. But in motion, the temperature of the foot`s five regions is about the same, the highest temperature is in the toes. In terms of average temperature, the heel part is still slightly lower than the sole, instep and toes. But the average temperatures of other parts are basically the same (Table 3, table 4). Secondly, among the three kinds of socks made from cotton, polyester cotton blended yarn, and bamboo fiber insulation of cotton socks is the best; bamboo fiber diathermanous performance is better. Specific analyses are as follows: From table 1, table 2 and Figure 4, it can be seen that the temperature of the instep is always the highest under any circumstances. While the temperatures in the heel and toes are the lowest. The temperatures of any part of the feet are the highest when they wear cotton socks, while the lowest temperature appeared when wear bamboo fiber socks. We can arrive at a conclusion that at rest the thermal insulation performance of cotton is better; while in the movement state, the bamboo fiber has the lowest heat preservation performance.

According to table 3, table 4 and figure 5, it can be seen that the toes, which had the lowest temperature at rest, turn out to be the highest because of the friction between joints after a 10-minute jogging. While in several other regions, the temperature difference is not that great. And heel’s temperature is still the lowest in the foot. It can be seen that bamboo fiber temperature is minimum in the five regions among the three types of material .So we can conclude that bamboo fiber has the best performance of diathermy. From table 7, table 8, it can be seen that at rest the results of subjective assessment for hotness feeling of cotton socks and polyester / cotton blended socks is highest and experimental results are consistent. It also shows that the thermal performance of cotton socks is good. And in a state of motion, bamboo fiber socks have the lowest subjective assessment for hotness and moisture feeling. It is about the same with experimental data, so bamboo fiber moisture thermal performance is the best.

4. Conclusions

The temperature distributions of foot measured by the infrared thermal imaging instrument, combined with the subjective assessment results, it can provide reference for designing the thermal and wet comfortable socks. From the above analysis, it was concluded that the warmest socks were made of cotton fiber, and the most comfortable socks of thermal-wet transmitting were bamboo socks. In the station of sports, the temperature of the instep and the sole of the feet are very high, especially the sole of the feet has more obvious feeling of moisture, so the in instep and part of the sole of the feet can choose bamboo fiber. The heel temperature is always very low, and the humidity is not high, so cotton fiber or polyester/cotton blended fiber can be chosen; toes are the hottest and wettest in the sports station, so the bamboo fiber can be chosen. Based on the experimental data of the infrared thermal imaging technology and the subjective assessment results, it can provide references for the design of thermal-wet comfortable socks.

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References

Wang yunyi, Yu qingwen, etal, The new heat and moisture coupling recycled fiber fabrics,Textile Journal, 2008, 29 (2): 37-45.

Chen yisong, Xu jun, Infrared the rmography used in the evaluation of fabric insulation performance, Textile Journal, 2007, 28 (12): 81-83.

Dong xia, Xu weilin, Yao mu, The application conditions and methods of infrared thermometers used in the textile, Journal of Northwest Textile Science and Technology University, 1997,11 (3):262-267.

Gong xiaozhou, Guoyilun, et al, The comfort improving design of body armor. Technology Research of Protective Equipment, 2013, 6 (3):9-12.

Liu sha, Li yunhong, Wang yannian, Evaluation the thermal conductivity of carbon fiber fabric base on the infrared thermal imaging technology, 2010 National conference of science Instrument innovation and application technology study, 2010,4 (2): 84-87,91.

Wu zongfan, the principle and technological development of infrared the rmography, Optics and optical instruments, 1997 (2): 28-43.