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Effects of Two Cooling Garments on Post-exercise Thermal Comfort of Female Subjects in the Heat

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Abstract: The purpose of the study was to investigate and compare the effect of two cooling garments with phase change material (PCM) and ventilation on thermal comfort. Eight female university students (age 24±1 years; height 162±4 cm; body weight 54±4 kg) exercised on a treadmill in an environment of 32 °C with 50 % relative humidity. Tests in three conditions were carried out after moderate exercise with t-shirt and shorts: cooling with a PCM vest (PCM); cooling with a ventilation jacket (VEN) and without cooling clothing (natural cooling, a control condition, CON). Results showed that no significant differences were observed in the mean skin temperature and heart rate among the two cooling garment conditions and the control condition ($p>0.05$). The local torso skin temperature was observed with significant difference among the three conditions ($p<0.05$) and it was mostly reduced by 0.7 °C and 0.9 °C, respectively in PCM and VEN. Significant differences were observed in the clothing torso micro-climate temperature and humidity among the three testing scenarios ($p<0.05$). The clothing micro-climate temperature was dropped by 2 °C in PCM and 0.8 °C in VEN. The clothing micro-climate humidity in PCM was 40 % higher than that in VEN after 30 minutes cooling. The perceived thermal sensation was the lowest in PCM whereas the perceived skin wettedness sensation was the lowest in VEN.

Keywords: PCM and ventilation cooling garments, Micro-climate, Thermal sensation, Skin wettedness

Introduction

Work or exercise preformed in hot environments can result in hyperthermia, which is characterized by impaired work productivity and performance [1,2]. It has been well documented that increased body temperature is detrimental to health in sporting events, military training and industrial settings in the heat [3-6]. Over the past few decades, various cooling garments have been developed to combat heat strain and improve thermal comfort in hot environments, such as, cooling vests with ice packs or phase change material (PCM) packs [7-11], garments with air or water cooling [12,13] and garments with forced air ventilation [14-17].

Phase change materials (PCMs) are latent heat storage materials and they absorb or release heat during phase change with a narrow temperature variation [18]. Clothing incorporated with PCMs has been used in protective clothing and have been reported to be effective in improving thermal comfort [9,10]. They have also been applied in sporting programs and some researchers reported that they were helpful in reducing the skin temperature [13,19] while others obtained opposite and negative results [20,21].

Clothing with ventilation has also been utilized in hot environments and most of the application was in the protective clothing [14-17]. Without the ventilation sweat secreted was often not evaporated and dripped from the body which would be a waste of cooling potential [22]. The ventilation could improve body cooling by increasing sweat evaporation.

It has been reported that even after the exercise and during resting in hot environments the body temperature may continue to rise [10,23,24]. The increasing body temperature with the induced heat disorders can threaten the safety of the workers or the athletes. Some past researches have focused on the cooling effectiveness of using different cooling strategies after exercises or during the industrial operation [13,20,25]. These cooling strategies included whole body immersion, passive resting and the employment of cooling garments, etc. It is generally accepted that the whole body immersion in cold water is the most optimal strategy for persons with hyperthermia which however, was not applicable in real practice and not necessary for non-acute situations [13,26]. Barwood *et al.* compared the efficiency of five post exercise cooling techniques, including hand immersion in cool water, whole body fanning and cooling by garments of air, liquid and PCMs. Based on the mean body temperature change the whole body fanning was represented as the most effective and practical cooling strategy among these five techniques [13]. Brade *et al*. examined the cooling rates of two jackets with PCMs (the melting temperature was 17 °C) and gels and found that no cooling benefits were associated [20]. Of relevance, few studies have been conducted to

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compare the cooling efficacy and thermal comfort of the PCM garment and the ventilation garment.

Previous studies carried out by the authors have investigated the cooling performance of PCM garments and ventilation garments respectively on thermal manikins. The study of PCM garments indicated that clothing evaporative resistance was increased by wearing PCM garments and they brought effective cooling in hot humid environments but a negative effect in hot dry environments [27]. The other study of ventilation garments demonstrated that clothing opening design and fan location could affect the feature of local cooling [28]. The present study was a further investigation on these two types of cooling garments. The purpose of the study was to compare the effect of these two garments (PCM garment with a melting temperature of 24 °C and ventilation garment with two integrated electrical fans located at the belly) on thermal comfort used by female subjects after exercise. Besides, the clothing micro-climate affected by these two garments was also the emphasis. It was hypothesized that the magnitude of improving thermal sensation, thermal comfort and clothing micro-environment would differ among the two cooling garments and compared to the natural cooling method (a control condition).

Experimental

Subjects

Eight female university students, unacclimatized to heat, were recruited to participate in the study which was approved by Donghua University. They had the following characteristics (Mean±SD): age=24±1 years; height=162±4 cm; body weight=54±4 kg; body surface area=1.51±0.07 m^2; body mass index=19.1±1.0 kg m^{-2}. They were notified not to drink coffee or tea 2 hours before the test or alcohol 24 hours before the experiment. Heavy exercise was not allowed at least one hour before the participation. The subjects were addressed briefly on the purpose of the study and the experimental procedure. Their written consent was obtained prior to beginning the test.

Cooling Garments

Two types of cooling garments were used in the study. The detail characteristics are shown in Table 1. The PCM garment was in the construction of a polyester vest with no sleeves and was incorporated with 21 PCM packs inserted in the pockets of inner vest layer [27]. The pockets were in the same size of the PCM packs to hold them tightly. The PCM packs could be inserted easily when used or taken out when not used. The melting temperature of phase change (T_m) of the PCMs was 24 °C. The total weight of the PCM vest was 2.14 kg and with a total thermal insulation of 0.75 clo. The total evaporative resistance of the PCM vest was 0.0402 kPa·m^2/W measured on a sweating thermal manikin by the heat loss method [29,30]. It was worn on top of a t-shirt and was worn tightly around the torso by adjusting the Velcro sewn on the placket.

The other cooling garment was a ventilation jacket with long sleeves which was equipped with two small fans with a diameter of 10 cm and each fan was embedded at the left and right belly of the jacket [28]. The fans were powered by four AA batteries of 2300 mAh and when they were connected to the battery box an air flow rate of 12 l/s (0.012 m^3/s) was produced. The total weight of the ventilation jacket was 0.6 kg. The total thermal insulation and the evaporative resistance of the whole ventilation clothing (the fans were turned off) were 0.74 clo and 0.0173 kPa·m^2/W, respectively. It was also worn on top of the t-shirt. Before the experiment the two garments were placed at room temperature of about 20 °C for at least 24 hours for the PCMs solidifying and the ventilation clothes pre-conditioning.

Experimental Condition, Procedure and Measurement

Experimental Condition

Each subject participated in three trials with three different cooling conditions: (1) cooling by the PCM vest (PCM); (2) cooling by the ventilation jacket (VEN); and (3) without any cooling garment and wearing short sleeve sports T-shirt and shorts (total thermal insulation 0.6 clo) (a control condition, CON). In all the three conditions, the climate chamber was set to 32±0.5 °C, 50±5 % relative humidity with an air velocity of 0.4 m/s. All trials were randomized to diminish the effect of order and all subjects performed at the same time of the day to minimize the circadian fluctuation.

Test Procedure and Measurements

When the subjects came to the lab they were required to put on the same short sleeve running t-shirt and shorts. Each subject had a set of these outfits for her own which were cleaned after each test and were used again in the next test. During preparation, all the clothing and equipment (i.e. chest strap, pulse monitor and sensors) and the subject (semi-nude

Table 1. Detail characteristics of the two cooling garments

	Textile material	Clothing construction	Cooling resources	Thermal insulation (clo)	Evaporative resistance (kPa·m^2/W)	Clothing weight (kg)
PCM vest	100 % polyester	Sleeveless	PCMs (T_m=24 °C)	0.75	0.0402	2.14
Ventilation jacket	100 % polyester	Long sleeves	Forced air ventilation by small fans	0.74	0.0173	0.6

with running bra and briefs, and with the clothing and equipment on) were weighed separately on a weighing scale (accuracy: ±5 g).

Skin temperature sensors (thermistors, 285-661, RS Component Ltd., UK, accuracy ±0.1 ^{o}C) were attached by tapes (produced by 3M company) on the forehead and the left side of chest, belly, scapula, lower back, upper arm, forearm, hand, thigh and calf. Temperature sensors (PT100, 362-9834, RS Component Ltd., UK, accuracy ±0.1 ^{o}C) and humidity sensors (HIH4000-001, RS Component Ltd., UK, accuracy ±2 %) were attached on the running t-shirt at the chest and the scapula to measure the clothing micro-climate temperature and humidity [31]. The skin temperature, the clothing micro-climate temperature and humidity were recorded by a LabVIEW® program (National Instrument, USA) at an interval of 15 s. Heart rate was monitored and recorded by a heart rate monitor and a chest strap (t6c, SUUNTO, Finland).

Each test included two stages. First, the subject exercised on a treadmill for 30 minutes (Motorized Treadmill 1000, Sport Art Ind. Co. Ltd.) at a walking speed of 4 km/h with 0 % inclination. During the exercise, they wore the running t-shirt and the shorts. After 30 min exercising, the pre-conditioned PCM vest (PCM) or the ventilation jacket (VEN) was put on immediately (for the VEN condition the fans were turned on at the same time), or they passively rested without any cooling garment in the same environment (CON). Then the subject rested for 30 minutes in one of these cooling conditions. Throughout the whole test the thermal sensation, skin wettedness sensation and thermal comfort of the whole body and the torso were asked and recorded every ten minutes. For the thermal sensation evaluation, a rating scale of 9 points (-4=very cold, -3=cold, -2=cool, -1=slightly cool, 0=neutral, 1=slightly warm, 2=warm, 3=hot, 4=very hot), and for the skin wettedness sensation, another rating scale (0=normal, 1=slight wet, 2=wet, 3=very wet) and a rating scale of 5 points for the thermal comfort (0=comfortable, 1=slightly uncomfortable, 2=uncomfortable, 3=very uncomfortable and 4=very, very uncomfortable) were utilized, respectively [32].

Calculations

Mean skin temperature (T_{sk}) was calculated using the equation: $0.07(T_{forehead}+T_{upper\ arm}+T_{forearm})+0.175(T_{chest}+T_{back})+0.05T_{hand}+0.19T_{thigh}+0.20T_{calf}$ [33]. Mean torso skin temperature (T_{torso}) was calculated from two torso skin sites as equation: $0.5(T_{chest}+T_{back})$ [14]. Clothing micro-climate temperature (T_{cl}) and humidity (RH_{cl}) were calculated as: $0.5(T_{cl\text{-}chest}+T_{cl\text{-}back})$ and $0.5(RH_{cl\text{-}chest}+RH_{cl\text{-}back})$ respectively. $T_{cl\text{-}chest}$ and $T_{cl\text{-}back}$ represented for the clothing micro-climate temperature at the chest and the back, respectively. And $RH_{cl\text{-}chest}$ and $RH_{cl\text{-}back}$ were the clothing micro-climate humidity at the chest and the back, respectively. Mass of sweat evaporated was calculated from the nude body mass before and after the test, corrected from the mass accumulated in tested clothes. Sweat evaporation efficiency was calculated using the evaporated sweat mass divided by the body mass loss.

Statistical Analysis

The data presented were mean values and standard deviation (SD). A two way analysis of variance with repeated measures was employed (Time×Clothing). T_{sk}, T_{torso}, T_{cl}, RH_{CL} and HR, etc. at the time of 0, 30, 40, 50, 60 min were examined. When the analysis revealed a significant difference, a LSD post hoc analysis was used to compare the three different clothing conditions. Statistical significance level was set at p<0.05.

Results and Discussion

Results

Physiological Responses

Figure 1 shows the evolution of the mean skin temperatures

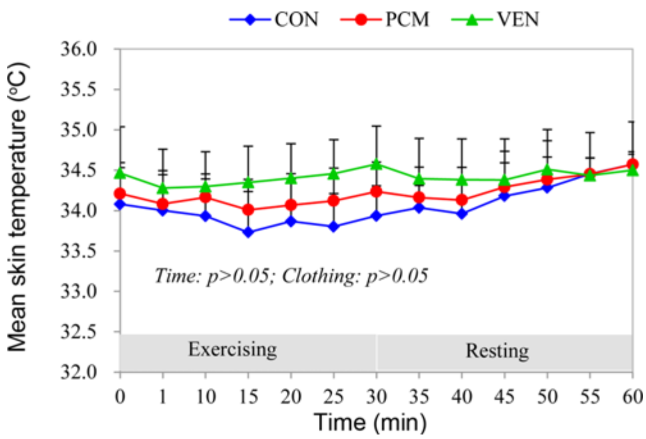

Figure 1. Evolution of the mean skin temperatures over time in the three conditions.

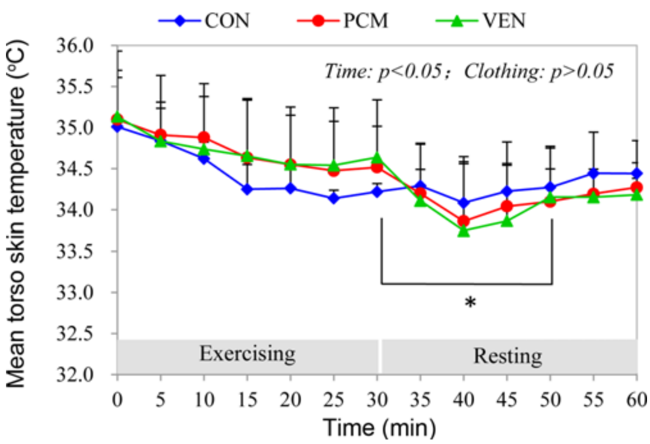

Figure 2. Evolution of the mean torso skin temperatures over time in the three conditions.

Table 2. Physiological responses of the HR and the mass loss in the three cooling conditions (Mean and SD)

Physiological responses \ Time points (min)		0	30	40	50	60
HR (bmp)	PCM	92(16)	107(13)	86(11)	84(8)	85(10)
	VEN	84(9)	105(12)	86(7)	85(8)	83(8)
	CON	90(14)	110(12)	87(11)	85(10)	86(10)
Mass loss (g)	PCM			170(15.2)		
	VEN			190(40.7)		
	CON			194(48.7)		

over time in the three conditions. As seen in the figure, with the exercise proceeded the mean skin temperature did not change greatly. After the exercise in both cooling conditions by PCM vest and ventilation garment, the mean skin temperature decreased a little, but only in the first 10 min of the cooling period. However, no significant difference of the mean skin temperature was observed between the PCM and the VEN (Clothing: p (0.765)>0.05).

Figure 2 shows the change of the mean torso skin temperature across the test. It can be seen that except for the CON condition the mean torso skin temperature decreased much when put on the cooling garments, especially for the VEN condition. The mean torso skin temperature in the PCM condition and the VEN condition at the 40th min had a significant difference compared with that at other time points (Time: p (0.02)<0.05). Compared with that at the 30 min, the mean skin temperature was decreased by 0.7 ^{o}C and 0.9 ^{o}C in the PCM condition and the VEN condition respectively.

The evolution of heart rate across the time in the three conditions and the mass loss are summarized in Table 2. Heart rate increased with the start of the exercise and then stabilized at about 105 bpm in the three conditions. After the exercise and rested in three different cooling conditions, the heart rate began to decrease greatly and stabilized at a normal level. No significant difference of heart rate and mass loss were observed among these three conditions (Clothing: p (0.638)>0.05).

Clothing Micro-climate Responses

Figures 3 and 4 show the clothing micro-climate temperature and humidity in the three conditions, respectively. As shown in Figure 6, the clothing micro-climate temperature did not increase during the exercise, but when wearing the PCM vest, it greatly decreased. Compared with that at the 30th min, it was dropped by 2 ^{o}C in the PCM, 0.8 ^{o}C in the VEN and not much change in the CON condition. Therefore, the clothing micro-climate temperature in the PCM condition was significantly different from that of the other two conditions (Clothing: p (0.009)<0.05).

With regard to the clothing micro-climate humidity, it increased gradually with the proceeding of the exercise. Then it greatly increased in the PCM condition and greatly

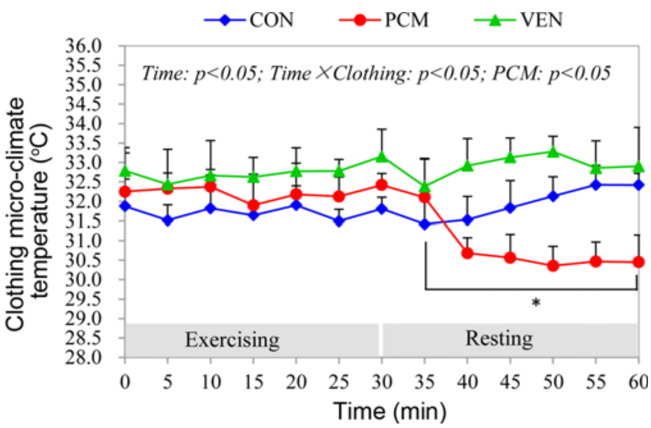

Figure 3. The change of clothing micro-climate temperatures over time in the three conditions.

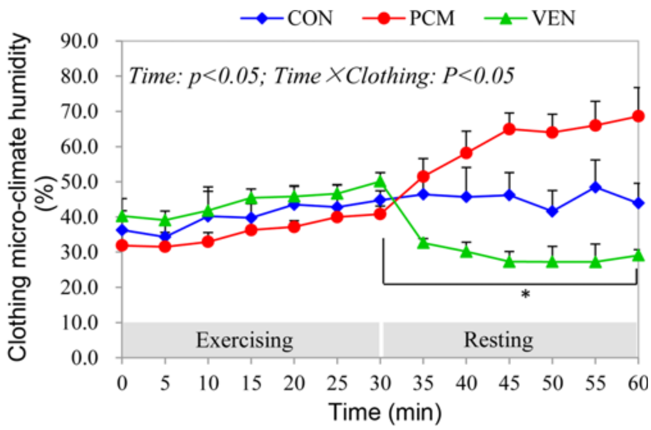

Figure 4. The change of clothing micro-climate humidity over time in the three conditions.

decreased in the VEN condition during the cooling period (see Figure 4). After 30 min cooling, the clothing micro-climate humidity in PCM was 40 % higher than that in the VEN. In contrast, no great change was observed in the CON condition and it fluctuated at about 45 % relative humidity. Both time and clothing had significant effects on the clothing micro-climate humidity (Time×Clothing: p (0.003) <0.05).

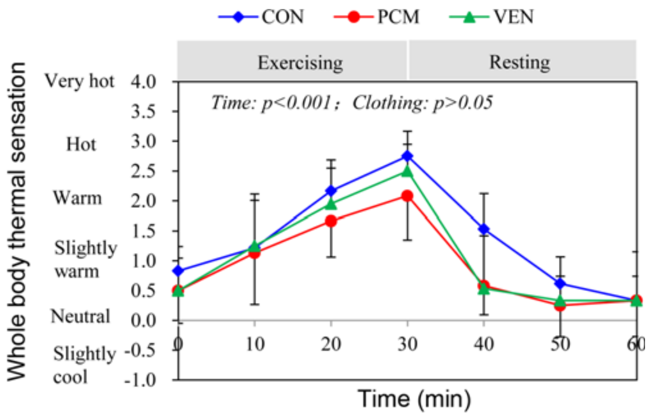

Figure 5. The change of the whole body thermal sensations over time in the three conditions.

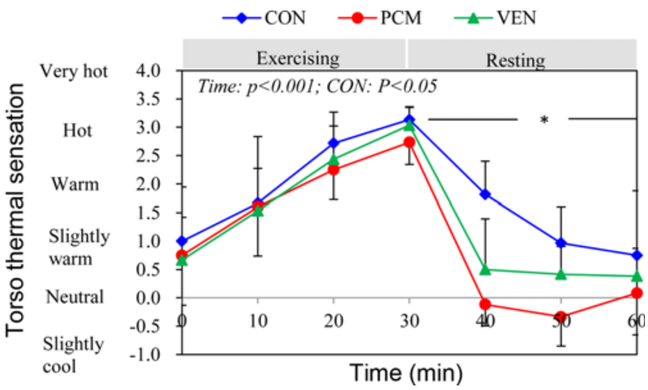

Figure 6. The change of the torso thermal sensations over time in the three conditions.

Subjective Responses

Thermal Sensations

The evolution of the thermal sensations of the whole body and the torso are displayed in Figures 5 and 6, respectively. As seen in the figures, with the exercise continued in the heat the whole body and the torso felt warmer and hotter. When rested and cooled by the three different conditions, the thermal sensations decreased, especially in the two cooling garments conditions. When wearing the PCM vest, the subjects felt much cooler on the torso than in the ventilation jacket (Figure 8). At 50 min, the subjects gave a -0.5 rating (slightly cool) in PCM which means that they felt cooler and more comfortable on the torso than that in the VEN.

Skin Wettedness Sensations

Figure 7 and 8 display the evolution of skin wettedness sensations of the whole body and the torso respectively. As shown in the figures, with the proceeding of the exercise the whole body and the torso felt wetter and wetter. Then all the three cooling strategies made the whole body and the torso felt less wet. For the whole body, skin wettedness sensations in the three conditions had no significant difference. For the torso, the ventilation jacket contributed to the lowest skin

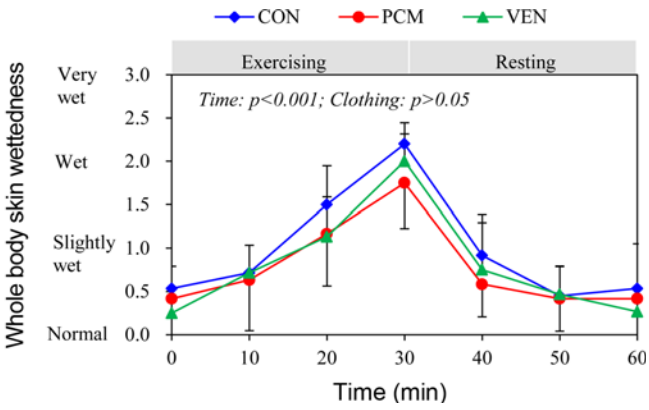

Figure 7. The change of the whole body skin wettedness sensations over time in the three conditions.

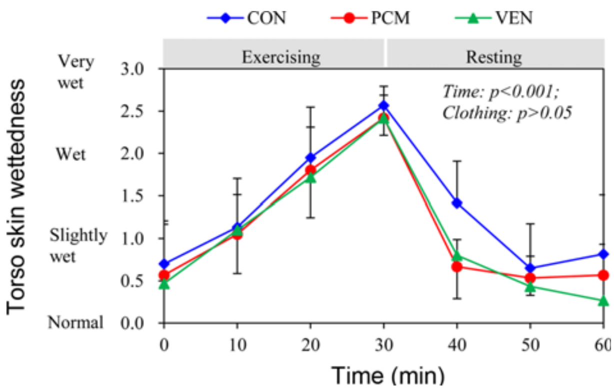

Figure 8. The change of the torso skin wettedness sensations over time in the three conditions.

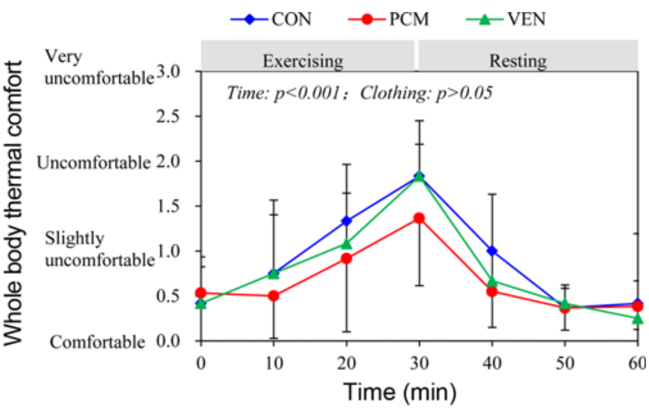

Figure 9. The change of the thermal comfort of the whole body over time in the three conditions.

wettedness sensation during the last 10 min resting period.

Thermal Comfort Sensations

Figures 9 and 10 show the evolution of the thermal comfort of the whole body and the torso, respectively. As shown in the figures, no significant difference of thermal

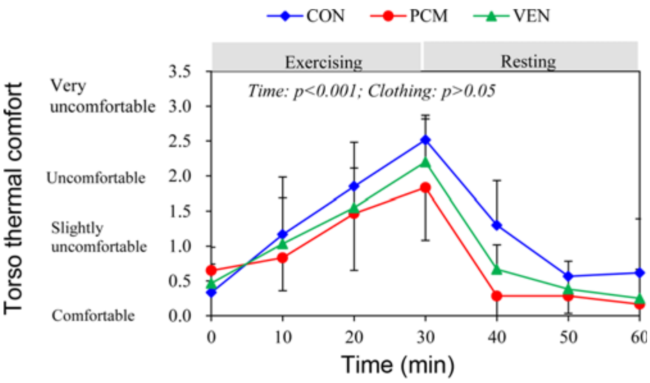

Figure 10. The change of the thermal comfort of the torso over time in the three conditions.

comfort was observed among the three cooling conditions. The PCM vest provided the best thermal comfort sensation for the whole body and the torso as well.

Discussion

The purpose of the study was to compare the two different cooling garments on improving the thermal comfort of female subjects after moderate exercise. Both the PCM vest and the ventilation jacket improved the thermal comfort than the CON in the items of T_{torso}, T_{cl}, the thermal sensation and the skin wettedness sensation of the torso. For the T_{sk}, *HR*, and the thermal sensation and skin wettedness sensation of the whole body, no significant differences were observed among these three conditions. Therefore, the cooling garments were more effective in improving the thermal comfort than the passive cooling method (cooling in CON condition). More precisely, the effectiveness was observed only on the local body site, i.e., the upper torso. This was attributed to the covering area of the cooling garments in which the upper torso was the direct beneficiary.

In the study the climate chamber was set to 32 °C and 50 % relative humidity. In such a thermal environment, the heat from the body to the environment could be dissipated by both dry and wet heat exchanges. With the moderate physical activity, heat still could be accumulated in the body and thermal sensation and skin wittedness sensation increased with the exercise. For the PCM vest, a higher skin temperate than the melting temperature of PCMs made the PCMs melted and absorbed heat from the body, which reinforced the conductive heat loss [10,13]. For the ventilation jacket, the forced air flow produced by the small fans accelerated sweat evaporation and improved the evaporative heat loss [22].

The enhanced conductive cooling and evaporative cooling also changed the clothing micro-climate temperature and humidity, particularly for the latter, the clothing torso micro-climate humidity in the VEN condition was thereafter decreased greatly due to the sweat evaporation by the ventilation. In the PCM condition, however, the great increase of the clothing micro-climate humidity was attributed to the great decrease of the clothing micro-climate temperature in which condensation may occur.

Besides, the clothing micro-climate temperature in the PCM condition was the lowest. This could be explained by the following reason: first, the PCM vest was balanced in a room temperature of about 20 °C (in such a room temperature the PCMs could not melt due to a higher melting temperature) before the test. Second, when the PCMs melted, its temperature stayed stable around the phase change temperature which in the study was 24 °C. Finally, the PCM vest was tightly fit around the body to obtain the highest cooling effect. Therefore, the measured clothing micro-climate temperature was the lowest. Additionally, this made the subjects fell cool on the torso and they gave -0.5 rating for the PCM vest on the thermal sensation after 10 min resting.

For the torso skin temperature, in the study of Gao *et al.* [11], after cooling by a PCM vest for an hour in a hot environment, it was reduced by 2.4 °C. Comparatively, the most reduced torso skin temperature in the present study was 0.7 °C and 0.9 °C, respectively by the PCM vest and the ventilation jacket. This might be due to a shorter cooling period and lower heat stress compared with their study. Besides, the torso skin temperature was lower in the VEN condition than that in the PCM condition, while for the torso thermal sensation, it was the opposite and the same situation for the torso thermal comfort, i.e. a lower torso skin temperature did not bring a lower thermal sensation nor better thermal comfort. This observation was not controversial. Regional differences in thermal comfort never correlated with differences in mean T_{sk} values. The slight differences in the local skin temperature produced by thermal stimulation could not simply explain the differences in thermal comfort [34].

The flow rate of the ventilation jacket was 12 l/s, which was higher than that in other studies [15-17]. However, the flow rate did not bring any discomfort to the subjects. The selected melting temperature of the PCMs was 24 °C, which could assure the PCMs would be solidified at the room temperature. Otherwise, a cold chamber was required to store it before use.

Finally, instead of male subjects, female subjects were used in the study. Females may be less tolerant to heat than males, but researchers also observed that gender difference in thermoregulation was minimal [35], especially with the heat acclimation and the effect of menstrual cycle on thermoregulation difference disappeared during heat acclimation [36]. The heat stress in the study was not high according to the mean skin temperature, the HR and the mass loss. Therefore, the heat exposure was tolerable and easy for the female subjects to finish. Nevertheless, higher and greater heat stress should be considered on this subject for both male and female subjects as a future study plan.

Conclusion

The study demonstrates that the two cooling garments were not very effective in reducing the whole body thermal physiological responses. The effective cooling was observed on the local body positions. The clothing micro-climate and the thermal sensations were also observed with effective influence by the cooling garments. The study indicates that the two cooling garments could be used for reducing thermal stress and improving thermal comfort after exercising in the mild heat. Further studies on male subjects as well and in a hotter environment should be conducted to improve and perfect the investigation.

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References

1. I. Holmér, *Ergonomics*, **38**, 166 (1995).
2. T. Kjellstrom, I. Holmér, and B. Lemke, *Glob. Health. Action.,* DOI:10.3402/gha.v2i0.2047 (2009).
3. Y. Epstein and D. S. Moran, *Ind. Health.,* **44**, 388 (2006).
4. S. A. Nunneley, *Scand. J. Work. Environ. Health.*, **15**, 52 (1989).
5. P. Bishop, P. Ray, and P. Reneau, *Int. J. Ind. Ergon.,* **15**, 271 (1995).
6. P. Bishop, D. Gu, and A. Clapp, *Int. J. Ind. Ergon.,* **25**, 233 (2000).
7. J. Smolander, K. Kuklane, D. Gavhed, H. Nilsson, and I. Holmér, *Int. J. Occup. Saf. Ergon.*, **10**, 111 (2004).
8. N. Nishihara, S. Tanabe, H. Hayama, and M. Komatsu, *J. Physiol. Anthropol. Appl. Hum. Sci.,* **21**, 75 (2002).
9. C. Chou, Y. Tochihara, and T. Kim, *Eur. J. Appl. Physiol.,* **104**, 369 (2008).
10. C. Gao, K. Kuklane, and I. Holmér, *Eur. J. Appl. Physiol.,* **111**, 1207 (2011).
11. C. Gao, K. Kuklane, F. Wang, and I. Holmér, *Indoor Air,* **22**, 523 (2012).
12. D. Kim and K. LaBat, *Ergonomics*, **53**, 818 (2010).
13. M. Barwood, S. Davey, J. House, and M. Tipton, *Eur. J. Appl. Physiol.*, **107**, 385 (2009).
14. T. Chinevere, B. Cadarette, D. Goodman, B. Ely, S. Cheuvront, and M. Sawka, *Eur. J. Appl. Physiol.*, **103**, 307 (2008).
15. M. J. Barwood, P. S. Newton, and M. J. Tipton, *Aviat. Space Environ. Med.*, **80**, 353 (2009).
16. A. Hadid, R. Yanovich, T. Erlich, G. Khomenok, and D. Moran, *Eur. J. Appl. Physiol.*, **104**, 311 (2008).
17. X. Xu and J. Gonzalez, *Eur. J. Appl. Physiol.*, **111**, 3155 (2011).
18. M. M. Farid, A. M. Khudhair, S. A. K. Razack, and S. Al-Hallaj, *Energy Conv. Manag.*, **45**, 1597 (2004).
19. M. Tate, D. Forster, and D. E. Mainwaring, *Sports Technol.*, **1**, 117 (2008).
20. C. Brade, B. Dawson, K. Wallman, and T. Polglaze, *J. Athl. Train.*, **45**, 164 (2010).
21. A. J. Purvis and N. T. Cable, *Ergonomics*, **43**, 1480 (2000).
22. J. A. Gonzalez, L. G. Berglund, M. A. Kolka, and T. L. Endrusick in "Proceedings of the Sixth International Meeting on Thermal Manikin and Modeling" (J. Fan Ed.), pp.165-169, The Hong Kong Polytechnic University, Hong Kong, 2006.
23. R. Bove, *Fire. Eng.*, **15**, 130 (2002).
24. I. Holmér, K. Kuklane, and C. Gao, *Int. J. Occup. Saf. Ergon.,* **12**, 297 (2006).
25. J. M. Carter, M. P. Rayson, D. M. Wilkinson, V. Richmond, and S. Blacker, *J. Therm. Biol.,* **32**, 109 (2007).
26. J. E. Smith, *Br. J. Sports. Med.*, **39**, 503 (2005).
27. M. Zhao, C. Gao, F. Wang, K. Kuklane, I. Holmér, and J. Li, *Text. Res. J.,* **83**, 418 (2013).
28. M. Zhao, C. Gao, F. Wang, K. Kuklane, I. Holmér, and J. Li, *Int. J. Ind. Ergon.,* **43**, 232 (2013).
29. F. Wang, C. Gao, K. Kuklane, and I. Holmér, *Ann. Occup. Hyg.*, **55**, 775 (2011).
30. F. Wang, S. del Ferraro, L. Y. Lin, T. Sotto Mayor, V. Molinaro, M. Ribeiro, C. Gao, K. Kuklane, and I. Holmér, *Ergonomics,* **55**, 799 (2012).
31. X. Zhang, J. Li, and Y. Wang, *Indian J. Fibre. Text. Tes.*, **37**, 162 (2012).
32. L. Y. Lin, F. Wang, K. Kuklane, C. Gao, I. Holmér, and M. Zhao, *Appl. Ergon.,* **44**, 321 (2013).
33. A. P. Gagge and R. R. Gonzalez, "Mechanisms of Heat Exchange: Biophysics and Physiology", pp.45-84, Wilely, Hoboken, 2011.
34. M. Nakamura, T. Yoda, L. I. Crawshaw, S. Yasuhara, Y. Saito, M. Kasuga, K. Nagashima, and K. Kanosue, *J. Appl. Physiol.*, **105**, 1897 (2008).
35. G. Havenith, Thesis, Soesterberg, The Netherlands, 1997.
36. C. L. Luecke, Ph.D. Dissertation, University of South Florida, Tampa, 2006.