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The influence of occupational heat exposure on cognitive performance and blood level of stress hormones: a field study report

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\textbf{Introduction.} This article aimed to investigate the effect of heat stress on cognitive performance and the blood concentration of stress hormones among workers of a foundry plant.

\textbf{Methods.} Seventy workers within the exposed (35 people) and unexposed (35 people) groups were studied. The wet bulb globe temperature (WBGT) index was measured for heat stress assessment. The cognitive performance tests were conducted using the Stroop color word test (SCWT) before and during working hours. For the assessment of the serum level of cortisol and the plasma level of adrenaline and noradrenaline, blood samples were taken during working hours from both groups.

\textbf{Results.} Only for SCWT III was there a significant relationship between heat stress and test duration, error rate and reaction time. The laboratory test results revealed significantly higher concentrations of cortisol, adrenaline and noradrenaline in the exposed subjects than in the unexposed group. There existed a positive correlation between cortisol, adrenaline, noradrenaline and WBGT index and also test duration and reaction time of SCWT III, and number of errors of SCWT I, SCWT II and SCWT III during work.

\textbf{Conclusion.} Heat stress can lead to an increase in the blood level of stress hormones, resulting in cognitive performance impairment.

\textbf{Keywords:} heat stress; cognitive performance; stress hormones; foundry industry

1. Introduction

Atmospheric conditions can be described by measuring a number of parameters, which are somewhat perceivable by the human senses. Temperature as a measure of the warmth or coldness of an object is one of the most important atmospheric parameters \cite{1,2}. The normal human body temperature is 36–38°C. When the internal body temperature exceeds normal levels, the thermoregulatory system reacts by increasing the rate of heat loss \cite{1}. When the thermoregulatory system fails to compensate for the heat stress, the risk of heat illnesses is increased \cite{3}. Heat stress assessment is usually conducted using valid tools like heat stress indices, which are single numbers used to integrate the effects of the basic parameters of atmospheric conditions \cite{4}.

Heat strain is a consequence of physiological responses of the body to heat stress, including increases in core and skin temperature, sweating and heart rate \cite{5,6}. Moreover, a decrease in cognitive performance in hot environments has been reported in numerous studies. This issue can result in human errors due to decreased attention and also increases the possibility for unsafe behavior \cite{7,8}. The term cognition refers to mental activities, conscious and unconscious processes, including sensation and perception, learning and memory, thinking and reasoning, attention and consciousness, imagining and dreaming, decision-making and problem-solving \cite{9}. The physiological reasons for the decrease in cognitive performance during hyperthermia can be related to different mechanisms in the body; however, all this remains completely theoretical \cite{10}. The proper recognition and control of the physiological mechanisms involved with hyperthermia can help prevent the effects of heat stress on cognitive performance.

Hormones present in the blood, such as cortisol, adrenaline and noradrenaline, are good predictors of changes in cognitive ability and mental functioning. An interaction between these biochemcials and cognition has also been demonstrated \cite{11,12}. These hormones are known as stress hormones which can be increased by stress factors in the environment \cite{11,12}. The main response of the human body to stressful stimuli is accomplished by a complex system, which includes the hypothalamus–pituitary–adrenal (HPA) axis and the sympathoadrenal system (SAS) \cite{13}. Physical and physiological stress, such as heat stress, can activate this complex system \cite{14–16}. Noradrenaline, a neurotransmitter in the central nervous system (CNS), plays a role in working memory performance and also influences alertness, arousal and mood. The release of adrenaline as a symptom of anxiety and high stress by the adrenal medulla is related to the secretion.

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of noradrenaline by the hypothalamus. Cortisol release in response to stress is produced in the cortex of the adrenal glands. High concentrations of cortisol are indicators of anxiety, whereas the elevated adrenaline level and noradrenaline are assumed to contribute to overarousal [11,17,18].

McMorris et al. [11] discovered that plasma cortisol levels significantly increased after heat exposure, and this reduced the performance of the central executive task. Changes in adrenaline concentrations and score of the central executive task tests were significantly correlated during heat stress. Iguchi et al. [19] showed that whole-body heat stress increased the plasma concentration of noradrenaline. They concluded that noradrenaline can act as a better index than adrenaline for the prediction of whole-body heat stress.

Few studies have examined the effects of heat stress on both concentrations of stress hormones and cognitive performance. Moreover, most related research has been focusing on changes of cognitive function and the endocrine system after heat stress and/or exercise induced in climatic chambers [11,20]. In fact, no previous studies have investigated this issue among workers in the workplace.

Field study is more time consuming and expensive than the laboratory, but a theory tested in the field can allow access for competition with the hypothesis, and is more suitable for investigating a wider range of effecting factors. Besides, in a laboratory some things cannot be tested adequately and some limitations can exist when trying to generalize the findings [21,22].

Because heat stress is one of the most occupational health hazards in hot industries, such as foundry industries, this research aimed to study the influence of heat stress on the blood (plasma and serum) concentration of stress hormones among workers of the foundry part of an automobile factory and their cognitive performance. In our workplace-oriented study, the objective variables were levels of stress hormones and score of cognitive tests. Environmental variables, including intensity of heat, noise and light, were assessed. According to previous studies, it was assumed that cognitive function will be negatively affected in the heat stress condition and the mentioned hormonal changes can be a predictor of cognitive performance decrement.

2. Materials and methods

2.1. Participants

The subjects ($n = 70$) were recruited from employees at an automobile factory, which is located in Tehran, Iran. The exposed group consisted of 35 men from three sections in the foundry part: Badische Maschinenfabrik Durlach (BMD), DISAMATIC molding machines (DISA) and casting. Both BMD and DISA use foundry molding equipment, but BMD employs vertical molding equipment and DISA engages horizontal equipment. The unexposed group consisted of 35 subjects from the computer numerical control machining (CNC) part with the same physical workload but without heat stress. Some demographic information of these subjects is presented in Table 1. In the first stage, participants gave their consent by filling out a consent form. They also filled out a comprehensive medical questionnaire and a demographic questionnaire. Ethical approval was granted by the research ethics committee of Tehran University of Medical Sciences. Subjects who were within the same age range and gender were chosen to be in the experiment. People with health problems like cardiovascular disease and mental disorder were excluded. Participants were asked to refrain from caffeine products on the morning of the test, to follow a normal diet and not to use a particular prescription. Participants were instructed to get adequate sleep and rest the night before the experiment. All measurements were done in the summer season for 3 consecutive weeks.

2.2. Heat stress measurement

The wet bulb globe temperature (WBGT) index, the most widely used estimator for assessing heat stress in industry, was measured in the workstations of the two groups based on Standard No. ISO 7243:1989 [23] using a calibrated Microtherm WBGT meter (Casella CEL, UK). Many international organizations have recommended the WBGT index in the assessment of heat stress conditions and it was adopted as an ISO standard [24,25].

The Casella WBGT meter can monitor simultaneously dry temperature, wet natural temperatures, radiant temperature and relative humidity. The WBGT index was measured at three heights — ankle, abdomen and
2.3. Cognitive test
Cognitive performance of the participants, including reaction time, accuracy and attention, was examined using the Stroop color word test (SCWT) in two stages: before starting work and during working hours. The SCWT is a general tool of cognitive flexibility and unexposed or executive functioning [26,27]. Because of the high diagnostic importance of the SCWT, it has attracted much attention which resulted in its frequent use in diagnostic and research aspects of executive functions [28].

The computerized Persian version of the SCWT was designed and used to assess workers’ cognitive ability. It consists of three parts: neutral, congruent and incongruent tests. The first task (SCWT I, naming the colors) involved random presentation of circles with three colors (green, red and blue) on the screen. The name of each color was labeled on the keyboard, and when a circle appeared the participants were required to push the key which corresponded to the color seen. In the second part (SCWT II, naming the congruent words), the name of colors appeared in a white box. The task was similar to part one, pushing the key which corresponded to the color seen. In the last trial (SCWT III, naming the incongruent words), which was the main part, the names of words with colors which did not correspond to their written word colors appeared on the screen and the participants were required to push the key which corresponded to the presented color of the word. In order to make participants familiar with the test, they were given theoretical and practical training. The best speed and performance and the highest correct answer were associated with participants who had high cognitive performance [27]. All SCWTs occurred between 9:00 and 11:00 in work environments in the understudy sections, while subjects were separate from each other.

2.4. Hormone assay protocol
To assess the serum level of cortisol and the plasma level of adrenaline and noradrenaline, blood samples (10 ml) were taken during working hours (9:30–10:00) from both study groups. Blood test results were compared with the baseline values, which were the normal value of cortisol between 7:00 and 10:00 (6.2–19.4 μg/dl) and normal range of adrenaline (0–900 pg/dl) and noradrenaline (0–600 pg/dl). The sampling occurred in conjunction with conducting the SCWT.

Samples were collected into tubes containing anticoagulant ethylenediaminetetraacetic acid (EDTA) and stored at –80 °C before carrying out laboratory analysis using the enzyme-linked immunosorbent assay (ELISA) method.

2.5. Measurement of noise and illumination
The ambient sound level and lighting were measured as environmental variables which can affect cognitive function and stress hormone levels [29,30]. Illuminance measurements were performed with a calibrated lux meter (Hagner Digital Luxmeter, model EC1; Hagner, Sweden) at each workstation. The A-weighted sound pressure level was measured by the lattice method in understudy parts, using a calibrated sound level meter (TES-1358 sound analyzer; TES, Taiwan) based on Standard No. ISO 9612:2009 [31,32].

2.6. Data analysis
The data were analyzed using SPSS version 16. The Kolmogorov–Smirnov statistical test was performed to check the degree of normality in the data. For quantitative variables, means and standard deviations were calculated. Quantitative variables were compared by the Student’s $t$ test (for data with normal distribution). Two-way, repeated-measures analyses of variance (ANOVAs) and the Mann–Whitney $U$ test were used to determine the effects of heat stress on the dependent variables, if any. Correlation analyses were carried out using the Pearson correlation coefficient. The regression analysis random effect model was performed to estimate the relationships between heat stress index and the cognitive and hormonal parameters. Partial correlation was used to determine the relationship between levels of WBGT and the dependent variables while controlling for noise and illumination. The level was set at 0.05 for all statistical analyses.

3. Results
Summary data for demographic characteristics of participants are presented in Table 1. The mean (SD) age was 36.41 (5.07) years, body mass index (BMI) was 25.51 (2.6) and work experience was 11.67 (5.07) years. As can be seen from Table 1, the two groups differed with respect to age, work experience and working time ($p < 0.05$, independent-sample $t$ test).

Results of WBGT measurement and the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLVs) for heat stress are presented in Table 2. The metabolic rate was calculated using body position and movement, activity level and type of work, based on Standard No. ISO 8996:2004 [25,33].
Table 2. Assessment of heat stress in understudy sections ($p < 0.001$).

<table>
<thead>
<tr>
<th>Group</th>
<th>Work section</th>
<th>Metabolic rate (kcal/h)</th>
<th>Work/rest regimen</th>
<th>WGBT ($^\circ$C)</th>
<th>TLV ($^\circ$C)</th>
<th>Heat stress condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposed</td>
<td>BMD ($n = 12$)</td>
<td>350</td>
<td>75% work, 25% rest, each hour</td>
<td>35.41</td>
<td>28</td>
<td>Under heat stress</td>
</tr>
<tr>
<td>DISA* ($n = 11$)</td>
<td>355</td>
<td>75% work, 25% rest, each hour</td>
<td>32.61</td>
<td>28</td>
<td>Under heat stress</td>
<td></td>
</tr>
<tr>
<td>Casting ($n = 12$)</td>
<td>315</td>
<td>Continuous work</td>
<td>30.81</td>
<td>26.71</td>
<td>Under heat stress</td>
<td></td>
</tr>
<tr>
<td>Unexposed</td>
<td>CNC ($n = 35$)</td>
<td>314</td>
<td>Continuous work</td>
<td>16.75</td>
<td>26.71</td>
<td>Thermal comfort</td>
</tr>
</tbody>
</table>

*DISAMATIC molding machines (DISA) employs various molding equipment, including vertical, horizontal and match plate molding technology.

Note: BMD = Badische Maschinenfabrik Durlach; CNC = computer numerical control machining; TLV = threshold limit value; WBGT = wet bulb globe temperature.

Table 3. SCWT scores for the exposed and unexposed groups before and during work.

| SCWT variable | Exposed | | | | | | Unexposed | | | | | | Exposed vs unexposed during the work |
|---------------|---------|---|---|---|---|---|---|---|---|---|---|---|---|---|
|               | Before work | During work | | | Before work | During work | | | | | | | |
|               | $M$ | $SD$ | $M$ | $SD$ | $p^{a}$ | $M$ | $SD$ | $M$ | $SD$ | $p^{b}$ | $p^{c}$ | |
| Test duration (ms) | | | | | SCWT I | 49,460 | 7550 | 51,151 | 7873 | 0.404 | 47,499 | 4492 | 50,295 | 7766 | 0.174 | 0.660 | SCWT II | 51,518 | 2210 | 53,073 | 7040 | 0.727 | 49,086 | 7326 | 50,562 | 8475 | 0.269 | 0.197 | SCWT III | 58,215 | 9340 | 66,131 | 8508 | 0.008 | 57,118 | 8326 | 59,707 | 7139 | 0.158 | 0.002 | SCWT I | 456.61 | 131.91 | 485 | 115 | 0.394 | 410 | 80 | 443 | 132.91 | 0.452 | 0.184 | SCWT II | 487.81 | 145 | 520 | 157 | 0.574 | 458 | 132.51 | 496 | 101 | 0.147 | 0.473 | SCWT III | 500 | 111 | 577 | 115 | 0.003 | 461 | 111 | 500 | 148 | 0.242 | 0.022 | SCWT I | 1.65 | 1.39 | 2.93 | 2.47 | 0.016 | 0.81 | 1.01 | 1.09 | 1.17 | 0.057 | 0.003 | SCWT II | 1.62 | 1.49 | 3.77 | 2.30 | 0.001 | 0.85 | 1.45 | 1.11 | 1.38 | 0.376 | <0.001 | SCWT III | 2.85 | 2.01 | 4.53 | 2.92 | 0.025 | 1.25 | 1.19 | 1.64 | 1.73 | 0.081 | <0.001 |

*Comparison of variables before and during work, for the exposed group.

bComparison of variables before and during work, for the unexposed group.

cComparison of variables during work, for the exposed and unexposed groups.

Note: SCWT = Stroop color word test.

Table 2 shows that the unexposed group was not under heat stress, while the workers of the BMD, DISA and casting sections experienced heat stress. BMD had the highest value of WBGT among the understudy sections. Differences of the mean WBGT index in the head, abdomen and ankle between groups were assessed using Student’s $t$ test. According to our findings, a significant difference existed between the two groups ($p < 0.001$), such that the mean WBGT index was higher in the exposed group than in the unexposed group.

The results of the SCWT for the exposed and unexposed groups before starting work and during working hours are presented in Table 3. As can be seen from this table, there was no statistically significant difference between test duration (ms), reaction time (ms) and number of errors of SCWT I, SCWT II and SCWT III in the unexposed group before starting work and during working hours ($p > 0.05$, Wilcoxon signed-rank test). For exposed participants, test duration (ms) and reaction time (ms) of SCWT III before starting work were statistically different from during working hours ($p < 0.05$, Mann–Whitney test). Test duration (ms) and reaction time (ms) of SCWT I, II and III were higher in the exposed group during working hours than unexposed workers, and this can reach a level of statistical significance ($p < 0.05$).

Mean concentrations of cortisol, adrenaline and noradrenaline in the exposed and unexposed groups are presented in Table 4. ANOVA results indicated a significantly higher concentration of cortisol, adrenaline and noradrenaline in the exposed subjects than in the unexposed group ($p < 0.05$). The highest concentrations of cortisol, adrenaline and noradrenaline were related to the DISA, BMD and casting sections, respectively.

Table 5 presents the results of environmental assessment, including sound and lighting levels, in both groups. Mean sound pressure levels in work environments corresponding to two groups were significantly different from each other ($p < 0.02$), and the exposed group was exposed...
Table 4. Mean blood concentrations of stress hormones in the exposed and unexposed groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Work section</th>
<th>Cortisol (μg/dl)</th>
<th>Adrenaline (pg/dl)</th>
<th>Noradrenaline (pg/dl)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>SD</td>
<td>p</td>
</tr>
<tr>
<td>Exposed</td>
<td>BMD</td>
<td>9.60</td>
<td>3.16</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>DISA</td>
<td>11.30</td>
<td>3.40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Casting</td>
<td>8.17</td>
<td>3.40</td>
<td></td>
</tr>
<tr>
<td>Unexposed</td>
<td>CNC</td>
<td>6.20</td>
<td>2.50</td>
<td></td>
</tr>
</tbody>
</table>

Note: BMD = Badische Maschinenfabrik Durlach; CNC = computer numerical control machining; DISA = DISAMATIC molding machines.

Table 5. Average of sound pressure level and illuminance in study work sections.

<table>
<thead>
<tr>
<th>Work section</th>
<th>Sound pressure level</th>
<th>Illuminance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;85 dB(A)</td>
<td>&gt;85 dB(A)</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td>M</td>
</tr>
<tr>
<td>Exposed</td>
<td>7</td>
<td>81.20</td>
</tr>
<tr>
<td>DISA</td>
<td>6</td>
<td>81.67</td>
</tr>
<tr>
<td>Casting</td>
<td>4</td>
<td>78.21</td>
</tr>
<tr>
<td>Unexposed</td>
<td>31</td>
<td>74.81</td>
</tr>
</tbody>
</table>

Note: 85 dB(A) and 200 lx are considered threshold limit values for occupational exposure to noise and lighting in these work sections. BMD = Badische Maschinenfabrik Durlach; CNC = computer numerical control machining; DISA = DISAMATIC molding machines.

Table 6 presents the degree of correlation between WBGT and variables of test duration, reaction time and number of errors related to the SCWT (Pearson r correlation test). As shown in the table, WBGT was significantly correlated with test duration (p = 0.01, r = 0.325) and reaction time (p = 0.047, r = 0.247) of SCWT III, and number of errors of SCWT I (p = 0.016, r = 0.303), SCWT II (p = 0.003, r = 0.366) and SCWT III (p < 0.001, r = 0.446) during the work.

The Pearson correlation test showed that there was a positive significant relationship between the WBGT score and the level of cortisol (r = 0.57, p < 0.001), adrenaline (r = 0.25, p = 0.04) and noradrenaline (r = 0.41, p < 0.001).

Moreover, regression analysis for SCWT scores during work and blood levels of stress hormones indicated that there was only significant correlation between the cortisol level and reaction time of SCWT I (r = 0.33, p < 0.009), the cortisol level and number of errors of SCWT III (r = 0.33, p < 0.009) and the noradrenaline level and number of errors of SCWT III (r = 0.34, p < 0.005).

4. Discussion

Several studies have shown that high levels of workplace stress can lead to an increase in stress hormones, including cortisol, adrenaline and noradrenaline [34,35]. Stress hormones are good predictors of changes in cognitive ability and mental functioning [11]. In hot working environments, heat stress in combination with other environmental factors can influence the relationship between levels of stress hormones and other variables.
stressors can lead to an increase in the workers’ mental workload and a decrease in the workers’ focus and concentration on their task, etc., thereby increasing the risk of occupational accidents [36].

Since heat stress is one of the most occupational health hazards in hot industries, such as foundry industries [25], the main aim of this article was to investigate the effect of heat stress on cognitive performance and the blood concentration of stress hormones in workers of the foundry part of an automobile factory.

Results of the cognitive performance test revealed that response and reaction time, as well as number of errors, were increased among subjects in the foundry part during their work (i.e., when exposed to heat), compared with when they had not yet started their work. The difference in test duration of SCWT III, reaction time of SCWT III and number of errors of all three SCWTs was statistically significant between the two groups (exposed and unexposed), and were of higher value for the exposed group. There are similar findings which confirm our results. Radakovic et al. [37] investigated the effects of acclimation status on physiological and cognitive performance of soldiers during exertional heat stress; they observed that exertional heat stress caused mild deficits in attention by means of prolonged movement time. Mackworth [38] evaluated the human task performance at four temperatures (21, 26, 31 and 36 °C) and found that response increased at 31 and 36 °C. Epstein et al. [39] reported an increase in reaction time when the temperature was elevated from 21 to 35 °C. Hancock et al. [40] emphasized that thermal stressors negatively influenced psychomotor capacities and information processing of individuals. The reaction time and number of errors can give a good estimate of the effects of heat stress on cognitive performance [41]. In our results there existed no significant correlation between heat stress (value of WBGT) and length of the test and reaction time. This might be attributed to the simple nature of SCWTs I and II which require a low level of attention. However, a significant correlation was observed between heat stress and the number of errors in SCWT I, SCWT II and SCWT III. To date, a large body of research has reported an increase in the number of errors under heat stress [36,37,42]. The physiological reasons for the decrease in cognitive performance during hyperthermia can be related to different mechanisms in the body, and fluctuation of hormones is one of these responses. This fluctuation is related to the effects of stress on the hypothalamus [10,43]. Many changes in the cardiovascular system occur as body temperature increases. Under heat stress, the skin blood vessels dilate in an attempt to increase heat loss. This leads to a reduction in the peripheral vessel pressure to about 40–70%. In this situation, within a few minutes the hypothalamus secretes adrenocorticotropic hormone (ACTH) and thus induces cortisol secretion from the adrenal cortex cells. This process leads to the constriction of blood vessels.
and an increase in heart rate and contractility. As a result, the human body is prepared to deal with the heat stress situation [13,44,45].

Our findings indicated that blood concentrations of cortisol, adrenaline and noradrenaline in the exposed group (in the heat condition) were significantly higher than those in unexposed group. The higher level of hormones than in the case group may be due to changes in the osmolality of blood, which are very probable under conditions of dehydration. Our results are similar to the findings of McMorris et al. [11] who found that blood concentrations of cortisol significantly increased following exposure to heat. They concluded that the effects of heat stress on the performance of central executive tasks and perceptions of mood state can be predicted by changes in blood concentrations of the hormones cortisol and adrenaline. Kappel et al. [46] demonstrated that the blood concentration of both adrenaline and noradrenaline increased under heat stress. In the present study, noradrenaline was more affected by heat stress when compared with adrenaline (correlation coefficient between adrenaline and WBGT index = 0.245 and correlation coefficient between noradrenaline and WBGT index = 0.435). Other studies also indicated that noradrenaline was a better indicator for assessing the physiological effects of heat stress than adrenaline, because secretion of adrenaline was greatly affected by emotional stress [47]. This is the reason why researchers found a greater increase in the noradrenaline concentration than adrenaline under heat stress [48–50].

Some studies have assessed the effects of other environmental stressors like noise level and incorrect illumination on cognitive functions and stress hormone level [29,30] and have shown controversial results. Melamed and Bruhis [51] studied the chronic effects of occupational noise on the human body in industry and found that noise exposure to 85–95 dB(A) (L_{eq}) increased the level of urinary cortisol. Ljungberg and Neely [52] concluded that relatively short exposures to noise and vibration typical of those levels found in industrial vehicles had no significant effect on performance in cognitive tasks or saliva cortisol levels, even though work in these environments can be experienced as more difficult or stressful. In considering the effects of other environmental variables, noise and lighting level were included in the study. Results for noise and lighting assessment showed that mean sound pressure levels were significantly different in work environments corresponding to the two groups, and the exposed group were exposed to higher noise levels than the unexposed group. However, mean illuminance did not differ significantly in their work environments. At sound pressure levels >85 dB (A) the mean concentration of cortisol and noradrenaline was increased, but this difference was not statistically significant (p > 0.05). However, the level of the adrenaline between the sound levels < 85 dB(A) and > 85 dB(A) was significantly different (p < 0.04). Noise therefore acted as a stressor and led to the increase in adrenaline concentration. Indeed in recent years, the measurement of adrenaline, noradrenaline and cortisol was considered a predictor for cardiovascular disorders for people exposed to noise [53–55].

In general, it is difficult to draw definite conclusions about heat stress and its deteriorating effects on cognitive performance because of the different types of research from the point of view of the study procedures, type of task, exposure duration to heat, etc., which exist in this area. Moreover, job performance depends on the personal reaction and sensitivity to heat [41,56]. The workplace (field) research studies are generally less controlled than laboratory efforts, and this presents many difficulties for the research team regarding obtaining data and interpreting them; however, a workplace-oriented research was carried out to serve as a useful guide for adopting preventive measures in hot industries.

5. Conclusion

The findings observed in this study showed that heat stress can result in a change in the blood level of stress hormones and can negatively affect cognitive performance. The increased levels of stress hormones in the blood due to exposure to extreme heat can lead to increased human error, resulting in an increased rate of occupational accidents and a reduction in productivity and efficiency of workers. In conclusion, to prevent human error due to heat-induced changes in mental performance and also in order to improve workplace safety in hot environments, the adoption of heat stress control measures, including administrative and engineering controls, can be useful.

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