Health Promotion Perspectives, 2014, 4(2), 240-246
doi: 10.5681/hpp.2014.031
http://journals.tbzmed.ac.ir/HPP

Evaluating Effects of Heat Stress on Cognitive Function among Workers in a Hot Industry

Adel Mazloumi [1], *Farideh Golbabaei [1], Somayeh Mahmood Khani [1], Zeinab Kazemi [1], Mostafa Hosseini [2], Marzieh Abbasinia [1], Somayeh Farhang Dehghan [1]

[1] *Department of Occupational Health Engineering, Tehran University of Medical Sciences, Tehran, Iran*
[2] *Department of Epidemiology and Biostatistics, Tehran University of Medical Sciences, Tehran, Iran*

ARTICLE INFO

Article type:
Original Article

Article history:
Received: Aug 09 2014
Accepted: Dec 10 2014
e-published: Dec 30 2014

Keywords:
Thermal Stress,
Attention,
Reaction Time,
Stroop Test,
Wet Bulb Globe Temperature

***Corresponding Author:**
Farideh Golbabaei
Tel: +98 21 88951390;
e-mail: fgolbabaei@tums.ac.ir

ABSTRACT

Background: Heat stress, as one of the most common occupational health problems, can impair operators' cognitive processes. The aim of this study was to evaluate the impact of thermal stress on cognitive function among workers in a hot industry.
Methods: In this cross-sectional study conducted in Malibel Saipa Company in 2013, workers were assigned into two groups: one group were exposed to heat stress (n=35), working in casting unit and the other group working in machining unit (n=35) with a normal air conditioning. Wet Bulb Globe Temperature was measured at three heights of ankle, abdomen, and head. In order to evaluate the effects of heat stress on attention and reaction time, Stroop tests 1, 2, and 3 were conducted before starting the work and during the work.
Results: A significant positive correlation was observed between WBGT and test duration (P=0.01) and reaction time of Stroop test 3 (P=0.047), and between number of errors in Stroop tests 1, 2, and 3, during the work (P= 0.001). Moreover, Stroop test 3 showed a significant higher score for both test duration and reaction time of workers in case group.
Conclusion: Results of the present study, conducted in a real work environment, confirmed the impairment of cognitive functions, including selective attention and reaction time, under heat stress conditions.

Citation: Mazloumi A, Golbabaei F, Mahmood Khani S, Kazemi Z, Hosseini M, Abbasinia M, Farhang Dehghan S. Evaluating Effects of Heat Stress on Cognitive Function among Workers in a Hot Industry. Health Promot Perspect 2014; 4(2):240-246

Introduction

Human performance is influenced by a vast range of environmental factors in working systems.[1] Heat stress is one of these factors, which can impair operators' performance. Human performance would be declined over time, through focusing on a tedious task in a hot environment.[2]

Since the internal body temperature should be kept around 37 °C, heat exchange between human body and surrounding environment seems to be essential.[3] Body must reach thermal equilibrium by dissipating excess heat transferred to the body and produced in the body. Failure to remove excessive heat will cause an increase in the deep body temperature.[4] Consequently, heat induced physiological strain may lead to health impairments such as heat stroke, heat exhaustion, heat cramps, heat collapse, heat rashes, and heat fatigue.[5] Furthermore, there are two types of external human responses to the increased internal temperature including: behavioral responses, and cognitive responses.[6]

Heat stress can cause operators' cognitive performance to undergo some changes due to lack of comfort, cognitive fatigue, disturbances, unconsciousness etc.[7] Relying on this theory that thermal stressors reduces the capacity of operators in processing the task-related information, Hancock et al. undertook a meta-analysis of performance under heat stress and reported that thermal stressors affect performance negatively.[2] Stubblefield et al. measured the effects of hyperthermia, during a heat stress test (HST), on four cognitive functions (including working memory, attention, response speed, and processing speed). Results showed that hyperthermia reduced working memory performance over time. However, response speed, processing speed and attention were less influenced by high body temperature.[8] The detrimental effects of thermal stress on working memory, information retention, and information processing have been confirmed.[2,6,7] Gaoua et al. have indicated impairment in working memory during heat exposure.[9]

Different factors including type of task, duration of the exposure, intensity of the stressor, and operators' skill level are key variables influencing the extent that thermal conditions influence the performance.[2,5] However, it had been shown that simple tasks are less affected by heat stress, comparing to the complex tasks such as tracking, monitoring, and multiple tasks.[10]

Hancock et al emphasized that thermal stressors negatively influence psychomotor capacities and information processing of individuals. Reaction time and number of errors can give a good estimate of the effects of heat stress on cognitive performance.[2] Variables including heart rate, maximal oxygen uptake (VO_{2max}), tympanic temperature, subjective responses, efficiency, and error rate were utilized for measuring workers' cognitive function.[10]

Although most of the abovementioned studies showed an impact of heat stress on cognitive function, it must be noted that in many of those studies, the investigations were based on the laboratory and experimental study design. We found no study examining such effects in a real working environment. This study aimed to evaluate the effects of thermal stress on selective attention and reaction time of workers in a hot industry.

Materials and Methods

Participants

The present study was conducted among 70 male workers recruited from a hot industry, Malibel Saipa Company in 2013. They were 35 workers, who were exposed to heat stress as case group, from the iron-casting unit where it had three sections of BMD (Badische Maschinen fabrik), DISA, and melting sections; and 35 workers as control group from machining unit. People with almost similar demographic characteristics were selected for case and control groups. Furthermore, those with any cardiovascular diseases or mental disorders were excluded from the study by asking the participants and referring to the medical histories and records of them. Participants were required to have enough sleep the night before the test.

Volunteers signed the informed consent form, which was approved by the Ethics Committee for participation in the study.

The two understudy units were almost similar in terms of environmental conditions (lighting and air condition) as well as work demands and differed merely in the degree of heat stress and somehow noise level.

Study Procedure and Instruments

At the beginning of the shift, first, demographic questionnaire was completed by the participants. The measurements and tests were done two times, before starting the work and during the work between 9-12 a.m.**)**. Environmental measurements and cognitive function assessments were done using the following methods and instruments:

- Metabolic rate of workers in study units were calculated according to the ISO 8996.
- Noise level was measured using sound level meter model TES 1358 (TES Co) and stationing method.

– Lux-meter model Hanger EC1 (Hanger Co, Sweden) was employed for illumination measurement.
– Thermal condition of the working environment was evaluated using global wet temperature, as recommended by ACGIH. Accordingly, measurements of this index were done by a WBGT meter (Cassella Co, England). In this sense, dry temperature, wet temperature, globe temperature and wetbulb glob temperature were measured in each workstation, in three heights including ankle, abdomen, and head. Since climate conditions change during the shift, these measurements have been performed several times. The mean score for each temperature was calculated using the following equation:

$$WBGT(TWA) = \frac{(WBGT1 \times T1) + (WBGT2 \times T2) + \cdots + (WBGTn \times Tn)}{T1 + T2 + \cdots + Tn}$$

– Cognitive function tests including reaction time, accuracy, and attention were conducted using the Stroop Colored-Word Test (SCWT).This test is a general tool of cognitive flexibility and control or executive functioning.[11] Up to now, a number of research articles have been published related to Stroop test and its versions.[12] The computerized Persian version of Stroop test was made in this study. The translationvalidity of the software was approved by the positive opinion of a panel of related experts. Additionally, the test-retest reliability (TRT) was evaluated by 15 subjects who conducted the tests twice. Results showed an acceptable level of correlation coefficient (r=0.742).

Similar to the original Stroop test, the paradigm of Persian version of the Stroop test was divided into 3 trials: neutral, congruent and incongruent. In this sense, the first trial circles with three colors (green, red, and blue) were presented to the participant and Name of each color is labeled on the keyboard. When a colored circle appears, participants must push the key fitted to the color of the shape. In the second trial, the name of colors appears in a white box. The task is similar to test 1, pushing the key fitted to the name of the presented color. In the third trial (incongruent), which is the main part, name of words with colors, which are not corresponds to their written word colors, appears on the screen and the participants should push the key which corresponds the printed color of the word. The participants in both groups were required to perform Stroop tests before starting the work and during the work.

Data analysis

The data are analyzed using SPSS software version 16 (Chicago, IL, USA). The *P*-value of the Kolmogorov-Smirnov test was calculated for determining the normality. Independent *t*-test, pair *t*-test, and Mann Whitney test were used for data analyzing. In addition, correlation of heat stress with other factors was examined by Pearson Correlation Test. *P*-value less than 0.05 was considered statistically significant.

Results

Results of heat stress level, based on WBGT index are presented in Table 1 for workers in case and control groups. According to the results of independent *t*-test, average score of WBGT index in the three heights of ankle, abdomen, and head were significantly higher for workers in case group (*P*=0.0001).

Table 1: WBGT index for working environments of case and control groups

Study groups	Section	Mean (SD) Metabolic rate (W m^{-2})	Mean(SD) WBGT (°C)	Permissible limit (°C)*	Presence of heat stress (Yes/No)	*P*-value.**
Control	CNC	314(25.1)	16.75(0.4)	26.7	No	< 0.001
	BMD	350(54.2)	35.4(5.8)	28	Yes	
Case	DISA	355(49.8)	32.6(5.3)	28	Yes	
	Melting	315(63.4)	30.8(6.8)	26.7	Yes	

*According to ACGIH recommended limit/** One-way ANOVA test/Mean (SD) is presented.

Table 2: Stroop tests for case and control groups

Stroop test variables		Case			Control			
		Before the work Mean (SD)	During the work Mean (SD)	*P*-value.*	Before the work Mean (SD)	During the work Mean (SD)	*P*-value**	*P*-value ***
Test duration (ms)	ST 1	49460 (7550)	51151(7873)	0.404	47499 (4492)	50295 (7766)	0.174	0.660
	ST 2	51518 (221)	53073(7040)	0.727	49086 (7326)	50562 (8475)	0.269	0.197
	ST 3	58215 (9340)	66131(8508)	0.008*	57118 (8326)	59707 (7139)	0.158	0.002
Reaction time (ms)	ST 1	456.6 (131.9)	485(115)	0.394	410 (80)	443 (132.9)	0.452	0.184
	ST 2	487.8 (145)	520 (157)	0.574	458 (132.5)	496 (101)	0.147	0.473
	ST 3	500 (111)	577 (115)	0.003*	461(111)	500 (148)	0.242	0.022*
Number of errors	ST 1	1.65 (1.39)	2.93(2.47)	0.016	0.806 (1.01)	1.09 (1.17)	0.057	0.003*
	ST 2	1.62 (1.49)	3.77(2.30)	0.001*	0.8529 (1.45)	1.11 (1.38)	0.376	< 0.001*
	ST 3	2.85 (2.01)	4.53 (2.92)	0.025*	1.25(1.19)	1.64 (1.73)	0.081	< 0.001*

ST : Stroop test / *: Comparison of variables before and during the work, for case group (Wilcoxon Signed Ranks Test)/ **: Comparison of variables before and during the work, for control group (Wilcoxon Signed Ranks Test)/ ***: Comparison of variables control and study groups, during the work (Wilcoxon Signed Ranks Test)

Table 3: Pearson correlation coefficient (r) between WBGT Index and variables related to Stroop tests

		Before starting the work		During the work	
Test duration	ST 1	0.196	0.127	0.092	0.475
	ST 2	0.100	0.438	0.147	0.243
	ST 3	0.191	0.143	0.325	0.010*
Reaction time	ST 1	0.281	0.127	0.087	0.499
	ST 2	0.084	0.511	0.076	0.542
	ST 3	0.088	0.497	0.247	0.047*
Number of errors	ST 1	0.063	0.632	0.303	0.016*
	ST 2	0.135	0.300	0.366	0.003*
	ST 3	0.250	0.056	0.446	<0.001*

Table 4: Pearson correlation coefficient (r) between noise and variables related to Stroop tests

Stroop test variables		Case				Control			
		Before work		During work		Before work		During work	
		r	*P*-value	r	*P*-value	r	*P*-value	r	*P*-value
Test duration	ST 1	0.137	0.463	0.069	0.711	0.1	0.591	-0.061	0.745
	ST 2	-0.128	0.777	-0.128	0.493	-0.286	0.106	0.083	0.642
	ST 3	0.319	0.105	-0.135	0.478	0.102	0.572	-0.227	0.211
Reaction time	ST 1	-0.133	0.475	0.044	0.812	0.060	0.75	0.263	0.193
	ST 2	-0.133	0.490	0.179	0.336	0.148	0.405	-0.302	0.148
	ST 3	0.209	0.296	0.023	0.903	-0.059	0.736	0.229	0.185
Number of errors	ST 1	-0.04	0.838	-0.137	0.461	0.213	0.250	0.043	0.078
	ST 2	-0.294	0.137	-0.441	0.113	0.112	0.528	0.141	0.419
	ST 3	0.035	0.863	-0.028	0.886	-0.144	0.431	0.094	0.597

Regarding Stroop tests 1 and 2, there were no significant differences for mean test time and mean reaction time during the work between case and control groups with $P>0.05$ (Table 2). However, workers in case group obtained a higher score for test duration and reaction time, comparing to the control group ($P= 0.002$ and 0.022, respectively). Furthermore, the paired *t*-test revealed that in the case group, test duration, and reaction time in Stroop test 3 were significantly higher during the work, comparing before starting the work ($P= 0.008$, and0.003, respectively). Regarding number of errors in the three trials of the Stroop test, Mann-Whitney test manifested significant higher errors during the work for case group in comparison with those of control groups. Additionally, Wilcoxon Signed-Rank Test was used to compare number of errors in the Stroop tests before starting the work and during the work and the results showed significant differences for workers in both case and control groups.

The Pearson correlation coefficient showed that there is a significant positive correlation between the global wet temperature and average time of Stroop test 3 ($r=0.325$ and $P=0.01$), reaction time in the Stroop test 3, ($r=0.247$and $P=0.047$) and also between number of errors in the Stroop test 1, 2, and 3, all during the work (Table 3).

Average of sound pressure levels in work environments corresponding to exposed group (82 (4.62) dBA) and unexposed group (79 (4.68) dBA) were significantly different from each other ($P=0.01$). Although, mean illuminance did not differ significantly in their work environments ($P=0.27$) and control group (178 (68.73) Lux) were exposed to higher level than case group (159(90) Lux).

In order to assess the possible effect of noise on cognitive performance, the Pearson correlation coefficient was calculated (Table 4). Accordingly, there was no significant correlation between background noise variable and test duration, reaction time, and number of errors in the case and control groups ($P= 0.05$).

Discussion

The present study investigated the possible effects of heat stress on cognitive performance of workers, in a casting plant. Accordingly, workers in case group were under heat stress with the mean WBGT of 32.93 °C. Generally, results showed that cognitive function was impaired due to heat stress exposure, through increase in task duration and response time, as well as number of errors. These findings are consistent with the several preceding studies, which many of them were laboratory-based.[13-14]

Up to now, a large body of researches reported the increase in number of errors under heat stress. Reaction time and number of errors can be considered as good indexes for evaluating the effects of heat stress on cognitive performance.[7,14] It was observed that response time of employees in the casting unit increased, which confirmed the hypothesis of effects of heat stress on selective attention and reaction time under hot conditions. There are similar findings confirming the results of the current study. Radakovic et al.,[14] investigated the effects of acclimation status on physiological and cognitive performance of soldiers, and observed that exertional heat stress in hot conditions caused mild deficits in attention by means of prolonged movement time. Thermal stressors negatively influence psychomotor capacities and information processing of individuals.[2]However, the mechanism of effects of heat stress on cognitive functions is not well documented and further investigation is needed.

There are controversial points relating to the influence of heat stress on congnitive fuction inpairment, in general. In this regards, Gaoua et al., reported no differences in the reaction time of the attention tasks between control group and hot conditions.[9] Overall, achieving a definite conclusion concerning the relationship between cognitive performance and heat stress is difficult maybe due to differences among various studies with different tests conditions, task types, and period of heat exposure.

Task performance under hot conditions depends on the individual reaction and sensitivity to heat.[7] Pilcher et al.,[15] concluded that the ambient temperature above 32 °C led to a significant decline in individual's cognitive function. However, the complexity of the task and the length and severity of heat exposure are important parameters in the influence of heat stress on cognitive performance.

Findings also showed no significant differences between test duration and reaction time in Stroop tests 1 and 2 in both groups, before and during the work, and between the two groups, during the work. Moreover, in these tests, there were not a significant correlation between heat stress (score of WBGT) and length of the test and reaction time. This might be attributed to the simple nature of Stroop tests 1 and 2, which require low level of attention. However, concerning Stroop test 3, the results were different in a way that test duration and reaction time had a significant difference between workers exposed to heat stress and control group. Additionally, both of these indexes were significantly different before and during the work, in the case group. These meaningful relationships are maybe due to the complexity of Stroop test 3, as incongruent test, accompanied by heat stress during working times. Heat stress affects cognitive performance differently and its effects depend on the type of cognitive task. In tasks, which require low attention, cognitive performance less, affected by heat stress, comparing more complex tasks, which require more attention.[7]

Number of errors in the Stroop tests 1, 2 and 3 in both case and control groups were significantly different, before starting the work and during the work. Additionally, a significant correlation was observed between heat stress and the number of errors in the Stroop tests 1, 2 and 3. Up to now, a large body of researches reported the increase in number of errors under heat stress.[7,14] Vasmatzidis et al,[6] examined the effect of heat stress on time-sharing performance and found that WBGT affects the number of human false alarms. In this sense, false alarms from 0.38 at 22 °C WBGT increased to 0.58 at 28 °C WBGT and to 0.90 at 34 °C WBGT.

Noise had no confounding effect when examining the impact of heat stress on cognitive performance. This finding is in accordance with those of Ljungberg and Neely[16] who found relatively short exposures to noise and vibration typical of those levels that are found in industrial vehicles do not significantly affect performance in cognitive tasks even if work in these environments can be experienced as more difficult or stressful.

Conclusion

In this study, Stroop tests were utilized which measure selective attention. Since heat stress can impair other elements of cognitive functions including long-term memory, short-term memory, decision making, and so forth, further studies is recommended to examine other aspects of cognitive functions, by adopting specific types of tests.

Acknowledgements

This study is a part of a research project funded by the Tehran University of Medical Sciences with grant no16275. The authors would like to thank all participants from Malibel Saipa for their kind contributions. The authors also acknowledge the kind cooperation of the Malibel Saipa's HSE personnel as well as Mr. Rahimi, as the software programmer in the present study.

Competing interests

The authors declare that there is no conflict of interests.

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