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Validation of Perceptual Strain Index to Evaluate the Thermal Strain in Experimental Hot Conditions

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ABSTRACT

Background: The incidence of heat stress is one of the most common problems in workplaces and industries. Many heat stress indices have been developed, and these indices have some disadvantages. The purpose of this study is to validate the perceptual strain index (PeSI) in experimental hot conditions.

Methods: This study is of cross-sectional carried out on 15 men at five different thermal conditions (35°C, 30°C, 27°C, 24°C, and 21°C) in a climate chamber and on a treadmill at three levels of light (2.4 kph), medium (4.8 kph) and heavy activity (6.3 kph). Heart rate and oral temperature were respectively measured to calculate the physiological strain index. Also, thermal sensation and rate perceive exertion were respectively measured to calculate the PeSI. Finally, the correlation between the indices was analyzed using Pearson correlation test and regression analysis.

Results: Pearson correlation test showed a high correlation ($r = 0.94$) between the PeSI and physiological strain index ($P = 0/001$). It was also observed a high correlation between the PeSI and the oral temperature ($r = 0.78$, $P = 0/001$) and the heart rate ($r = 0.90$, $P = 0/001$). In addition, there was found a moderate correlation ($r = 0.71$) between the PeSI and the wet bulb glob temperature ($P = 0/001$). However, there was no correlation between the PeSI and the body mass index ($r = 0.0009$, $P = 0.79$).

Conclusions: The research findings showed when there is no access to other forms of methods to evaluate the heat stress, it can be used the PeSI in evaluating the strain because of its favorable correlation with the thermal strain.

Keywords: Evaluation of thermal strain, hot experimental conditions, perceptual strain index, physiological strain index

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INTRODUCTION

One of the most common problems found in the occupational health sector is unfavorable climate conditions in workplaces, in other words, working in hot environments. In addition to the reduction in human's work capacity, hot workplaces can induce various diseases

in human including thermal strain. The thermal strain is defined as any human physiological responses to the thermal stress. Heat also considers as a risk factor for cardiovascular disease and results in the increased work-related accidents.[1] Also, the exposure to heat is regarded as a major problem of occupational health in many countries.[2] The heat stress is a serious threat in many industries, including steel, petrochemicals, and glass, and also in kitchens, bakeries, and road construction, and it can affect directly the performance and health of peoples. Many heat stress indices have been developed by researchers to evaluate heat stress. In fact, the index is a criterion to show the severity of heat stress in workplaces.[3,4] Some of these indices are: Wet glob temperature developed by Haldan in 1905 as the first index for evaluating the thermal stress,[5] effective temperature index developed by Houghton Yaglou in 1923,[6] and wet bulb glob temperature (WBGT) developed by Yaglou and Minard in 1957.[7] Many proposed indices are categorized in rational and empirical indices. Rational indices are those developed based on heat exchange between human's body and the environment, whereas the empirical indices are those based on human's response to various factors and are applied to conditions for which they have been defined and are not used in different weather conditions.[1] Considering the number of job positions with thermal problems is very high, and hence each of above indices developed to assess the heat stress has some disadvantages and it cannot be used as a single index to evaluate the heat stress in environments with different climate conditions, or some of indices have variables difficult and time-consuming to be measured,[8] such as Required Sweat Rate Index which needs tools and instruments and is calculated by a very complicated and time-consuming method which requires a computer,[9] index of thermal stress which is not applicable for assessing the thermal strain such as internal temperature and heart rate, index of predicted 4-h sweat rate which is used only in environments with high humidity and is not applicable in environments with low humidity[10] modified discomfort index which was developed by Epstein and Moran in 1999 and doesn't consider the radiation temperature in environments in evaluating thermal stress.[3] On the other hand, of the existing methods for assessing the risk of heat stress, the observational and perceptional methods have been continuously developed and used because of their simplicity and inexpensiveness, rapid answers, and feasibility to be used without interfering with the workplaces.[10]

Chen *et al*. concluded in their study that heart rate, systolic blood pressure, and individuals' subjective judgment of physical and mental exhaustion caused by heat increase when the index of WBGT rises, and there is a direct significant relationship between the index of WBGT and heart rate, systolic blood pressure, and physical and mental exhaustion caused by heat.[11]

Cheung suggested that the individuals' mental perception of and psychological responses to heat stress of the environment should be considered whereas it is not considered human's perceptional response to heat stress and the temperature of the body in most of indices of heat stress.[12]

Ohnaka *et al*. concluded in their study in Japan that there is a significant direct relationship between participants' thermal sensation by Likert scale, deep body temperature, and standard effective temperature.[13]

Considering the aforementioned disadvantages about the thermal indices, Tikuisis *et al*. have developed perceptual strain index (PeSI) which measures the thermal strain in individuals through the thermal sensation and the Borg Rating of Perceived Exertion for physical activity intensity level. This index is indeed a method to assess the risk of thermal strain through perception. PeSI is a simple and inexpensive method to evaluate the thermal strain, and it can be used to determine the health risks to workers exposed to heat.[14] Many heat stress indices have been developed, and these indices have some disadvantages, and purpose of this study is to validate the PeSI in experimental hot conditions.

METHODS

Participants in the study

This experimental study was performed carried out on 15 male students in the laboratory of thermal stress in School of Health. The sampling method was the invitation of the subjects, considering inclusion criteria for the study. Participant's characteristics in this study were 15 men with a mean and standard deviation of 24.53 ± 2.47 years old, 174.66 ± 12.31 cm height, 71.41 ± 4.49 kg weight, and 23.28 ± 3.86 kg/m^2 body mass index (BMI). Inclusion criteria were lack of cardiovascular diseases, pulmonary diseases, hypertension, diabetes, neurological diseases, musculoskeletal diseases, consuming coffee, caffeine and alcohol for 12 h before the test. The subjects were informed about the test procedures and signed participation consent. Selection and number of samples were based on the similar empirical studies.[14,15] After approving the subjects for the test, a cardiograph apparatus RS 100 POLAR model,[16,17] which has been used in various researches was fasten on the subject's chest and wrist. The subject was in resting position for 15 min, and then his heart rate and oral temperature were measured by cardiograph apparatus and oral thermometer (Rossmax

Digital Thermometer Model 100 TB) Med First, India, respectively, and the variables thermal sensation and Borg Rating of Perceived Exertion for physical activity intensity level were recorded. After resting, the subject performed a physical activity (walking) in five different thermal stages of 21°C, 24°C, 27°C, 30°C and 35°C each for 45 min. Each thermal stage was executed in a separate day, including a 45 min physical activity on a treadmill. The subject engaged in physical activity on a treadmill at each of the above temperatures for the first 15 min at the rate of 2.4 kph (light physical activity) and 10 min rest for recovery time heart rate and core temperature, the second 15 min at the rate of 4.8 kph (medium physical activity) and 10 min rest for recovery time heart rate and core temperature, the third 15 min at the rate of 6.3 kph (heavy physical activity) and 10 min rest for recovery time heart rate and core temperature.[1] The physical activity was performed with normal clothes (0.6 clo). And at the end of each 15 min session and at each of above speeds and temperatures, the heart rate and the deep body temperature were recorded during the physical activity to calculate the physiological strain index, and the thermal sensation and the exerted power by the subject were recorded to calculate the PeSI.

The PeSI is calculated as follows:[14]

$$PeSI = 5 \times ([TS - 1]/4) + 5 \times (PE/10).$$

The score for thermal sensation and perceived exertion is presented in Tables 1 and 2.

The final score for the PeSI is from 0 to 10 that is presented in Table 3.

One of the important indices used in this study as one of the main factors validating the PeSI is the physiological strain index. It is used to assess the physiological strain caused by the heat, in which it is considered the load on the cardiovascular system and the system regulating the body's temperature.

The physiological strain index is calculated as follows:

$$PSI = 5 \times (T_{ot\ w} - T_{ot\ r})/(39.5 - T_{ot\ r}) + 5 \times (HR_a - HR_r)/(180 - HR_r).$$

Where:

$T_{ot\ r}$ is oral temperature at rest, $T_{ot\ a}$ is oral temperature during the activity, HR_a is the heart rate during the activity, and HR_{c0} is the heart rate at rest.[15]

The final score for the physiological strain index is from 0 to 10 that is presented in Table 4.

Environmental temperature was monitored using the WBGT apparatus of Casella model, Britain that sensitivity 0.1°C. Air temperature ranged at this study was between 19.5°C and 44.3°C. The results from the study were analyzed using SPSS, version 20 (IBM, United States). Finally, Pearson correlation test and regression analysis were used to determine the relation between PeSI and the physiological strain index, oral temperature, heart rate, wet bulb globe temperature and BMI. This study was performed after getting permission from the Ethic Committee in Medicine and participant's informed about the test procedures and signed participation consent.

Table 1: Thermal sensation score

Thermal sensation	Evaluate
1	Comfortable
2	Slightly warm
3	Warm
4	Hot
5	Very hot

Table 2: Perceived exertion score

Perceived exertion	Evaluate
0-1	Extremely easy
2-3	Easy
4-5	Somewhat easy
6-7	Somewhat hard
8-9	Hard
10	Extremely hard

Table 3: The final score the perceptual strain index[14]

Score	Evaluate
0-2	No heat strain
3-4	Low heat strain
5-6	Moderate heat strain
7-8	High heat strain
9-10	Very high heat strain

Table 4: The final score the physiological strain index[15]

Score	Evaluate
0-2	No heat strain
3-4	Low heat strain
5-6	Moderate heat strain
7-8	High heat strain
9-10	Very high heat strain

RESULTS

The mean and standard deviations of the studied indices and the relevant variables are presented in Table 5.

Examining the relationship between the perceptual strain index and the physiological strain index, oral temperature, heart rate

Pearson correlation test showed that there is a very high correlation between the PeSI and the physiological strain index ($r = 0.94$, $P = 0.001$).

The linear regression analysis in Figure 1 shows a very high correlation between the PeSI and the physiological strain index; so that, the PeSI will increase when the physiological strain index increases. The linear equation and the linear correlation coefficient are shown in the Figure 2.

Pearson correlation test also showed that there is a high correlation between the PeSI and the oral temperature ($r = 0.78$) and the heat rate ($r = 0.90$, $P = 0.001$).

The linear regression analysis shown in Figure 1 reveals a good correlation between the PeSI and the oral temperature and the heat rate. The linear equation and the linear correlation coefficient are shown in figure.

Examining the relationship between the perceptual strain index and body mass index and wet bulb glob temperature

Pearson correlation test showed no relationship between the PeSI and the BMI ($r = 0.0009$, $P = 0.79$). In Figure 3, the linear regression analysis not shows correlation between the PeSI and BMI.

Pearson correlation test also showed that there is a moderate correlation between the PeSI and WBGT ($r = 0.71$), so that the PeSI will increase when WBGT increases ($P = 0.001$).

In Figure 4, the linear regression analysis shows a moderate correlation ($r = 0.71$) between the PeSI and WBGT, so that the score of the PeSI will increase when WBGT increases from 21°C to 35°C.

Table 5: Mean and SD of the studied indices and the relevant variables

Index	Mean (SD)	Minimum-maximum range
Thermal sensation	3.48 (1.2)	1-5
Perceived exertion	6.2 (3.6)	0-10
Perceptual strain index	6.52 (3.4)	0-9.5
Oral temperature (°C)	37.4 (1.2)	35.8-38.9
HR	148 (12.2)	66-173
Physiological strain index	6.97 (2.89)	0-8.5

SD= Standard deviation, HR= Heart rate

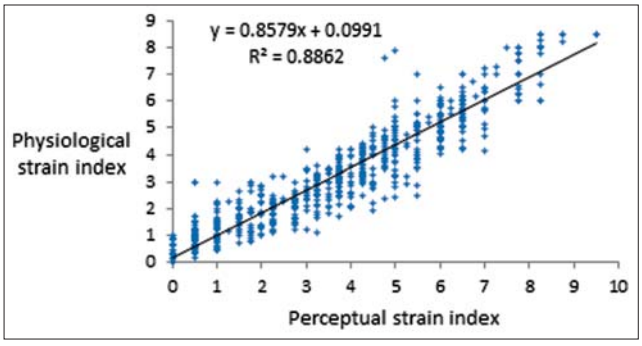

Figure 1: The linear regression analysis between the perceptual strain index and the physiological strain index

DISCUSSION

The present study showed a high correlation between the perception strain index and the physiological strain index, oral temperature, and heart rate. Also, the study showed a moderate correlation between the PeSI and WBGT, indicating the suitability of such index for evaluating the thermal strain in all places. The correlation of the deep temperature (oral temperature) which is the gold standard for the thermal stress with the PeSI is high, indicating that this index is suitable for evaluating the thermal strain. Gagge *et al*. concluded examining the relationship between the thermal sensation and the physiological responses that when participants had a comfortable thermal sensation, the physiological responses of their skin and their heart rate were desirable and their perception of heat was proportional to their physiological responses.[18] Hostler *et al*. studying the effect of the increased perspiration on the PeSI and the physiological strain index, reached to this conclusion that both PeSI and physiological strain index showed similar results and there was observed a high correlation between these two indices.[19] Dehghan *et al*. examined the observational-perceptional index as heat strain score index (HSSI) in the form of a questionnaire, and concluded that participants have a good subjective

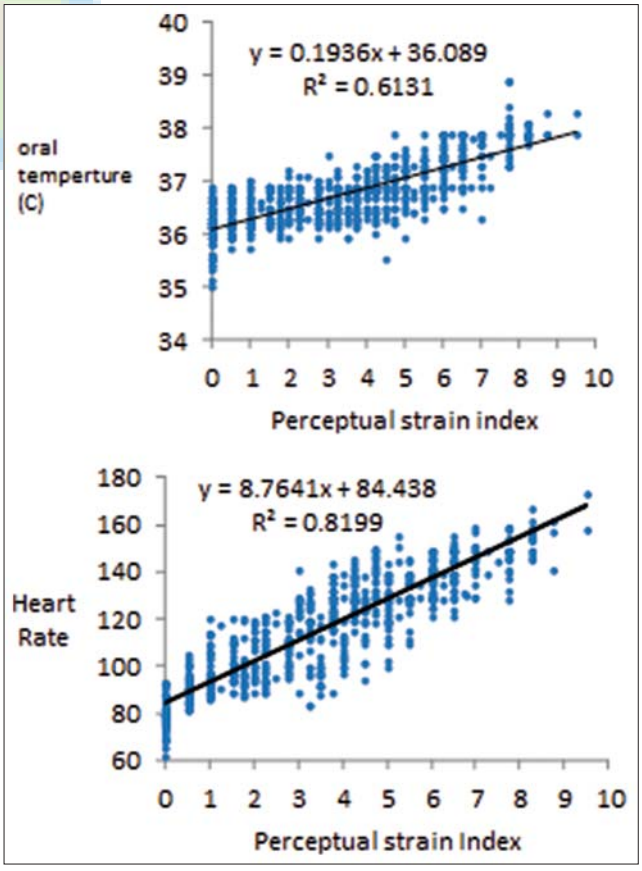

Figure 2: The linear regression analysis between the perceptual strain index and the oral temperature and the heat rate

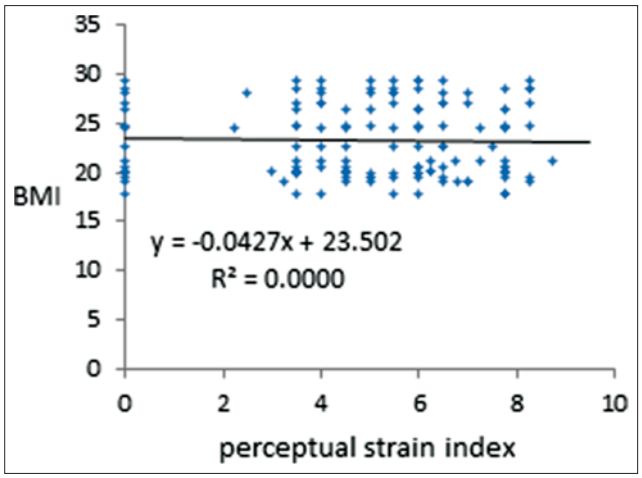

Figure 3: The linear regression analysis between the perceptual strain index and body mass index

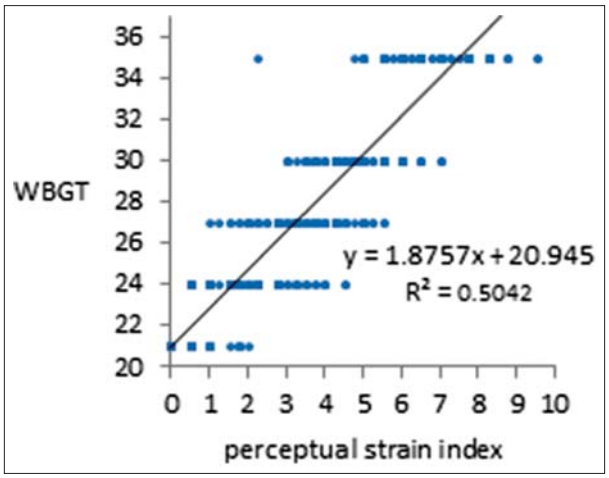

Figure 4: The linear regression analysis between the perceptual strain index and wet bulb glob temperature

perception of the heat stress in workplaces, and the obtained score of this index has a direct and significant correlation with the resulted physiological strain index, heart rate, oral temperature. Also, there is a direct and significant correlation between this index and WBGT, which is consistent with the findings of the present study.[20]

Gallagher *et al.* developed perceptual hyperthermia index (PHI) based on a laboratory pilot study in which firefighters wore protective clothing in a fire drill. They concluded that there was a direct significant correlation between the PHI and the physiological strain index under different environmental temperatures, and they also had a good subjective perception of the heat, which is consistent with the present study's findings.[16]

Haroyama *et al.* studied participants' subjective judgment of the thermal stress using Subjective Judgment Scale and concluded a direct significant correlation between Subjective Judgment Scale and WBGT, so that the scores from the subjective judgment scale increased by increasing the WBGT. Participants had a proper perception of the heat, which is consistent with the findings of the present study.[21]

Ansaldi *et al.* studied the subjects' thermal comfort and their subjective responses in the classroom and reached to this conclusion that the participants had a comfortable subjective response to the hot workplaces when the temperature of the environment was in the desirable range. By increasing the ambient temperature, the participants' subjective responses changed, and this finding is consistent with the findings of the present study.[22]

Habibi *et al.* concluded in a study on the relation between the physiological strain index and the HSSI among women that the increase in the physiological strain index will increase the thermal strain index. The participants showed a proper subjective response to the heat stress, which is consistent with the findings of the present study.[23]

No correlation was seen between the PeSI and the BMI. Tuomaala *et al.* studied the effects of individual's characteristics and BMI on the thermal sensation through predicted mean vote and concluded that there is no correlation between the thermal sensation and BMI <25, which is consistent with our findings from the present study. The participants in this study had mostly a BMI <25.[24]

In a study, Dehghan *et al.* examined the relation between the heart strain and BMI and concluded that peoples with BMI more than 25, compared to the ones with BMI <25, are subject to the heart strain and these peoples should not work in hot and humid conditions.[25]

CONCLUSIONS

This study showed a higher correlation between the PeSI and the physiological strain index, oral temperature and heart rate, compared to the index of WBGT, indicating that the PeSI can assess the thermal strain, on the other hand, this index is easy and quick to use and imposes much less costs as well. In fact, to evaluate the thermal strain by the PeSI is a cheap and simple method and also can be used to determine the health risks of workers exposed to heat and in the risk assessment of thermal strain. The process of assessing the risk of thermal strain by the PeSI is in fact a management decision tool which can be used in prioritizing various workstations in terms of the thermal strain in order to conduct the interventions to control the heat.

The results of the present study showed that when there is no access to other methods to assess the heat stress, the PeSI can be used in the assessment of the thermal strain because it has an acceptable correlation with

reliable indices of heat stress as well as its easy, quick and low-cost application in assessing the thermal strain.

This study was conducted on men young *in vitro*. It is recommended to conduct similar studies middle-aged and older people and to be done in actual conditions in industries with hot environment to evaluate this index.

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