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Development and Validation of a Questionnaire for Preliminary Assessment of Heat Stress at Workplace

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ABSTRACT

Background: Current heat stress indices are not completely suitable for heat strain screening in developing countries due to their inherent and applied limitations. The aim of this study was development a questionnaire entitled "Heat Strain Score Index" (HSSI) in order to perform a preliminary assessment of heat stress at work.

Methods: This research included six phases (i) Item generation (ii) Content validity (iii) Reliability analysis (iv) Structure validity (v) Concurrent validity and (vi) Classification of thermal risk level. In item generation phase, 40 items were identified to have impact on the heat strain. Content validity was evaluated by occupational health specialists.

Results: In consistency assessment, Cronbach's coefficient (α) of items was 0.91. Exploratory factor analysis on items HSSI draft identified four subscales, which explained 71.6% of the variance. Correlation between the HSSI score with aural temperature was 0.73. Cut-off point, sensitivity and specificity for upper no thermal strain zone were 13.5, 91% and 50%, respectively and for lower thermal strain zone were 18, 86% and 73% in that order.

Conclusions: Eighteen variables that were measurable through subjective judgment and observation in the HSSI scale covered heat stress key factors. This scale demonstrated reliability and initial validity in scale were suitable. Therefore, HSSI scale for primary evaluation heat stress is appropriate.

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Introduction

Workers are frequently exposed to heat stress, in outdoor or indoor jobs, especially in warm seasons. Consequences of prolonged exposure to heat stress leads to thermal fatigue, muscle cramps heat syncope, heat stroke, decreased physical and mental performance, reduced productivity, increase of accidents and reduce of the safety level in workplaces.

Heat stress is the net heat load on the body with contributions from both metabolic heat production and external environmental factors including temperature, relative humidity, radiant heat transfer, and air movement, as they are affected by clothing. The physiological response to dissipate heat and maintain a core body temperature of 37°C is referred to as heat strain.

In the last century, a number of heat stress indices have been developed that application of some of them requires to use some special equipment. Moreover, the calculation procedure in some of these indicators is, long, complex and requires to use computer besides that measuring process of some indices may interfere with individuals activities (PSI) and its pragmatic application is difficult in the working field[1]. In addition, time measurement requires measuring T_g in WBGT index a relatively long period of time [2]. Therefore, current heat stress indices are not completely suitable for heat strain screening in developing countries (such as Iran) due to their inherent and applied limitations.

According to the following reasons, for an appropriate management of heat strain in small and medium-sized enterprises (SMEs) in the climatic conditions of Iran, it is necessary to access a thermal strain screening method:

In most countries, including Iran, a significant percentage of the workforce is working in SMEs with fewer than 100 workers (60% in Germany [3] and 36% in Iran). In order to improve working conditions in SMEs, it is necessary to access appropriate tools (easy to use, cheap) to evaluate the thermal stress.

Due to geographic location of Iran, (Low latitude) compared to European and North American countries and the nature of exothermic processes in the majority of industrial activities in south and central parts of Iran. The number of workstations with heat problems is very high so regular evaluations of heat stress detailed in this workplaces are impractical through current methods. In the majority of the cases, prevention measures can be performed easily based on screening methods.

a. On the other hand, with the weather conditions in the region of the Persian Gulf in warm seasons, even in the light physical activities, the work - Rest schedules of WBGT do not have acceptable efficiency[4]. For example, WBGT mean (SD) was 33.2 (2.0) in 72 workstations of the National Petrochemical Company (located in Assaluyeh) between 9 a.m. to 6 p.m. of August 2010.

b. The International Standard Organization (ISO) has proposed the predicted heat strain (PHS) model for predicting human physiological responses (the sweat rate and the internal core temperature) in hot environments (ISO7933) but the data collection and calculation procedure of this index is long and complex, therefore is not suitable for heat stress screening method.

Among various methods that are now available for evaluation of risk factors, observational techniques have been developed due to their ease of use, inexpensiveness, fast response, non-interference with duties and their user-friendliness, and are continuously been used [5]. This method has been used successfully to assess risk factors for skeletal - muscular disorders and cold stress[6]. For heat stress evaluation, a limited number of observational methods were introduced as follows:

Coles et al in Australia introduced a check list (draft) entitled " Basic Thermal risk assessment " that included three levels of heat stress risk .This check list includes a combination of the observational, perceptual and measuring WBGT items [7]. Of course, basis of classification of risk levels was not mentioned and unfortunately, reliability and validity of this checklist was not established.

Bethea and Parsons introduced an observational checklist for evaluation of heat stress risk entitled "Observational checklist for heat stress risk assessment”. This checklist included air temperature, thermal radiation, air velocity, humidity, work rate and clothing[5]. The criteria albeit were not applied for the variables scoring. Furthermore reliability and validity of the method has not been evaluated either.

In the thermal risk evaluation method based on observational and thermal subjective judgments of individuals, Malchaire et al. offered scoring scales that consists of seven factors: air temperature, humidity, thermal radiation, air movement, and physical activity, type of clothing and opinion of the workers. However, this method has no scale risk level category, has no scoring system, and the validity and reliability of the method have not been mentioned[8].

On the other hand, due to the importance of perceptual indices in heat stress evaluation in the British standard(BS EN ISO 10551:2001), another standard “Assessment of the influence of the thermal environment using subjective judgment scales” is developed to provide a guideline for designing heat stress assessment tools [9].

Malchaire et al. proposed a strategy for the evaluation and prevention of risk due to work in hot environments which rests on two basic principles: first individuals participation in evaluation procedure and second four stage structure (Screening, Observation, Analysis and Expertise)[8].

According to (a) the advantages of observational methods (b) the successful application of Malchaire et al. strategies for assessment of risk factors in musculoskeletal disorders and cold stress (c) the lack of reliability and validity of observational – perceptual methods of current thermal stress evaluation, (d) the existence of significant relationship between subjective judgments and physiological responses to heat exposure, (e) the unsuitable current heat stress indices in preliminary assessment of thermal strain in developing countries and (f) the requirement for an easy and inexpensive method of preliminary assessment thermal strain in SEMs.

Therefore, the purpose of this study was to construct and examine reliability and validity an observational – perceptual scale entitled “Heat Strain Score Index" (HSSI) to preliminary assessment of heat stress in the workplace.

Methods

This study was conducted in five phases, as follows:

Item generation

In item generation stage, effective factors in heat strain were identified through a literature review of related articles and books, interview with occupational health experts. The purposes of the interview were to determine whether the risk factors identified in the literature review are related to heat stress or not, and to determine if there are other important factors affected on heat strain. Therefore, the initial item pool is generated based on the literature review and interviews.

Content validity

In this study, content validity refers to the success in creating HSSI items that cover the content domain of heat stress. To establish the content validity, the items were reviewed by nine experts in Departments of Occupational Health at the Universities of Medical Sciences in Iran. They received a packet, including the objective of the study, the HSSI draft with its format modified for the examination of content validity. The content validity version uses a 4-point Likert format to assess each item's relevance, clarity and simplicity [10]. Then, usability of the scale (easy to use and items understanding) was tested by 30 Occupational Health Services provider (OHSP), Experts and OHSP comments were considered in the structure scale.

Reliability analysis

The purpose of this stage was to evaluate the reliability of the HSSI in heat stress exposure workers, therefore HSSI draft was filled by 96 workers that they exposed to heat in different workstations in 2012. Cronbach’s coefficient alpha (α) was calculated separately for total scale and each item. Generally, all α values greater than 0.7 were considered sufficient[11]. Items were refined by dropped items that showed very low item-total correlations below 0.30. Data analysis was performed using SPSS software version 18 (Chicago, IL, USA).

Construct validity

Exploratory factor analysis (EFA) is an important tool for refining measures, evaluating construct validity. Therefore in this study to assess construct validity, HSSI draft was filled by 150 workers exposed to heat in different workstations. To select the most suitable rotation, oblimin rotation was chosen to determine real factor because the results demonstrated a noticeable correlation among extracted factors (Table 2). Internal consistency (α), explained variance and Kaiser-Meyer-Olkin coefficient (KMO) each factor and for total scale were calculated.

For convergent validity analysis, item- total correlation was evaluated in a way that the correlation of each item with the sum of the remaining items was calculated [12]. Then those items with low item-total correlations (less than 0.35) were removed from the scale. In discriminant validity, the correlation matrix of the constructs was examined. It can be evaluated by comparing the squared correlations between each of constructs to the average extracted variance for these constructs. If the average variance extracted for each construct is greater than the square of the correlation between the constructs, discriminant validity will be demonstrated.

In this research, the measurement model was tested through employing the confirmatory factor analysis (CFA) and using the AMOS-16.0 software. The CFA technique employs fit indices to provide estimates of how well the data fit or unfit the hypothesized model. In the present study, model fit was assessed using the following goodness of- fit indices: Chi-square (X^2), normed Chi-square(X^2/df); Goodness of Fit Index (GFI); adjusted goodness-of-fit index (AGFI); the Comparative Fit Index (CFI) and root mean square error of approximation (RMSEA). GFI, AGFI and CFI indices generally range between 0 and 1, with high values (GFI >0.90, AGFI >0.80 and CFI >0.90) reflecting a good fit of the model. RMSEA value of 0.05 indicates a close fit and values up to 0.08 represent reasonable errors of approximation in the population[13].

Concurrent validity

Concurrent validity is the type of validity demonstrated when scores obtained from a new measure are directly related to those from a more established measure of the same variable. In this present research, to perform concurrent validity, a cross sectional study was conducted on 122 workers during 3 months from June 2010 to October 2010, in the center (Isfahan Steel Company) and south (Assaluyeh region) of Iran.

This section of study was approved by the Medical Ethics Committee of the Faculty of Medical Science at Tarbiat Modares University, Tehran, Iran. All subjects signed an informed consent form according to the Helsinki Declaration.

The participants were medically screened for cardiovascular disease, respiratory disease, infectious disease, diabetes, hyperthyroidism and no medicine use. Having informed individuals about the aim of the study, parameters to be measured (aural temperature and complete of HSSI scale form), the test has been done. All subjects were reminded of no drinking coffee and alcohol at the night before the testing day. The subjects rested for 30 min in HSE room (WBGT= 22.6 ± 1.9) before starting actual work in field, aural temperature measured in two stage rest (base line)and actual work by heat stress monitoring device (Questemp II)[14]. All measurements were performed between 9:00 to 12:00 and 15:00 to 18:00. Then the Pearson correlation between HSSI scores and aural temperature was evaluated.

Three levels of heat strain were classified on the basis of aural temperature (criteria variable)[15]

a. Aural temperature in the range 36.0 to 37.4 °C, that is no risk for any subject, was considered to be the equivalent with safe level of HSSI scale.

b. Aural temperature in the range 37.5 to 37.9 °C, that is subjects may be at risk, was considered to be the equivalent with alarm level of HSSI scale.

c. Aural temperature in more 38.0 °C, that is subjects could be at risk, was considered to be the equivalent danger level of HSSI scale.

Receiver operator curves (ROC) analysis was performed to optimize the cut-off points resulting in the best of sensitivity, and specificity of the aural temperature and HSSI scale[16].

ROC curves were also used to determine the ability of the HSSI scale to distinguish between workers with and without heat strain. The cut-off points were set by finding the cut-off points that gives the highest sensitivity and specificity values.

Results

In the item generation phase, 40 items were identified to have impact on the heat strain which includes: thermal Sensation[17], humidity sensation[18], feeling of heat exposure on the face, feeling of surrounding surfaces temperature, air movement[19] , air condition, industrial ventilation, noise intensity, sunshine state, work location (indoor or outdoor), sky conditions, confined space[18], distance from drinking water location, distance from cool rest room[18], physical activity[17,18], clothing[20] and personal protective equipment[21,22], size of clothing [23], color of clothing [24], exposure time[18], exposure status (continuous or intermittent), shift work, body posture[23], number of breaks in the shift work, task complexity and concentration[18], restrictions on leaving workstation, thermal acclimatization[18], age[25], body mass index[26], salt intake[27], sleep status[28], heat stress education[18], conditions leading to drinking water, sensation of evaporation severity[29], thirsty intensity [30], fatigue[31], thermal discomfort[8], limitation in sweating[5], history of heat stroke[28], and clinical signs.

A descriptive sentence or phrase was developed for each agent based on its certain nature so that they may be measured through subjective judgments or observational methods; revised pictorial perceived exertion scale was used to physical activity intensity estimation[32] then the collection of these sentences led to the creation of HSSI draft.

In content validity evaluation on the 40 items of HSSI scale draft, 27 items were revised, 2 items were removed (noise intensity and sleep status), 2 items merged (air conditions and industrial ventilation) and 3 items were added (material of clothes, amount of water drunk and temperature of drinking water) and 7 items were rescored based on emendations of nine experts. In re-evaluation of HSSI scale draft by OHSP, 19 items were reformed and finally, 40 measurable items remained in HSSI draft. Therefore, it has been conceived that the whole HSSI scale has valid contents.

The results of internal consistency analysis showed that the cronbach's α value for the HSSI scale (40 items) was

0.88. The fact that α value was at an acceptable level, makes the scale reliable. However, item "fatigue" had the highest correlation (0.75) and item "size of clothing" had the lowest correlation (0.007) with the total correlation. Nineteen items were excluded from the scale because they had item-total correlations less than 0.3[33] and 21 reliable items remained in the scale. Elimination of non-reliable items led to the increase of cronbach's alpha from 0.88 to 0.91 (Table 1). Moreover, the correlation of the remaining items in the scale were also in an acceptable range (0.35-0.80) (P<0.010). Therefore, it did not need to change items.

Table 1: Items, factor loading (FL), Item-total correlation (ITC) and variance explained (VE) and cumulative variance explained (CVE) in HSSI scale

Items	FL	ITC	VE (%)	CVE (%)
Factor 1			46.5	46.5
Fatigue intensity	0.74	0.80		
Thirsty intensity	0.70	0.79		
Discomfort intensity	0.65	0.77		
Clinical signs	0.63	0.44		
Body posture	0.49	0.39		
Factor 2			12.2	58.7
Clothing	0.90	0.69		
Material of clothing	0.84	0.37		
PPE	0.76	0.67		
Surface temperature	0.61	0.57		
Color of clothing	0.58	0.42		
Thermal sources	0.58	0.39		
Factor 3			7.1	65.8
Drinking water temp	0.80	0.35		
Work location	0.64	0.35		
Air movement	0.56	0.60		
Air condition	0.50	0.68		
Physical activity	0.44	0.65		
Factor 4			5.8	71.6
Evaporation rate	0.93	0.63		
Air umidity	0.92	0.66		
Air temperature	0.64	0.78		
Confined space	0.49	0.35		

The primary result of factor analysis showed that KMO and Bartlett's test of sphericity were 0.86 and 2031 (df=21, P<0.001) respectively. Both tests indicated the suitability of the variables for factor analysis based on correlation matrix. Also KMO value was more than 0.80 for each item to determine the number of factors. To determine the number of factors (latent variable) procedure eigenvalue greater than one and percentage variances were used. Exploratory factor analysis run on 21 items showed that 20 items (item of "heat stress education" was omitted due to low factor loading) loaded on 4 factors and these factors explained 71.6% of the total variance (Table 1). All 4 factors totally had good internal consistency (Table 3). Convergent validity analysis or item-total analysis indicated that, item-total correlations were in an acceptable range (0.35-0.80). Therefore, the convergent validity was confirmed.

Result of discriminate validity analysis demonstrated that the greatest value of correlation square between factors was 0.18 that is smaller than the lowest of the variance explained by factors (0.53) therefore discriminate validity was established (Table 2 and 3). Confirmatory factor analysis on one-factor, three-factor and four-factor models were done to indicate whether the four-factor model has the best fitting to the data. In CFA analysis, items of "water drinking temperature" and "thermal source" were excluded because of low factor loading and high correlation to "surface temperature" respectively. Finally, 18 items remained in the HSSI scale. The values of goodness of fit indices for four–factor model were as follows: chi-square=139.7 (P=0.080), chi-square/df=1.194, CFI=0.99, GFI=0.91, AGFI=0.87 and RMSEA=0.036. The four-factor model was therefore accepted (figure 1).

In concurrent validity, or evaluation of HSSI scale, Pearson coefficient correlation between HSSI scale and WBGT index with physiological heat strain parameters (in this study gold standard was considered aural temperature) in hot/dry and hot/wet conditions is shown in Table 4. In addition, Pearson correlation between variables of HSSI scale with physiological strain index and aural temperature is shown in Table 5 so that correlation between HSSI scale and aural temperature (gold standard) was 0.73.

The optimal cut-off point for the boundary point between green and yellow zone was 13.5 score with sensitivity and specificity, 91% and 50%, respectively. The area under the ROC curve (AUC), that is a global summary statistic of diagnostic accuracy, was 0.826 (95% CI: 0.77, 0.90) (P<0.001) (Figure 2a). The optimal cut-off point for the boundary point between red and yellow zone was 18 score, with sensitivity and specificity, 86% and 73%, respectively.

AUC was 0.846 (95% CI: 0.774, 0.917) (P<0.001) (Figure 2b) .

Table 2: Correlation and square correlation (brackets) matrix between the factors in HSSI scale

Factors	1	2	3	4
1	1.00			
2	0.25 (0.06)	1.00		
3	0.17 (0.03)	0.24 (0.06)	1.00	
4	0.43(0.18)	0.23 (0.05)	0.27 (0.07)	1.00

Table 3: Internal consistency, variance explained (%) and Kaiser-Meyer-Olkin (KMO) coefficient of factors in unifactorial test

Factors	Cronbach's alpha	Variance explained	KMO
1	0.85	69.3	0.83
2	0.85	71.8	0.78
3	0.78	53.0	0.78
4	0.84	80.9	0.77

Table 4: Pearson correlation between Heat Stain Score Index (HSSI) and Wet Bulb Globe Temperature (WBGT) index with physiologic heat strain parameters

Physiologic heat strain parameters	Total (hot/ dry & wet conditions)		Hot/dry conditions		Hot/wet conditions	
	WBGT index	HSSI index	WBGT index	HSSI index	WBGT index	HSSI index
Aural temperature	0.36	0.66	0.57	0.57	0.37	0.63
Increase of aural temp.	0.33	0.73	0.69	0.80	0.36	0.50
Heart rare	0.31	0.62	0.53	0.75	0.19	0.48
Increase of heart rate	0.37	0.56	0.58	0.75	0.18	0.41
Physiological strain index	0.37	0.76	0.68	0.81	0.35	0.60

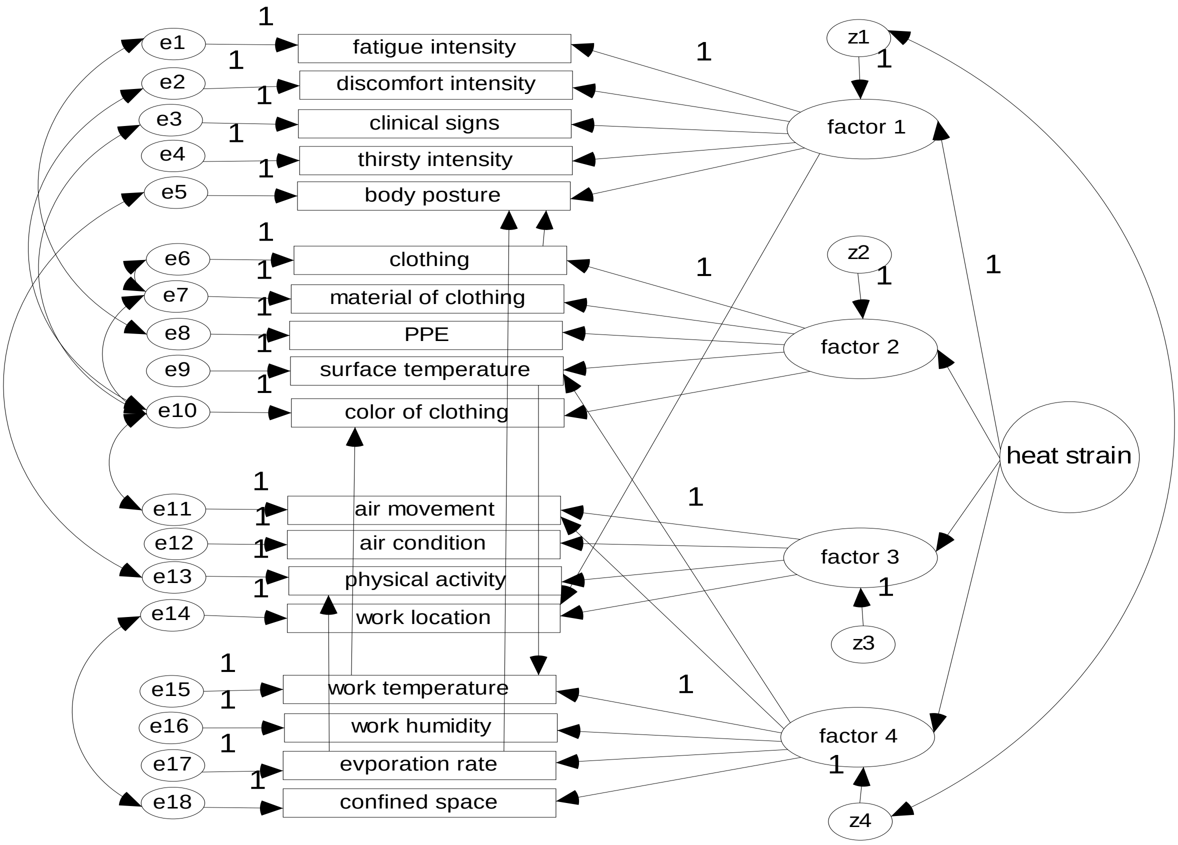
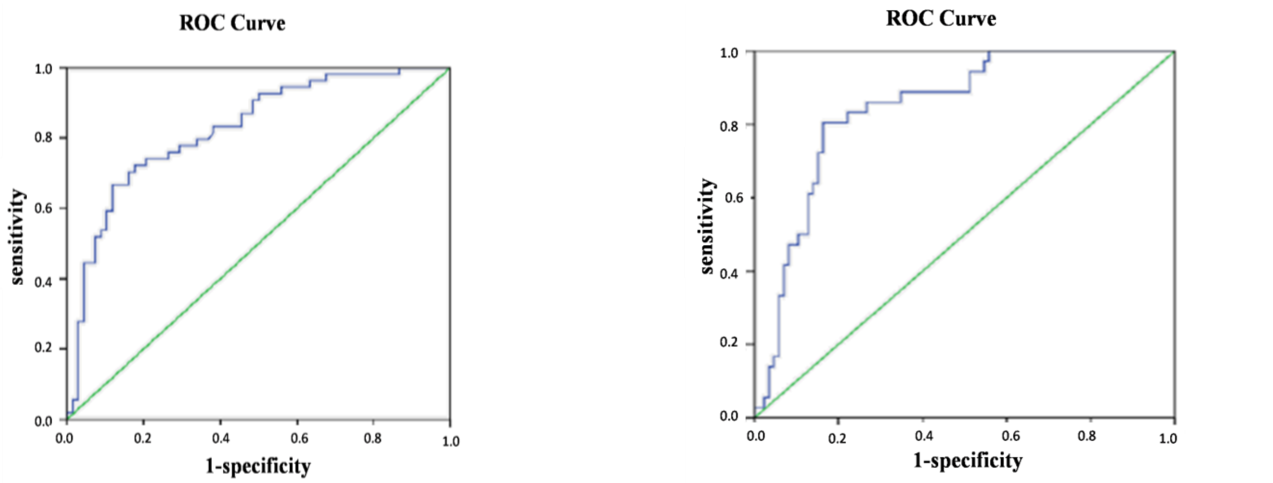


Figure 1: Confirmatory Factor Analysis (CFA) model



a b

Figure 2: (a) Receiver operating characteristic (ROC) curve of both green zone (safe level) and yellow zone (alarm level) in HSSI total scores (b) Receiver operating characteristic (ROC) curve of both yellow zone and red zone (danger level) in HSSI total scores

Discussion

The aim of this study was to construct, validate and study the reliability of a questionnaire for assessment of heat strain primarily entitled "Heat Strain Score Index".

The results of content validity analysis illustrated that items selected in the HSSI scale can cover the majority of factors related to heat strain. In addition, reliability analysis indicated that internal consistency of scale and quadric-subscales of HSSI were suitable. Results of exploratory and confirmatory factor analysis provided valuable information over the structure of HSSI scale. The criterion validity was supported enough by a significant positive correlation between scores of HSSI scale and aural temperature (Table 4 and 5).

In addition, cut-off points were well defined for separation of boundary heat strain zones (green, yellow and red). Sensitivity and specificity of these points were sufficiently appropriate.

The most important effective factors in the heat strain were selected in HSSI scale (Appendix 1). The following documentations and studies confirm this conclusion.

According to the WBGT index procedure, air temperature, humidity, radiation temperature, air movement, clothing, physical activity are used to calculation and interpret the heat stress[34]. These parameters were included in the HSSI scale. These variables showed a high reliability and a large loading factor in the HSSI scale.

Table 5: Pearson correlation between variables of Heat Stain Score Index (HSSI) scale with physiological strain index and aural temperature

Variables	Aural temperature		physiologic strain index	
	correlation	*P* value	Correlation	*P* value
Feeling of air temperature	0.60	0.001	0.70	0.001
Feeling of the humidity level	0.47	0.001	0.59	0.001
Feeling of surface temperature	0.60	0.001	0.65	0.001
Feeling of air movement	0.40	0.001	0.38	0.001
Physical activity	0.45	0.001	0.55	0.001
Feeling of the sweating	0.46	0.001	0.61	0.001
Fatigue intensity	0.53	0.001	0.57	0.001
Thirsty intensity	0.58	0.001	0.58	0.001
Thermal discomfort	0.56	0.001	0.61	0.001
Clinical signs	0.26	0.004	0.33	0.001
Ventilation situation	0.46	0.001	0.43	0.001
Workstation situation	0.21	0.022	0.09	0.270
Clothes types	0.53	0.001	0.47	0.001
Clothes colors	0.26	0.004	0.18	0.060
Clothes materials	0.48	0.001	0.40	0.001
Protective device	0.54	0.001	0.51	0.001
Body posture	0.33	0.001	0.51	0.001
Total of variable=HSSI scale	0.73	0.001	0.76	0.001

According to Budd opinion, the assessment of thermal stress can be done rapidly and easily, with simple and inexpensive instruments. Moreover, the assessment could be performed by routinely measuring and evaluating these six factors: air temperature, mean radiant temperature, humidity, air velocity, workers' clothing and activity [35]. These six variables have been entered into the HSSI scale with high reliability and high factor loadings., Malchaire et al. provided a scoring scale to evaluate the thermal strain observationally. They selected the most important parameters affecting the incidence of heat stress including air temperature, humidity, radiant temperature, air movement, workload, work clothes, and workers opinions. All these factors have been selected in the HSSI scale [5,8].

Presenting an observational checklist (draft) specialized in heat stress determination; Bethea et al. applied air temperature, radiant temperature, humidity, airflow rate, work severity, type and material of clothing applied as key factors in determining the thermal stresses [5]. These items were also included in the HSSI scale.

Warmth or coldness feeling and skin wetness are determinants of thermal comfort[36]. The correlation between skin temperature and heat feeling, in hot-humid conditions, was 0.71 and the correlation between skin moisture and humidity sensation was 0.96[37]. Therefore, the results of these studies showed that thermal and humidity sensation factors can be applied as the heat stress assessment variables. These two variables with high factor loading have been entered into HSSI scale.

In many studies, age and body mass index (BMI) have been considered as heat stress risk factors (but with less importance)[21,26]. These two factors were included in the prototype of the scale; however, they were later excluded due to their low item – total correlation. One reason for removing these two variables, is the low effect of these two factors on heat stress compared to more effective environmental factors (such as air temperature, high humidity, radiant temperature and air movement) in climate conditions of Assaluyeh and Steel Co (WBGT = 32.1 ±3.3). In fact, the effect of these two factors can be largely covered by harsh weather. In other words, in the extreme stressful environmental conditions, people suffer from heat stress even those having an young age or low BMI.

Based on the results of this study, we conclude that:

Major factors in heat stress indices, heat stress evaluation check lists and questionnaires have accumulated in HSSI scale and they have formed a unite structure.

Factors affecting heat stress can be measured through the subjective judgment and observation because these subjective judgment and observation factors explained high variance (72%) in HSSI scale; this represents a great deal of changes in the thermal stress caused by changes in these 18 variables.

Based on the favorable variance explained (72%) by the factors entered in HSSI scale, it is unexpected that there are key factors affecting heat stress, while they have been ignored.

Conclusions

The results of this study showed that 18 variables that could be measured by subjective judgment and observation in the HSSI scale include key factors in heat stress evaluation indices and consistent with other heat assessment check lists. The HSSI scale also has an acceptable reliability and initial validity. Therefore it could be used for a preliminary assessment of heat strain in warm climate conditions of Iran. However, the results may not be necessarily generalizable to other climate conditions in Iran. Moreover, given that age, BMI, and acclimatization were not included in the HSSI scale, hence it is recommended that the prototype should be investigated if ever planned to be used in other climate conditions.

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Conflict of interest statement

Authors declare that have no conflict of interest.

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