Original Article

Performance evaluation of Iranian cooling vest on the physiological indices in hot climatic chamber

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ABSTRACT

Background: Heat stress is a threat to those who work in high temperatures. The purpose in this study was an examination of the cooling ability of Iranian phase change material (PCM) cold vest in hot and dry conditions in a climatic chamber. **Materials and Methods:** This experimental study was implemented on 12 male students (age 23.7 ± 2.8 years, weight 66.1 ± 11.4 kg, and VO_2 max 2.53 L/min) in 2013. The heat strain score index (HSSI), skin temperature and oral temperature, and heartbeat in two phases with and without cooling vest was measured during 30 min in a climatic chamber (temperature 38.8 ± 1.3°C humidity ratio 32.9 ± 2.3%) and in two activity intensity of 2.4 and 4.8 km/h speed on the treadmill, and the data differences between groups "with" and "without" vest were tested by *t*-test and repeated measurement. The level of significance was considered as 0.05. **Results:** The change in heartbeat at two activities, the oral temperature and heat strain score at 4.8 km/h, did not differ significantly between groups (with and without vest), as expected ($P > 0.05$). However, the change in skin temperature at two activities, oral temperature and heat strain score at 2.4 km/h, was significant between groups, as expected ($P < 0.05$). The average of skin temperature at 15th and 30th min during the experiment at two activities of 2.4 and 4.8 km/h was significant. **Conclusion:** The findings of the study indicated that using the Iranian PCM cold vest in hot and dry climate can affect the reduction of skin temperature, oral temperature, and HSSI in light activities.

Key words: Heat strain score index, heat stress, Iranian cooling vest, phase change material

INTRODUCTION

This paper is based on the topic "evaluation of the effects of Iranian phase changed material cold vest on the physiological indices in hot and dry temperature in climatic chamber," appropriate for those who are interested to understand the body central temperature in which increase in those people who work in hot climates is natural phenomena, instead of wearing of suitable cloth, could be lead to thermal strain. However, the symptoms of expose to high temperature fatigue, thermal weakness, thermal syncope, thermal trauma, and ultimately death are also explained.[1] In the USA, annually, around 5–10 million workers expose to heat stresses.[2] Every year, only in Hong Kong, in military and training operations, two percent, and in Britain more than 80 service staff get to the hospital. Therefore, controlling this physical factor, can prevent these health problems and can increase the staff efficiency and the quality of products.[3] According to the statistic of Iran central health and work environment, in the year of 2010, the overall number of industrial workshops was 625,000 which have 2,500,000 workers, of which 10% of

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these workshops and 9% of the workers are exposed to these heat and humid harmful conditions.

Heat strain can be reduced through the use of personal cooling systems. Personal cooling systems include active systems (e.g., air or liquid cooling garment) and passive systems (e.g., ice vest, gel-ice vest, and phase change materials [PCMs]). Active systems require a source of power to operate while passive systems require material supplies such as cold water and ice. Although many physiology studies have demonstrated that personal cooling systems reduce heat strain, the actual use of personal cooling systems in practice is limited. The main barriers are that personal cooling systems require logistic supply such as ice, power source, and cold water, and add an extra load of several kilograms to users.[4] PCMs are here divided into two main families: Organic and inorganic. Organic materials can be further classified into paraffin and non-paraffin's such as esters, fatty acids, alcohols, and glycols.[5] PCMs have been put into use for several innovative applications such as cooling of electronic devices, transporting sensitive medications, and cooling vest for athletes. Thermal energy storage with PCMs is one of the most efficient ways of storing available energy because of its advantages such as providing higher heat storage capacity, lower storage temperature, isothermal operation, and less storage space.[6] PCM is a substance with a high heat of fusion, in which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCM are classified as latent heat storage units. Jovanovic *et al*., during the study of heat stress activity test on 10 male soldier volunteers, which consist of walking on treadmill with a speed of 5.5 km/h in 40°C temperature in one climatic chamber, and by wearing of nuclear, biological, and chemical protecting suit was done and the results indicated that with using of cooling vest, temperature of ear and skin, compared to without using of cooling vest, was significantly lower.[7] In another study from Jovanovic *et al*., with a goal to evaluation of one kind of changed phase material with paraffin wax that consist of n-hexadecane that have been done on 10 male soldier volunteers in a condition of 40°C temperature on treadmill with 5.5 km/h, indicated that dressing of cooling vest on changed phase material basis with combat uniform M10, relation to control group that they have only combat uniform, has caused reduction of physiological strain (average of skin and ear temperature).[8] Gao *et al*., during study by the title of personal cooling with PCMs in a very hot environment, indicated that PCM (sodium sulfate type) cooling vest, has more effect on torso skin, in which, this area was covered by vest. Because this vest reduced the chest skin temperature around 1°C to 3°C, the reduction of rectal temperature was 0.2°C.[9] Also, Gao *et al*., in their previous studies indicated that phase change material cooling vest (mostly sulfate sodium with melting point 28°C) either on thermal manikin or persons, were effective,[10] although in another study from Kuklane with the goal to investigate personal cooling vest in kind of phase change material on improving of thermal comfortable in one simulated office, with temperature of 34°C, with study on 8 male volunteers in climatic chamber indicated that torso skin temperature has decreased around 2–3°C and remained in about 33.3°C, and the findings indicate that the personal cooling with PCM can be used as an option to improve thermal comfort for office workers without air conditioning.[11] Because that there was no research have done about the function of Iranian cooling vest, the purpose of the present study was an investigation of the effectiveness of PCM cooling vest on thermal strain indices. The results of this study could be useful in working environment that have heating sources to prevent diseases caused by heat.

MATERIALS AND METHODS

Subjects

This research is an intervention from the kind of experimental; the participants in this examination were the male students of Isfahan University of Medical Sciences (this was due to this fact that the experiment had to be done in climate chamber, there was no possibility to choose workers to participate). The test was performed on 12 male student volunteers with the average age: 23.66 ± 2.83 years, the average weight: 66.09 ± 11.43 kg, and the average of VO_2 max (maximum oxygen consumption) of 2.53 L/min. The criteria for choosing the volunteers were normal body mass index (18.5–25 kg/m^2) and the absence of precedent of cordial, pulmonary, nervous, skeleton-muscular, epilepsy, paroxysm, diabetes diseases, disusing of blood pressure and heartthrob drugs, and disusing of coffee, caffeine, and alcohol before 12 h to initiate the test. Any time that heartbeat of volunteers, increases from 180 beats/min and body core temperature increases from 39°C, test become stopped.[3] All information that mentioned above was collected by the questioner, and a written consent has been taken from participants to perform the test. All volunteers have been visited by a doctor before commencing the test.

Change phase material characteristics

In this research, cooling vest from the type of phase change material has been used. The quality of vest that contains change phase material was from cotton 70/30 including 30% of cotton and 70% of polyethylene material. Inside of the vest, there are eight pockets for phase change material packs. The phase change material is liquid in its normal form, for using of PCM packs, it has to be charged (become solid), and for this reason, they have to be placed inside the freezer for 2 h, and then will be placed inside the pockets that is designed in the vest, and be usable for 3–4 h. This type of vest has been used for middle-heavy activities.

Clothes

In order to prevent the effects of different clothes of volunteers on thermal strain and equality of the vest using condition, all of the volunteers wear the same boiler suite that it has separate blouse and trouser and it is made up of 30.2% cotton and 69.8% polyester.

Experimental protocol

This experiment was done on a volunteer with and without cooling vest. Moreover, the effect of vest on physiological indices: Skin temperature, oral temperature, heartbeat, thermal sense, and vest comfortable were tested. Because here to fore that there was no similar study on Iranian persons has been performed and volunteers were university students in this study, participants fulfilled the test by activities of intensity of 2.4 and 4.8 km/h, and 0% incline by using treadmill (Kettler model) in a climatic chamber, they considered the weather condition which has the capability of adjusting temperature and humidity with and without vest. During the test average, dry temperature, wet temperature, radiant temperature, relative humidity, and wet-bulb globe temperature have been measured in the following order 38.83 ± 1.29°C, 25.30 ± 1.34°C, 39.33 ± 1.32°C, 32.85 ± 2.26°C, and 29.84 ± 0.9°C, respectively, in warm and dry conditions of the climatic chamber. The test duration for each was 30 min, the number of all activities was 4 with 1 per day, once they were running at a speed of 2.4 km/h without vest and once with vest for 30 min on treadmill, this has been done for 4.8 km/h, as well. During the activity, physiologic indices, such as oral temperature (with the use of Emerson digital thermometer), skin temperature which consists of two sensors for measuring skin temperature which refer to chest and shoulder, heart rate (with usage of Polar Sport Tester), VO_2 max (maximum oxygen consumption) with the use of a strand nomogram and thermal sense, were measured and registered for both with and without vest. Heart rate and skin temperature were checked and registered every minute.

For collecting thermal sense data, heat strain score index, or HSSI questionnaire is used, this questioner consist of 17 questions from environment weather, the question 1 to 12 is answered through asking, questions 13 to 17 through observing, and the score of each option (which is inserted beside of each option) was multiplied by effect factor (which is inserted in parenthesis beside of each question) and the result is inserted in a square beside of each question, and finally the numbers in squares are added to get to the final result and if the overall numbers is <13.5, shows that the person is out of thermal strain (level one thermal strain risk or green zone) and if it is between 13.6 and 18, shows that the person probably has the thermal strain and a more precise evaluation is needed (level two thermal strain risk or yellow zone) and if it is more than 18.1, shows that the person has thermal strain and it is necessary to take suitable control actions for minimizing strain (level three thermal strain risk or red zone).

At the end of the test for the condition of vest usage, vest comfortable rate check list is completed by the volunteers. Also, for collecting vest comfortable rate check list, it has been used.[12] This consists of 9 questions from vest comfortable rate such as being tight, comfortable, flexibility, wearing and easy taking off, movement limitation, and adjustability with body size and design which can be expressed by option namely strongly disagree, disagree, normal, agree, and strongly agree. Thermal sense questioner was filled with and without vest, but check list for vest comfortable rate was completed in a situation while using the vest.

For data analyzation, with attending to the possibility of correlation between the dependent variables of study and the consideration of correlation that should be made, by their values for these correlation, the independent *t*-test for comparing the differences between dependent variables before and after the interference has been used. Comparison of changes in groups also with the assistance of repeated measurement and all analyses with the help of SPSS 20 (IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp) have been made, the level of significance has been considered as 0.05.

RESULTS

During the test, none of the volunteers have showed the sickness from heat and in all stages of test, the heartbeat for all persons was 180 beats/min and core temperature at 39°C as well, the result of study showed that PCM cooling vest has much lowered the physiologic indices in the activity with the intensity of 2/4 km/h rather than 4/8 km/h [Figure 1]. The start of the test until the final moments of the test heart rate was increased due to the heat and run operation, in the condition of with the usage of cooling vest, expected that the results of heart rate in this condition are less than no vest, and unexpectedly, there is no relationship between the increase or decrease in this variable.

The result of comparison changes in both groups during the time of study which is obtained by the usage of repeated measurement is shown in Table 1.

The results of Table 1 shows that the changes of both conditions with and without the usage of cooling vest during the test on heartbeat variable in both speeds, oral temperature, and heat strain score was not significant at speed 4/8, but the changes of both conditions with and without the usage of cooling vest during the test on skin temperature in both

Table 1: The results of repeated measurement test for physiological indicators changes with and without the use of cooling vest

Variable	Activity intensity (km/h)	Mean±SD		*P**
		With vest	Without vest	
Skin temperature (chest)	2.4	31.35±4.73	36.09±0.75	0.001
	4.8	30.36±4.06	35.28±1.18	0.001
Skin temperature (shoulder)	2.4	32.5±5.53	36.87±0.93	0.013
	4.8	32.58±4.17	35.42±1.27	0.025
Oral temperature	2.4	36.4±0.37	36.69±0.34	0.047
	4.8	36.5±0.99	36.66±0.38	0.36
Heart rate	2.4	95.24±9.44	96.15±11.21	0.983
	4.8	102.82±7.4	105.85±8.31	0.395
Heat strain score index	2.4	9.43±3.03	12.32±3.26	0.029
	4.8	10.87±2.84	12.74±3.55	0.163

*Significance level for all tests has been considered as 0.05. SD=Standard deviation

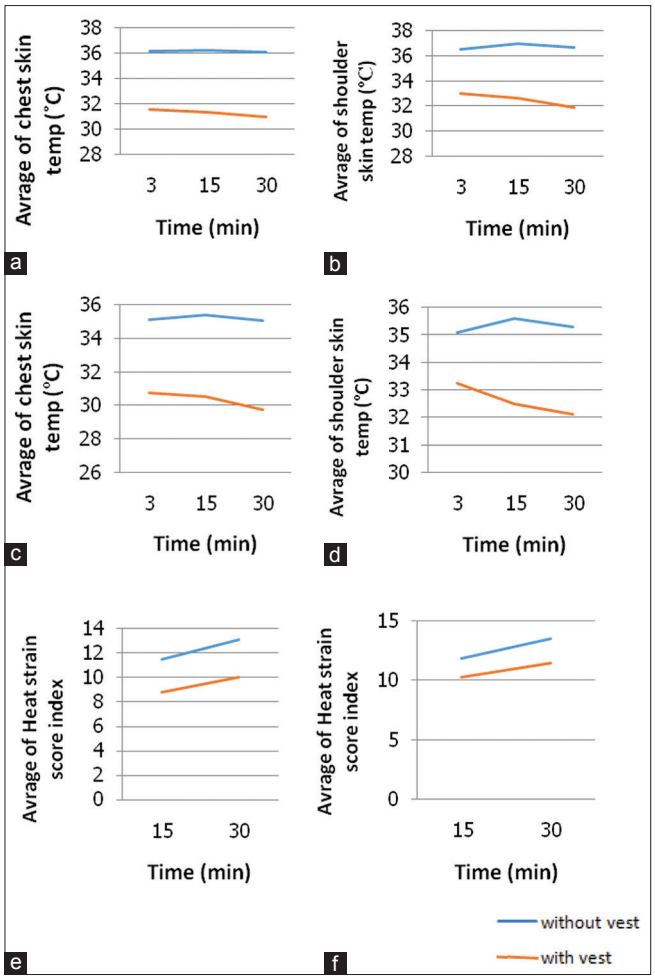

Figure 1: Average of shoulder, chest skin temperature, and heat strain score index with a speed of 2.4 km/h (a, b, and e) and with a speed of 4.8 km/h (c, d, and f)

speeds, oral temperature, and heat strain score was significant at 2.4 km/h.

Table 2 shows that the results of independent *t*-test, different values of the skin temperature variable in both conditions with and without the use of cooling vest between 15 and 30 min of test at both speeds 2.4 and 4.8 km/h, was significant, whereas the variables such as oral temperature, heat strain score, and heartbeat were not significant in their different values. Most of the people were agreed on the comfortable rate and vest design in both activities [Figures 2 and 3]. Moreover, Wilcoxon test showed that people's view about the comfortable rate and vest design were the same in both activities. (The comfortable rate for all of the option in check list was obtained at $P > 0.05$).

DISCUSSION

The finding showed that during a 30 min test, PCM type cooling vests in hot and dry weather condition has affected the rate of decline in skin temperature, oral temperature, and heat strain score but not on the decrease or increase of heartbeat,

Table 2: The results of independent *t*-test for physiological indicators changes with and without the use of cooling vest

Heat stress indices	Activity intensity	Mean±SD		*P**
		With vest	Without vest	
Chest skin temperature	2.4 km/h - 15th min	31.4±4.82	36.28±0.85	0.005
	2.4 km/h - 30th min	31.01±5.42	36.08±0.87	0.008
	4.8 km/h - 15th min	30.51±4.08	35.43±1.05	0.002
	4.8 km/h - 30th min	29.76±4.42	35.05±1.01	0.002
Shoulder skin temperature	2.4 km/h - 15th min	32.66±5.63	37±0.78	0.022
	2.4 km/h - 30th min	31.89±6.33	36.7±1.14	0.024
	4.8 km/h - 15th min	32.06±4.59	35.59±1.21	0.024
	4.8 km/h - 30th min	32.11±4.53	35.3±1.09	0.035
Oral temperature	2.4 km/h - 15th min	36.32±0.37	36.62±0.42	0.968
	2.4 km/h - 30th min	36.47±0.37	36.75±0.26	0.155
	4.8 km/h - 15th min	36.44±0.45	36.64±0.37	0.736
	4.8 km/h - 30th min	36.56±0.54	36.69±0.39	0.263
Heat strain score index	2.4 km/h - 15th min	8.8±2.87	11.53±3.11	0.678
	2.4 km/h - 30th min	10.06±3.18	13.1±3.41	0.609
	4.8 km/h - 15th min	10.28±2.88	11.91±3.6	0.489
	4.8 km/h - 30th min	11.47±2.8	13.56±3.51	0.781
Heart rate	2.4 km/h - 15th min	96±9.42	95.83±11.97	0.11
	2.4 km/h - 30th min	98.08±9.31	96.25±12.32	0.11
	4.8 km/h - 15th min	103.5±7.06	107.33±8.66	0.397
	4.8 km/h - 30th min	104.91±7.64	107.41±8.06	0.071

*Significance level for all tests has been considered as 0.05. SD=Standard deviation

while during 15 and 30 min of test, the skin temperature had decreased but oral temperature, heat strain score, and heartbeat in both conditions, with and without the use of cooling vest, did not have a significant difference. Thermal energy storage with the usage of phase changing material is one of the most efficient ways for saving the accessible energy, because of many advantages that it has such as high thermal storage capacity and lower temperature storage.[6] As the body temperature reaches the skin surface by the blood flow circulatory system it is absorbed by PCM pockets and results in skin temperature reduction and thermal strain score, therefore, PCM is able to absorb, store, and release large

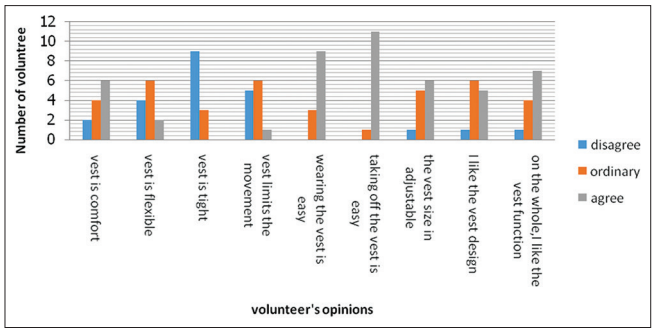

Figure 2: Volunteer's opinions about the comfortable rate of cooling vest at 2.4 km/h

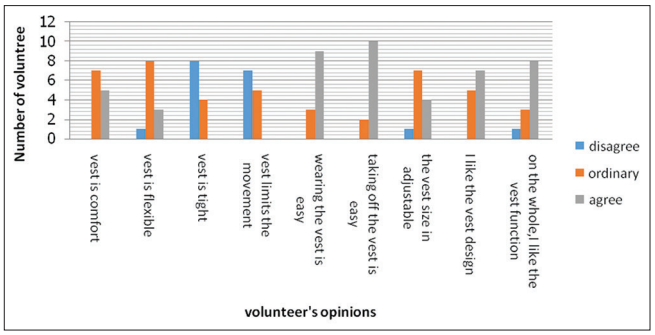

Figure 3: People's comment about the comfortable rate of cooling vest at 4.8 km/h

amount of energy in the form of hidden heat to higher than a define temperature value during phase transfer between solid and liquid.[13] PCM is able to store and release a high amount of energy and while the materials transform from liquid to solid and vice versa, heat is absorbed or released. In a study, which is done by Jovanovic *et al*. on two different types of PCM cooling vest, they showed that both cooling vests have affected on skin temperature reduction which is compatible with the result of this study, and the results of thermography from PCM during their study showed that the heat which is made inside the body, is the main factor of PCM melting time as well. In this study, the thermography has been used for the verification of PCM cooling effects. Until now, lots of studies in the field of PCM applications with different goals by different people have been done, which, in many of them, the thermal manikin have been used instead of real people (7 and 8). Moreover, on the other hand, there have been a few researches in relation to temperature change effects on PCM cooling system applications on individuals.[14] Gao *et al*. also in a study, under the title personal cooling with PCMs in a very hot environment, showed that in the condition of hot weather, PCM cooling vest (sulfate sodium) has the highest effect on the torso part which is covered by vest, as the vest reduces the temperature of chest skin about 1 to 3°C but the rate of rectal temperature decrease was 0.2°C,[9] which showed the compatibility between the results of this study and trivial oral temperature difference in both conditions with and without the usage of cooling vest, whereas in Kuklane study, with the goal of the evaluation of PCM personal cooling on person thermal comfortable improvement which is simulated in a 34°C office with eight male volunteers in the climatic chamber showed that temperature of torso skin has decreased about 2–3°C and remained in about 33.3°C,[11] which the results of skin temperature obtained in this study is approximately close to our study's results. On the other hand, the different value of heartbeat diversity during the test and the different values of heat strain score, oral temperature, and heartbeat variables on 15 and 30 min of test were not significant because of the consideration of few people participation, which was compatible with the results of study that has been done by Smolander *et al*. in Sweden, with the goal for evaluation of the influence of ice vest, which has been committed on four firefighters, and because of few samples, none of the statistical tests were significant.[15]

Investigation of volunteer's opinions about vest comfortable rate showed that most persons were agreed about comfortable rate, wearing and taking off, and vest design as well, but the comments were ordering about the flexibility, as it could be related to the PCM's size and being solid, so it reduces the movements, which is totally adaptable to Kopias results that they mention disadvantage is the reduction of movements in PCM cooling vests.[13]

Because the PCM package started to melt, in the second 15 min of test, the subjects felt more heavily than in the first 15 min, to resolve this problem, we suggest that PCM packs were smaller, more, and used PCM with a high melting point. Also, to prevent skin frostbite, caused by contact with PCM package, in addition, coverage of PCM packages, the subjects were asked to use thicker underwear. Since the lack of awareness of workers and employers workshops in the tropics, especially in the South of the country, his study could be useful in order to increase their information about the cooling vest.

CONCLUSION

The findings of study showed that in hot and dry conditions, Iranian cooling vest (PCM type) was effective in reduction of skin temperature, oral temperature, and HSSI in light activity (speed of 2.4 km/h) but has no influence on person heart beat rate). Moreover, in medium activity (speed of 4.8 km/h), cooling vest was lower effective to the reduction of oral temperature, HSSI, and heart beat compared to light activity (2.4 km/h).

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Conflicts of interest

There are no conflicts of interest.

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