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Original Article

Comparison of the Impact of an Optimized Ice Cooling Vest and a Paraffin Cooling Vest on Physiological and Perceptual Strain

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A B S T R A C T

Background: Ice cooling vests can cause tissue damage and have no flexibility. Therefore, these two undesirable properties of ice cooling vest were optimized, and the present study was aimed to compare the impact of the optimized ice cooling vest and a commercial paraffin cooling vest on physiological and perceptual strain under controlled conditions.

Methods: For optimizing, hydrogel was used to increase the flexibility and a layer of the ethylene vinyl acetate foam was placed into the inside layer of packs to prevent tissue damage. Then, 15 men with an optimized ice cooling vest, with a commercial paraffin cooling vest, and without a cooling vest performed tests including exercise on a treadmill (speed of 2.8 km/hr and slope of %0) under hot (40°C) and dry (40 %) condition for 60 min. The physiological strain index and skin temperature were measured every 5 and 15 minutes, respectively. The heat strain score index and perceptual strain index were also assessed every 15 minutes.

Results: The mean values of the physiological and perceptual indices differed significantly between exercise with and without cooling vests ($P < 0.05$). However, the difference of the mean values of the indices except the value of the skin temperature during the exercises with the commercial paraffin cooling vest and the optimized ice cooling vest was not significant ($P > 0.05$).

Conclusions: The optimized ice cooling vest was as effective as the commercial paraffin cooling vest to control the thermal strain. However, ice has a greater latent heat and less production cost.

1. Introduction

Heat is considered as one of the harmful factors in workplaces, which can be generated because of climatic conditions or energy wastes in industry processes [1]. The prolonged exposure to heat can cause heat strain in human [2]. Wearing the personal protective clothes for the prevention of the physical and chemical hazards can also be effective. These clothes strongly confine the sweat evaporation from the skin surface because of the impermeable nature. In the heat strain, the body shows physiological responses such as increased sweating, skin temperature, core temperature, and heart rate under severe thermal conditions [3]. If the thermal strain is closed to the human tolerance threshold, it will cause thermal stress in workers [4]. Thermal stress can result in disorders including heat syncope, heat exhaustion, heat cramps, heat shock, confusion, and fatigue [5–7].

To control the heat stress, there are various solutions, including engineering and management controls. One of the strategies for decrease of the heat strain in hot environments is the use of personal cooling vests [8]. These vests absorb the excess heat and create a thermal comfort in hot environments [9]. Cooling vests of the phase-changing material (PCM) are one of the well-known personal cooling equipment. PCM cooling vests absorb the heat generated by the circulatory system on the skin surface via the phase change [10]. Of PCMs, water is the most well-known PCM. Advantages of the ice cooling vests include high latent heat, good

Abbreviations: PCM, phase-changing material; PSI, physiological strain index; HSSI, heat strain score index; Ta, ambient temperature; RH, relative humidity; WBGT, Wet Bulb Globe Temperature; PeSI, perceptual strain index.

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availability, and low cost. However, long-term contact with ice can cause tissue irritation, and this problem limits its usage [11]. In addition, ice has no flexibility at the solid phase. The paraffin cooling vest has none of these properties [12]. Therefore, in the present study, these two undesirable properties of ice cooling vest were optimized and the study was aimed to compare the impact of the optimized ice cooling vest and a commercial paraffin cooling vest on physiological and perceptual strain under wearing chemical protective clothes in the hot conditions.

2. Materials and methods

For optimizing the ice cooling vest, hydrogel produced by composition of the water and gel (a polymer) was used for increasing the flexibility in the ice packs. As well as, the ice packs can cause skin tissue irritation owing to the low melting point. For solving this problem, packs of polyvinyl chloride with a thickness of 0.7 mm were used and a layer of the ethylene vinyl acetate foam with a thickness of 3 mm was placed into the inside layer of packs. The thermal conductivity of the ethylene vinyl acetate was 0.23 ($Wm^{-1}K^{-1}$) [13]. The packs were filled by hydrogel and sealed by heat. Ten packs were placed in the vest designed and made of 70% cotton and 30% polyester with an adjustable pattern based on the size of various individuals. The total weight of the vest was 2.3 kg.

In the present study, the effectiveness of the optimized ice cooling vest compared with that of the paraffin cooling vest model Techkewl-7026 (made of 100% cotton with four pockets for PCM packs, melting point 14°C, and total weight 2.2 kg) was evaluated. For this purpose, an interventional study was carried out on 15 male students from Isfahan University of Medical Sciences. The inclusion criteria included the absence of diseases including pulmonary disease, cardiovascular disease, musculoskeletal disease, neuromuscular disease, seizures, diabetes, and epilepsy and nonconsumption of drugs or medications affecting the heart rate and blood pressure. In addition, participants were asked not to drink coffee or alcohol for at least 12 hours before the test. The exclusion criteria included an increased heart rate greater than 180 bpm and fatigue [14]. Volunteers were screened by a physician based on the inclusion criteria and informed about the date of each trial. Before beginning the test, stages of the test and instruments were clearly explained to participants and they signed the consent form developed by the medical ethics committee of the medical university of Isfahan.

On the day of testing, demographic information including the height, age, and weight was collected. To assimilate the conditions and simulate the real work conditions, participants were asked to wear the chemical protective clothes on the vests. The study comprised three tests, including exercise without a cooling vest (A), with a Techkewl-7026 cooling vest (B), and with an optimized ice cooling vest (C). First, participants were asked to rest in a lying position on a bed in a moderate environment for 30 minutes before each test. Each participant then performed the test on a treadmill (speed of 2.8 km/hr and slope of 0%) under hot and dry condition [dry temperature = 40°C and relative humidity (RH) = 40%] in a sealed climatic chamber (length: 4m, width: 3m, and height: 2.7m and equipped with intelligent heating and cooling) for 60 minutes [15]. Participants were given no fluids during the tests. The temperature and humidity of the chamber were monitored using a Wet Bulb Globe Temperature (WBGT) meter (Casella model) with the accuracy of 0.01°C and humidity meter (Beurer model). In the rest phase, all indices were measured and assessed every 15 minute. During the test, the physiological strain index (PSI) and skin temperature were measured every 5 and 15 minutes, respectively. The heat strain score index (HSSI) and perceptual strain index (PeSI) were also assessed every 15 minutes.

Table 1
The range, mean, and standard deviation of participant characteristics.

Parameters	Range	Mean (±SD)
Age (years)	21–27	24 (2.32)
Height (meter)	1.69–1.88	1.76 (0.05)
Weight (kg)	60–90.32	74.03 (9.03)
Physical activity (hour/week)	0–9	4.36 (3.44)
BMI (Kg/m^2)	21.01–25.35	23.16 (1.33)

BMI, body mass index; SD, standard deviation.

A brief overview of indices used in this study is given below.

PSI: This index measures the thermal and physiological strain in the range of zero to 10 [16]. PSI was calculated by the following formula [17]:

$$PSI = \left(5 \times \frac{T_o - T_{or}}{39.5 - T_{or}}\right) + \left(5 \times \frac{HR - HR_r}{180 - HR_r}\right) \quad (1)$$

T_{Or}: Rest oral temperature.T_O: Exercise oral temperature.HR_r: Rest heart rate.HR: Exercise heart rate.

For calculating the PSI index, the heart rate and oral temperature were measured using a sport tester (polar model) with accuracy of one beat per minute and a thermometer (Beurer model) with accuracy of 0.1°C, respectively.

Skin temperature: It was measured using a noncontact thermometer (thermofocus model 0700) with accuracy of 0.1°C at four points of the trunk including the left upper part of the chest, the right side of the abdomen, behind the right shoulder, and the waist. Finally, the mean value of the skin temperature at stated points as the trunk skin temperature was calculated.

HSSI: It is an observational-perceptual technique. The HSSI questionnaire with 17 questions was used for determining this index. Some questions were answered by participants based on the personal perception and some others, through the environmental observation. The coefficient of each question was multiplied by its score and, finally, all outcomes were gathered. Risk levels of this index include low heat strain (the final score less than 13.5), probably heat strain (the final score from 13.6 to 18), and certainly heat strain (the final score more than 18.1). Dehghan et al. [18] reported an internal reliability of 0.90 (Cronbach α) for this questionnaire.

PeSI: This index measures the perceptual heat stress by two parameters including the personal thermal sensation and the perceived exertion intensity [19]. The results of a study demonstrated that the PeSI index has a high correlation with the heart rate (r = 0.90), oral temperature (r = 0.78), and PSI (r = 0.94) [18]. The personal thermal sensation and perceived exertion intensity have a Likert scale in the range of one to five and one to 10, respectively. Participants were asked to determine the scores of Likert-type scales. In general, the PeSI index was calculated by the following formula:

$$PeSI = \left(5 \times \frac{TS - 1}{4}\right) + \left(5 \times \frac{PE}{10}\right) \quad (2)$$

TS: Personal thermal sensation.PE: Perceived exertion intensity.

Data were analyzed using Kolmogorov–Smirnov test, descriptive statistics, repeated measurement analysis of variance test, and *post hoc* tests with Statistical Package for the Social Sciences (SPSS), version 16. The significance level was 0.05 for all tests.

3. Results

Participant demographic information including age, height, weight, physical activity, and body mass index is presented in Table 1. The results of Kolmogorov–Smirnov test demonstrated the

Table 2
The range, mean, and standard deviation of physiological parameters during exercise without a cooling vest (A), with a paraffin cooling vest (B), and with an optimized ice cooling vest (C).

Parameters	Range	Mean (±SD)
HR res (bpm)	65−91	80.84 (7.26)
HR A (bpm)	97−133	113.33 (11.23)
HR B (bpm)	81−118	103.64 (10.9)
HR C (bpm)	84−110	100.55 (8.12)
T_{or} res(°C)	35.7−36.87	36.29 (0.36)
T_{or} A(°C)	36.54−37.55	37.05 (0.35)
T_{or} B(°C)	36.44−37.73	36.98 (0.34)
T_{or} C(°C)	36.49−37.22	36.83 (0.25)
T_{skin}res	34.69−36.67	35.57 (0.58)
T_{skin}A	36.99−38.64	37.93 (0.48)
T_{skin}B	32.11−36.44	34.2 (1.4)
T_{skin}C	28.61−35.19	31.52 (1.85)
PSI A	2.03−4.27	2.81 (0.59)
PSI B	0.92−2.89	2.1 (0.58)
PSI C	1.13−2.69	1.9 (0.39)

HR, heart rate; T, temperature; PSI, physiological strain index; SD, standard deviation.

normal distribution of data ($p > 0.05$). Based on the results of the statistical analysis, values of the ambient temperature (Ta), RH, and WBGT had no a significant difference among the three tests. The mean values (standard deviation) of Ta, RH, and WBGT were 39.91 (2.92)°C, 39.92 (0.24) %, and 31.88 (0.47)°C, respectively.

Table 2 presents values of the range, mean, and standard deviation for physiological parameters in the rest and exercise phases of tests. Mean values of PSI and skin temperature during performing three tests have been displayed in the Figs. 1 and 2, respectively. Mean values of PSI differed significantly between an exercise without cooling vest and the exercises with the commercial paraffin cooling vest ($P = 0.008$) and the optimized ice cooling vest ($P = 0.001$). However, there was no significant difference between mean values of PSI during the exercises with the commercial paraffin cooling vest and the optimized ice cooling vest ($P = 0.277$). In addition, a significant difference was seen between mean values of the skin temperature during an exercise without the cooling vest and the exercises with the commercial paraffin cooling vest ($P < 0.001$) and the optimized ice cooling vest ($P < 0.001$). As well as, mean values of skin temperature differed significantly between the exercises with the commercial paraffin cooling vest and the optimized ice cooling vest ($P < 0.001$). Mean values of the heart rate, oral temperature, and skin temperature in the rest phases before the three tests had no meaningful difference (P > 0.12).

Table 3 describes values of the range, mean, and standard deviation for perceptual parameters in the rest and exercise phases. Mean values of HSSI and PeSI during the exercise with and without cooling vests has been shown in Figs. 3 and 4, respectively. The results showed a meaningful difference between mean values of HSSI during an exercise without cooling vest and the exercises with the commercial paraffin cooling vest (P = 0.002) and the optimized ice cooling vest (P < 0.001). However, there was no significant difference between mean values of HSSI during exercises with the commercial paraffin cooling vest and the optimized ice cooling vest (P = 0.345). Moreover, the mean values of PeSI differed significantly between an exercise without cooling vest and the exercises with the commercial paraffin cooling vest (P < 0.001) and the optimized ice cooling vest (P < 0.001). However, the difference of the mean values of PeSI during the exercises with the commercial paraffin cooling vest and the optimized ice cooling vest was not significant (P = 0.426). Mean values of HSSI and PeSI in the rest phases had no a significant difference (P > 0.167).

4. Discussion

In general, results showed that mean values of physiological and perceptual indices during the exercise with cooling vests were significantly lower than those during the exercise without cooling vest. Mean values of these indices in rest phases had no significant difference. In addition, difference among parameters of climate conditions was no meaningful. Therefore, it can be concluded that indices were affected by the cooling effect of vests. However, the impact of the cooling vests on the physiological and perceptual indices except the skin temperature was not different.

These types of cooling systems can remove the heat from a part of the body surface [20]. Indeed, the heat conduction from the skin surface toward cooling packs decreases the torso temperature. Moreover, the motion on the treadmill causes the air flow due to vest movements and increases the heat transfer. These mechanisms decrease the skin and core temperature [21]. The heart rate is also affected owing to the correlation with body temperature [22]. Based on the results of the present study, values of the oral temperature, heart rate, and PSI were decreased during the use of cooling vests. A study conducted by Jovanovic et al. [23] on the effectiveness of the paraffin cooling during exercise on a treadmill (speed of 5.5 km/h) under hot condition

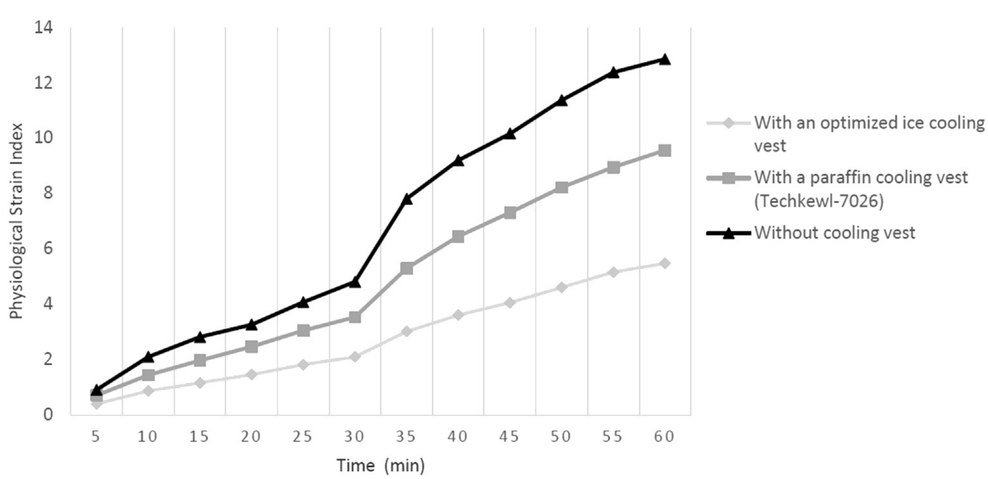

Fig. 1. Compression of physiological strain index (PSI) during the exercise with and without cooling vests.

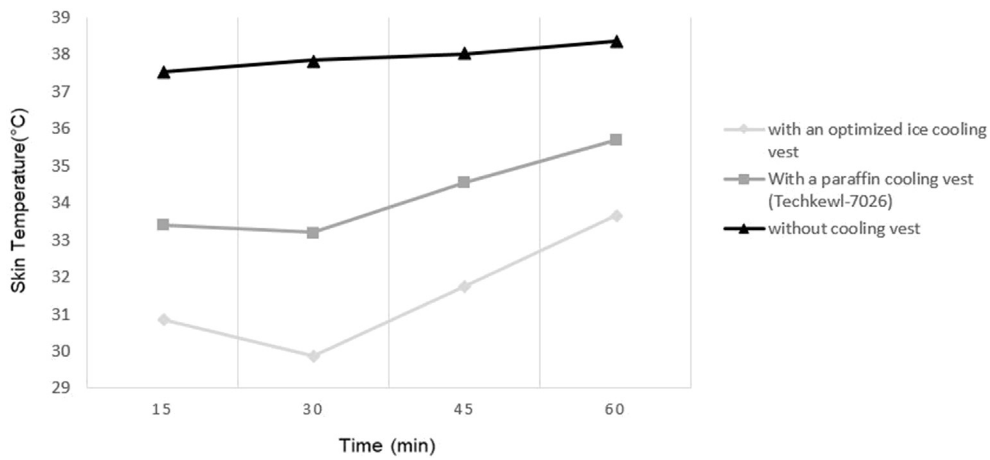

Fig. 2. Comparison of skin temperature during the exercise with and without cooling vests.

Table 3
The range, mean, and standard deviation of perceptual parameters in exercise without a cooling vest (A), with a paraffin cooling vest (B), and with an optimized ice cooling vest (C).

Parameters	Range	Mean (±SD)
HSSI res	4.32–9.36	6.44 (1.47)
HSSI A	15.98–20.67	17.92 (1.49)
HSSI B	10.95–19.67	14.01 (2.72)
HSSI C	10.94–16.11	13.37 (1.93)
PeSI rest	0–0.75	0.35 (0.23)
PeSI A	3.75–6.50	5.14 (0.71)
PeSI B	2.38–4.69	3.65 (0.72)
PeSI C	1.69–4.81	3.48 (0.75)

SD, standard deviation; PeSI, perceptual strain index; HSSI, heat strain score index.

(Ta of 40°C) also indicated that PCM cooling vest can reduce the physiological strain. Moreover, Barr et al. [24] revealed that the use of the ice cooling vest during walking on the treadmill (speed of 5 km/h and slope of 7.5 %) in a hot environment (Ta of 50°C and RH of 14 %) can improve the cardiovascular conditions of firefighters. In addition, in the present study, values of the skin temperature during the use of optimized ice and paraffin cooling vests were close to that of the natural skin temperature. Therefore, results demonstrated that the use of ethylene vinyl acetate foam in the ice packs for the decrease of the cooling temperature had been effective.

As well as, the mean values of HSSI and PeSI during the exercise with cooling vests were significantly less than those during exercise without the cooling vests. Indeed, the use of these cooling vests increases the thermal comfort. Results of some studies show that the thermal comfort and sensation are linked to the body temperature and affected by the mental perception [25]. Comfort is a term created by psychologists but has a physiological basis that is not very clear. There are studies that show the effect of cooling vests on comfort indices. In the study of Loumala et al. [26], participants received lower scores in the thermal sensation and comfort assessment during the use of the ice cooling vest when cycling under hot condition (Ta of 30°C and RH of %40). In addition, the use of the cooling vest significantly improved the cycling performance and increased the exercise time from 61 to 74 minutes. As well as, a study conducted by Smolander et al. [27] on the effectiveness of the ice cooling vest during exercise on a treadmill (speed of 4 km/hr and slope of %0) under hot conditions (Ta of 45°C and RH of 30%) indicated that the use of the vest significantly decreases the mental sensation of the effort and heat in addition to physiological parameters in firefighters.

The results of the present study showed that the optimized ice cooling vest was as effective as the commercial paraffin cooling vest to control the thermal strain. In addition, there was no a high difference between skin temperatures during the use of the vests. As well as, the ice cooling vests are cheaper than paraffin commercial cooling vests. Therefore, the optimized ice cooling vest can be a good replacement for paraffin cooling vest owing to a greater latent heat and less production cost.

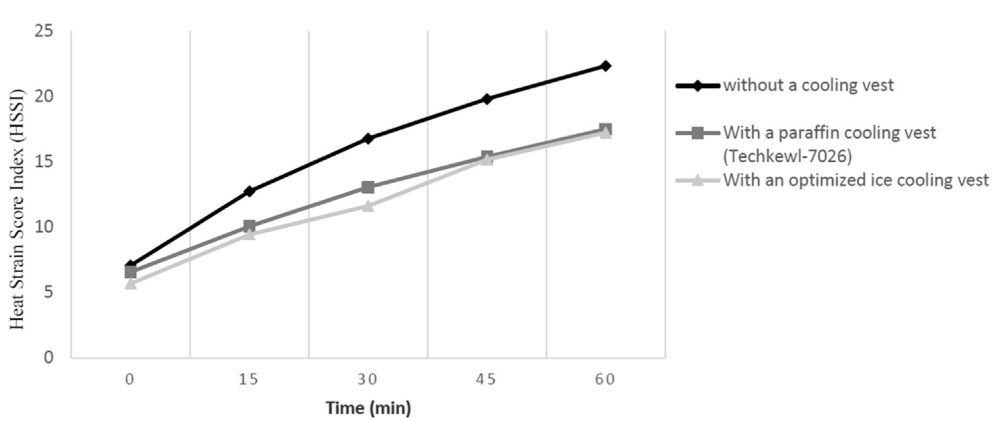

Fig. 3. Comparison of Heat Strain Score Index (HSSI) during the exercise with and without cooling vests.

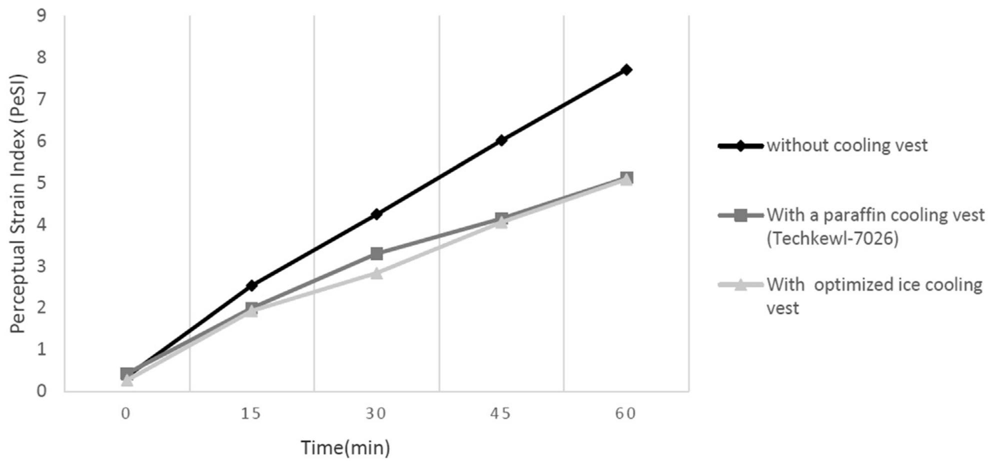

Fig. 4. Comparison of Perceptual Strain Index (PeSI) during the exercise with and without cooling vest.

Conflict of interest

The authors declare that they have no conflict of interest.

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Contribution details

Mansoor zare helped in analysis and interpretation of data, drafting of manuscript, and critical reversion of manuscript for important intellectual content. Habibollah dehghan participated in acquisition of data, analysis and interpretation of data, and drafting of the manuscript. Saeid yazdanirad contributed to the study concept and design, acquisition of data, analysis and interpretation of data, drafting of the manuscript, critical reversion of the manuscript for important intellectual content, statistical analysis, administrative, technical and support, and study supervision. Amir hossein khoshakhlagh involved in drafting of the manuscript.

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