original article

Effect of fabric stuff of work clothing on the physiological strain index at hot conditions in the climatic chamber

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ABSTRACT

Aims: The purpose of the present study was to evaluate the effect of fabric stuff of work clothing that are widely used in Iran industries on the physiological strain index (PSI) at hot conditions in the climatic chamber.
Materials and Methods: This interventional study was performed upon 18 male students in 16 trials, which included combination of four kinds of work clothing (13.7% viscose (VIS) 86.3% polyester(PES), 30.2% cotton [CT]-69.8% PES, 68.5% CT-31.5% PES, 100% CT, two activity levels (light and moderate) and two kinds of climatic conditions included hot-wet (T_a = 35, RH = 70%) and hot-dry (T_a = 38, RH = 40%). During each trial, the RH and core temperature was recorded once a minute and then PSI was calculated. Data were analyzed by using SPSS-16 software.
Results: The results showed that in hot-wet conditions, the least value of PSI in light and moderate activities was related to 100% CT clothing and 30.2% CT-69.8% PES clothing, respectively. In hot-dry conditions, the least value of PSI in both of activities was related to 30.2% CT-69.8% PES clothing. The mean value of PSI in hot-wet conditions, during moderate activity had significant difference for various clothing types (P = 0.044).
Conclusion: The research findings showed that for a heat strain reduction in hot-wet conditions at light activity level, 100% CT clothing is suitable. Furthermore, at moderate activity level, 30.2% CT-69.8% PES clothing and in hot-dry conditions, 30.2% CT-69.8% PES is suitable.

Key words: Climatic chambers, core temperature, heart rate, physiological strain index, work clothing

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INTRODUCTION

Working at hot environment exposes the body to the heat stress. This can result in early fatigue, concentration reduction, human error increase, work efficiency and productivity reduction.[1] When heat stress exceeds the allowable limit, this would cause some disorders like: headache, heat rash, heat cramp, heat exhaustion, heat stroke.[2-4] The incidence of heat-related illnesses is so much that one case among 500 men in educational and

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martial operations in Hong Kong and about 80 service personnel in the UK are hospitalized. This statistics show a remarkable estimation to the heat illnesses as well as a small document to productivity reduction, error increase and safety reduction.[5] So, control of this physical factor not only prevents from health problems, but also increases the efficiency of workers and finally, the quality of products.[6-8]

Heat strain depends on various factors, that the clothing as one of these factors affects the thermal exchanges between man and environment through conduction, radiation, evaporation and cause thermal strain.[9] Even, in evaluation of thermal strain at work environment as well as control and reduction of it, the clothing has a main role. For example, in the wet bulb globe temperature (WBGT) index, the clothing adjustment factor is calculated and added to the environmental WBGT index with regards to work clothing material.[10] Clothing is an important as far as replacing long pants with shorts under the firefighting protective clothing reduces the heat stress associated with wearing the firefighting protective clothing and extend heat toleration times approximately 10-15% during light exercise.[11]

Clothing, as an interactive barrier, increasingly affects thermal balance. Some of this interaction is resulted from the physical properties of the clothing materials.[12,13] In a study, on three kinds of clothing; A (wool and cotton [CT] blend with high moisture absorbency), B (100% CT with an intermediate moisture absorbency) and C (100% polyester with low moisture absorbency), rectal and skin temperature (Tr) in A was significantly less than B and C. the heart rate (HR) in C was significantly greater than A and B.[14] In other study, by Brazaitis *et al*., thermo-physiological and subjective sensations were the same for polyester and CT clothing. In polyester, skin Tr returned to its basic value faster, and the thermal and rating of shivering/sweating sensations were lower than CT after activity.[15]

It is need to study more for understanding of the relationship between clothing material and physiological responses.[16] Therefore, the purpose of the present study was to evaluate the effect of fabric stuff of work clothing that are widely used in Iran industries on physiological strain index (PSI) at hot conditions in the climatic chamber.

MATERIALS AND METHODS

Subjects

This research was an interventional study that was done on 18 male students of Isfahan University of Medical Sciences. The physical characteristics of the participants were as follows (means ± SE): Age 22.50 ± 1.83 year and body mass index (BMI) 23.02 ± 1.92 kg/m^2. Sampling method was convenience non-probability. Participants were informed of all details of experimental procedures and the related risk and discomforts. Each participant gave informed consent before participation. Participants were examined by an occupational medicine specialist. They had normal BMI (18.5-25); no background of cardiovascular, pulmonary, neuromuscular and musculoskeletal diseases; no epileptic, convulsionary and diabetic history; no background of hypertension and HR drugs usage; no smoking; no existence of paraffin sediments in the ear channel. If there were paraffin sediments, channel of the ear was washed. They were prohibited to use coffee, caffeine and alcohol since 12 h before the test. The activity was stopped when HR or core Tr exceeded 180 b/min and 39°C, respectively.[17,18]

Experimental clothing

Four kinds of work clothing following were examined in this experiment. 13.7% viscose (VIS)-86.3% polyester (PES), 30.2% cotton (CT)-69.8% PES , 68.5% CT-31.5% PES and 100% CT. The physical characteristics of experimental clothing are given in Table 1.

Experimental protocol

In this study, every participant was exposed to combination of four kinds of work clothing (13.7% VIS-86.3% PES, 30.2% CT-69.8% PES, 68.5% CT-31.5% PES and 100% CT), two activity levels (light and moderate intensity) and two kinds of climatic conditions [Table 2]. Total number of trials were 16 states. Protocol for each participant consisted 8 times of referring to the climatic chamber and each time, 60 min of walking on the treadmill (TX1, Kettler, Germany) including 30 min of light activity (4.8 km/h, 0% grade) and 30 min of moderate activity (4.8 km/h,

Table 1: Physical characteristics of work clothing

Work clothing	Producer	Material	Weave type	Mass (g/m^2)	Warp density (1/cm)	Weft density (1/cm)	Warp count (tex)	Weft count (tex)
1	—	13.7% VIS-86.3% PES	Twill 1,2	223.15	34	24	48	21
2	Padjame company	30.2% CT-69.8% PES	Taffeta	253.56	31	24	48	35
3	Jeykar company	68.5% CT-31.5% PES	Tabby	249	33	23	30	30
4	Jeykar company	100% CT	—	354.25	—	—	—	—

VIS: Viscose, PES: Polyester, CT: Cotton

5% grade). There was a 15 min rest interval after light activity. Trials were performed in the climatic chamber, which was Tr and humidity adjustable.

In order to control the effect of underwear clothing and also friction between shoes and treadmill surface on thermal strain, all the participants were supplied similar CT underwear, short and similar shoes.

Measurements

After 15 min of rest in the room and also at 1 min interval during each activity, HR and aural Tr were measured and recorded with a HR monitor (RS100, Polar, Finland) and a Personal Heat Stress Monitor (Questemp II, Quest Technologies, USA), respectively. It should be mentioned that core Tr measurement methods from precision and accuracy aspects are included rectal Tr method, digestive tablets, respectively. Because, the rectal sensors and digestive tablets are invasive[19,20] and unavailable, aural Tr method was chosen. Environmental conditions during the experiments were monitored continuously using a WBGT heat stress monitor (Microtherm; Casella, Bedford, UK).

CALCULATIONS

Then PSI was calculated according to following equation.

$$PSI = (5(T_{ri} - T_{r0})/(39.5 - T_{r0})) + (5(HR_i - HR_0)/(180 - HR_0))$$

Table 2: Dry, wet and globe temperature, relative humidity and wet bulb globe temperature during experiments

Climatic condition parameter	Hot-wet (M±SD)	Hot-dry (M±SD)
Dry bulb temperature	35.1±0.4	37.8±0.6
Wet bulb temperature	30.4±0.5	27.4±0.9
Globe bulb temperature	35.3±0.4	38.2±0.7
Relative humidity	69.6±2.9	42.4±1.9
WBGT index	31.9±0.9	30.6±0.5

SD: Standard deviation, WBGT: Wet bulb globe temperature

Where T_{ri} and HR_i are simultaneous measurements taken at any time during the heat exposure; and T_{r0} and HR_0 are the resting values prior to beginning the exercise protocol. The index was scaled to a range of 0-10 within the limits of the following values: 36.5°C ≤ Tr ≤ 39.5°C and 60 ≤ HR ≤ 180 b/min.[18]

Statistical analysis

Data were analyzed with using SPSS-16 software. To compare the means of PSI in different combination of four work clothing, two activity levels and two climatic conditions, a statistical test of "Repeated Measures analysis of variance (ANOVA)" was used, where significant main effect was found. A *post hoc* test with Bonferroni correction was applied to locate the difference. The significance level was set at $P < 0:05$. Data are presented in this study as mean ± SD.

RESULTS

Results showed that in hot-wet conditions at light activity, the least value of PSI was due to 100% CT clothing and the highest value of it was due to 13.7% VIS-86.3% PES clothing. With the use of ANOVA test and Sphericity Assumed method, there was no significant difference in mean values of PSI among four clothing types ($F_{(3,48)} = 0.554$, $P = 0.648$) [Table 3 and Figure 1].

In hot-wet conditions at moderate activity, the least value of PSI was related to 30.2% COT-69.8% PES clothing and the highest value of it was related to 13.7% VIS-86.3% PES clothing. With the use of ANOVA test and sphericity assumed method, there was a significant difference in mean values of this index among four clothing types ($F_{(3,48)} = 2.912$, $P = 0.044$) and with the use of *post hoc* test and Bonferroni correction, we found that this difference is related to 13.7% VIS-86.3% PES clothing and 30.2% CT-69.8% PES clothing ($P = 0.065$) [Table 3 and Figure 2].

Table 3: Mean, standard deviation and significance level of physiological strain index in different trials

Climatic conditions	Activity level	Work clothing fabric	PSI	
			Mean (SD)	*P* value
Hot-wet	Light	13.7% VIS-86.3% PES	2.27 (0.48)	0.648
		30.2% CT-69.8% PES	2.19 (0.47)	
		68.5% CT-31.5% PES	2.25 (0.53)	
		100% CT	2.12 (0.42)	
	Moderate	13.7% VIS-86.3% PES	3.82 (0.54)	0.044
		30.2% CT-69.8% PES	3.40 (0.64)	
		68.5% CT-31.5% PES	3.71 (0.75)	
		100% CT	3.60 (0.76)	
Hot-dry	Light	13.7% VIS-86.3% PES	2/06 (0.50)	0.111
		30.2% CT-69.8% PES	1.85 (0.47)	
		68.5% CT-31.5% PES	2.09 (0.52)	
		100% CT	1.95 (0.40)	
	Moderate	13.7% VIS-86.3% PES	3.03 (0.65)	0.113
		30.2% CT-69.8% PES	2.84 (0.74)	
		68.5% CT-31.5% PES	3.16 (0.68)	
		100% CT	3.19 (0.63)	

SD: Standard deviation, PSI: Physiological strain index, VIS: Viscose, PES: Polyester, CT: Cotton

In hot-dry conditions, at light activity, the least value of PSI was due to 30.2% CT-69.8% PES clothing and the highest of it was due to 68.5% CT-31.5% PES clothing. With the use of ANOVA test and Sphericity Assumed method, there was no significant difference in mean values of this index among four clothing types ($F_{(3,42)} = 2.130$, $P = 0.111$). In hot-dry conditions at moderate activity, the least value of PSI was for 30.2% CT-69.8% PES clothing and the highest value of it was in 100% CT clothing that there was no significant difference among the index value in four clothing types ($F_{(3,42)} = 2.113$, $P = 0.113$). It is noticeable that in all states during the Repeated Measures test, equality of variances was checked [Table 3, Figures 3 and 4].

DISCUSSION

Findings of this study showed, that in hot-wet conditions during light activity, the least values of PSI are related to 100% CT clothing and the highest is related to 13.7% VIS-86.3% PES clothing. As for, 100% CT clothing is made of CT fiber and CT has high moisture absorbency, so it causes an increase in evaporating surface of sweat and therefore, a reduction in PSI values. A study conducted by Kwon *et al.* (1998) on three kinds of clothing A (wool and CT blend with high-moisture absorbency), B (100% CT with moderate moisture absorbency) and C (100% polyester with low-moisture absorbency) in Tr of 30°C and relative humidity of 50%, showed that rectal and skin Tr's in state A were significantly lesser than B and C [14] that are consistent with our study findings. Results of this study showed, that in hot-wet conditions within moderate activity, the least values of PSI relate to 30.2% CT-69.8% PES clothing and the highest of it relates to 13.7% VIS-86.3% PES clothing. So, in hot-wet conditions, 30.2% CT-69.8% PES and 100% CT clothing cause the least and 13.7% VIS-86.3% PES clothing causes the highest heat strain level [Figures 1 and 2].

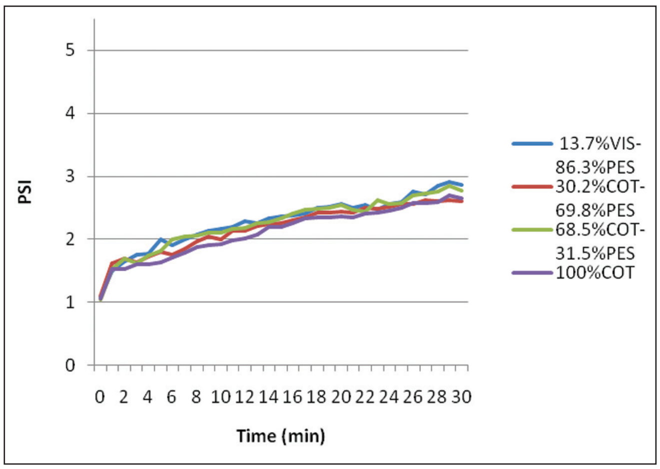

Figure 1: The values of physiological strain index in hot-wet conditions and light physical activity for four different types of clothing

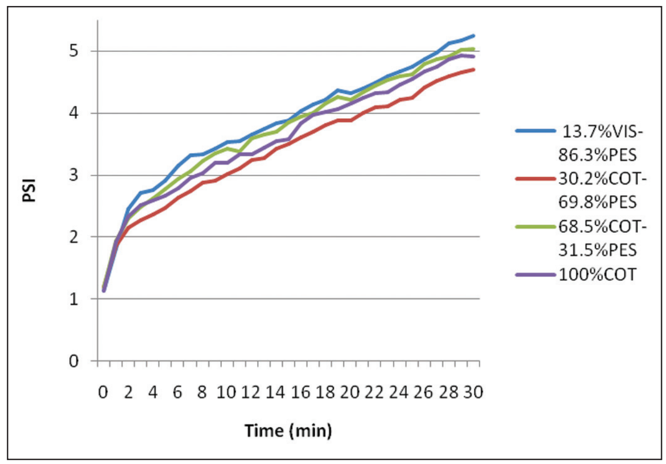

Figure 2: The values of physiological strain index in hot-wet conditions and moderate physical activity for four different types of clothing

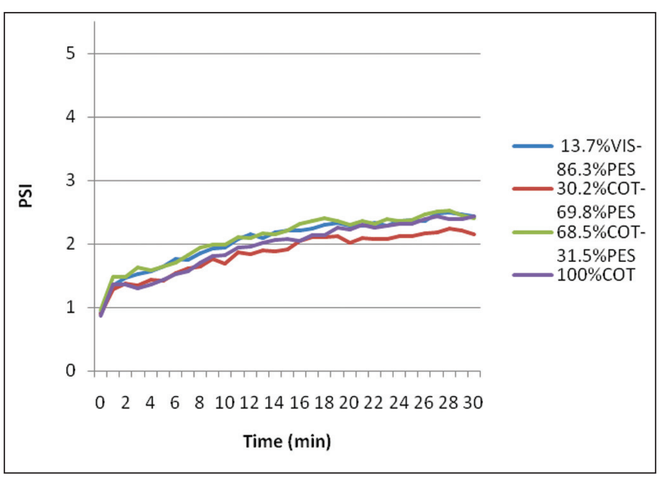

Figure 3: The values of physiological strain index in hot-dry conditions and light physical activity four different types of clothing

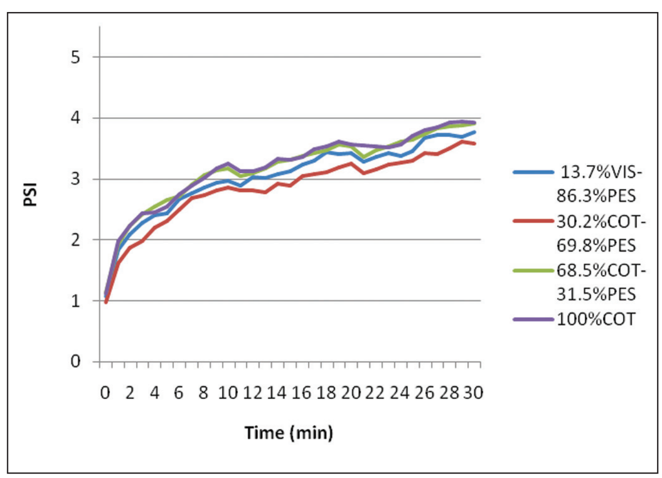

Figure 4: The values of physiological strain index in hot-dry conditions and moderate physical activity four different types of clothing

Findings of this study showed, that in hot-dry conditions, within light activity, the least values of PSI relate to 30.2% CT-69.8% PES clothing and the highest of them relate to 68.5% CT-31.5% PES clothing. In hot-dry conditions and at moderate activity, the least values of PSI relate to 30.2% CT-69.8% PES clothing and the highest of them relate to 100% CT clothing. So, in hot-dry conditions, 30.2% CT-69.8% PES clothing causes the least and 68.5% CT-31.5% PES and 100% CT clothing cause the highest heat strain level [Figures 2 and 4].

Under normal climatic condition, when the person has no activity, the body sweat is low and putting on CT or polyester clothing does not result in significant difference in sensation of person.[21] However, in hot conditions, conduction, convection and radiation mechanisms cannot keep heat balance of body and a sensible sweating in surface of skin starts with the aim of heat loss by sweat evaporation.[22] Natural fibers such as wool and CT that are hydrophilic can absorb large amount of moisture.[23] The preview studies have shown that in the same sweat generation conditions, CT clothing absorbs more moisture than polyester.[24,25] However, the absorbed moisture in CT fabric can act as a barrier to an effective moisture transfer. While, synthetic fibers like polyester are not hydrophilic and absorb low-level of moisture, because of their hydrophilic fiber surface, they can transfer the moisture[26] and cause high evaporation.[9] So, 30.2% CT-69.8% PES clothing (with 69.8% polyester), which has more polyester than 68.5% CT-31.5% PES and 100% CT clothing causes less PSI values. Furthermore, according to the studies, the heavier clothing cause more metabolisms and heat generation in the body.[27,28] Because clothing type 30.2% CT-69.8% PES has the less weight than types 100% CT, it causes a reduction in PSI.

There was no significant difference among mean values of PSI except in hot-wet conditions during moderate activity [Table 3]. Gavin *et al.* (2001) in study on polyester clothing and traditional CT clothing at 30 ± 1°C and 35 ± 5% relative humidity, demonstrated that there is no difference in mean body Tr, rectal Tr or mean skin Tr as well as in oxygen intake, number of HR and comfort sensation during and after the activity.[29] Brazaitis *et al.* (2010) evaluated the effect of two kinds of long-sleeve T-shirts made of polyester and CT on physiological and psychological thermal responses at Tr of 25°C and relative humidity of 60%, they found out same thermo-physiological and subjective sensations for both of clothing that approves findings of the present study.[15]

CONCLUSION

Findings showed that in hot-wet conditions, 30.2% CT-69.8% PES and 100% CT clothing causes the least and 13.7% VIS-86.3% PES clothing causes the highest level of heat strain. However, in hot-dry conditions, 30.2% CT-69.8% PES clothing causes the least and 68.5% CT-31.5% PES and 100% CT clothing cause the highest level of heat strain. The results of this research showed that for heat strain reduction, in hot-wet conditions, 100% CT clothing is suitable for light activity and 30.2% CT-69.8% PES clothing for moderate activity and in hot-dry conditions, 30.2% CT-69.8% PES clothing is suitable.

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