



Research article

Evaluating the effect of heat stress on cognitive performance of petrochemical workers: A field study



Zahra Rastegar^a, Mohammad Reza Ghotbi Ravandi^a, Sajad Zare^{a,*}, Narges Khanjani^b, Reza Esmaili^c

^a Department of Occupational Health Engineering and Safety at Work, Faculty of Public Health, Kerman University of Medical Sciences, Kerman, Iran

^b Department of Statistics and Epidemiology, School of Public Health, Kerman University of Medical Sciences, Kerman, Iran

^c Department of Occupational Health Engineering, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran

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ABSTRACT

Introduction: Heat stress disrupts blood hormones and reduces workers' cognitive performance. To further shed light on the dysfunction of heat stress, the present study aimed to evaluate its effect on cognitive performance of petrochemical workers.

Materials and methods: This descriptive-analytical cross-sectional study was conducted in 2020 in one of the Iranian petrochemical companies. Participants were divided into 2 case groups and 1 control group. They worked 12 h and their shift entailed one week working day and one week working night. According to the ISO 7243 standard, the heat stress index of employees was measured at the beginning, in the middle and at the end of the shift separately. Continuous Performance Test (CPT) and N-back cognitive performance tests were performed at the beginning, in the middle and at the end of the shift to determine the level of cognitive performance. The data were analyzed using SPSS software version 20 and the significance level was set at 0.05.

Results: Comparison of the results in the continuous performance test showed significant differences between the three groups with regard to the omission error and response time at the end of the shift. Moreover, according to the working memory test, participants reaction time during the shift significantly increased. Besides, average correct responses significantly reduced during the shift. Finally, the heat stress throughout the shift had a significant effect on the commission error and the response time of individuals.

Conclusion: Heat stress affects people's cognitive performance in such a way that it can decrease their cognitive performance by increasing the commission error and response time and reducing the average correct response of site operators, generally reducing the cognitive performance of people at the end of the shift.

1. Introduction

One of the important variables that affect people's level of performance is heat stress, which is a major problem for many occupations, especially industries that operate in tropical or subtropical regions such as the Persian Gulf, including southern and southwestern Iran, and especially Assaluyeh. In many industries, including petrochemical companies, in addition to the regional climate, artificially produced heat is exacerbated by industrial processes [1]. One of the most important and common problems of occupational health in work environments is unfavorable weather conditions, i.e. working in hot environments. A hot work environment not only reduces working performance in the human body, but also can cause many diseases. In fact, the human body has the

best performance if the internal temperature ranges between 36 to 38 °C [2]. If the amount of heat received and produced is greater than what the body is able to excrete, the internal body temperature will increase and may lead to heat-induced disorders [2]. Heat stress in the workplace can also directly or indirectly affect cognitive performance and metabolism or body temperature, heart rate and blood pressure and cause disorders and disease. It also decreases working memory, storage, and information processing and increases the rate of work error, eventually leading to the occurrence of accidents [3]. In addition, in other studies, it has been observed that some cognitive tasks were exposed to extremely hot weather conditions (in contrast to moderate and extreme heat weather conditions) and heat stress was recognized by considering the receipt and duration of activity requirement [4,5]. It has also been observed that

* Corresponding author.

E-mail address: ss_zare87@yahoo.com (S. Zare).

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during heavy operational activities such as firefighting in hot environments, cognitive performance and decision-making are impaired [6] and the rise of body temperature can affect the performance of individuals [7]. Heat is an environmental stressor and in combination with other stressors can cause mental disorders and, even under certain conditions, can affect cognitive performance and cause human error [8, 9, 10]. Furthermore, co-exposure to physical harmful agents in the workplace, such as noise and heat, cause the release of stress hormones in the workers [11, 12, 13]. Thus, the effects of heat stress exposure on physiological responses are well documented. According to the results of Gaoua's study, cognitive performance is more sensitive to heat disorders and warm environmental conditions than physiological responses. Nonetheless the effects of this exposure on cognitive performance is still unclear [14]. Considering that the oil and gas industries cover a significant volume of the country's labor force, the importance of this research becomes more apparent. And since most of the studies that have examined the effect of thermal stress on individuals' cognitive performance have not been field-based or only a small number of cognitive performance variables have been studied, the present study was conducted to achieve the following goals to address the existing lacunas:

1. Determining the heat stress index in the work environments of petrochemical workers in their specialized jobs at the beginning, in the middle and at the end of the shift.
2. Determining the cognitive performance of workers at the beginning, in the middle and at the end of the shift.
3. Determining the relationship between heat stress index and cognitive performance of workers at the beginning, in the middle and at the end of the shift.

2. Method

2.1. Research design

The present research comprises a descriptive-analytical cross-sectional study that was conducted in 2020 in Kavian petrochemical company located in south Pars region (Assaluyeh). Prior to data collection, the purpose of the study was explained to the participants. The gleaned demographic data included: age, work experience, body mass index, metabolism and level of education (Bachelor of Science or higher educational degrees). In the current study, subjects were selected based on the following recruitment criteria:

a: No cardiovascular diseases; b: Having mental health with no mental disorders; c: No use of caffeinated beverages regularly; d: No use of hypnotic drugs; e: No drug addiction and smoking; f: No hearing loss and deficiency in hearing system; g: No sleep disorders; h: No major systemic diseases.

Finally, subjects were classified into three groups (30 participants in each group) with different WBGT TWA level as follow:

1. Control group members came from control room operators with WBGT TWA of 21.39 ± 1.11
2. First case groups were selected from site operators with WBGT TWA of 24.32 ± 0.61
3. Second case groups were selected from site operators with WBGT TWA of 29.29 ± 3.31 .

The effect of exposure to heat (less than allowable heat stress) on control room operators and the impact of exposure to excessive heat (more than allowable heat stress) on site operators were investigated. The metabolism rate of participants in the three groups was determined according to ISO 8996 [15]. Participants in this study had a work schedule of one week day working, one week night working and one week off. Staff members were living in camps constructed by the company far from their family. In this study, working days encompassed a 12-hour shift varying from 7 a.m. to 7 p.m. To investigate the effect of heat on workers' cognitive performance, first the Time-Weighted Average of heat stress index (WBGT

TWA) was measured during the shift (at the beginning beginning (7 a.m.), in the middle (11 a.m.) and at the end (7p.m.) of the shift). The participants' cognitive performance was also gauged on these three occasions utilizing CPT and N-back for all three groups.

2.2. Measurements

2.2.1. Time-weight average of heat stress index (WBGT_{TWA})

WBGT was developed by Yaglou and Minard in 1957 and is regarded as one of the main experimental indices for measuring heat stress [16]. Environmental parameters, including air temperature, natural wet bulb temperature, globe temperature, relative humidity and dew point, were assessed by WBGT meter model MTH-1 made in England in different working places according to ISO 7243 standard. It can be used to assess both indoor and outdoor heat stress. Depending individuals' location, different variables (i.e., natural wet temperature, radiation temperature, and metabolic rate) are used in calculating this index [17]. For outdoor environments, to calculate WBGT according to ISO 7243, Eq. (1) was used:

$$\text{WBGT}_{\text{OUT}} = 0.7 T_{\text{nw}} + 0.2 T_g + 0.1 T_{\text{db}} \quad (1)$$

where T_{nw} denoted natural wet temperature, T_g glowing (radiation) temperature, and T_{db} denoted dry temprature.

For indoors, to calculate WBGT according to ISO 7243, Eq. (2) was used:

$$\text{WBGT}_{\text{in}} = 0.7 T_{\text{nw}} + 0.3 T_g \quad (2)$$

According to standards, WBGT index for different times of day during shift work is calculated using the followig formula [13,18]:

$$\text{WBGT}_{\text{TWA}} = \frac{\text{WBGT}_1 \times t_1 + \text{WBGT}_2 \times t_2 + \dots + \text{WBGT}_n \times t_n}{t_1 + t_2 + \dots + t_n}$$

where WBGT_{TWA} is average time weighted wet bulb glob temperature, t_n is measurement time and WBGT_n is measured wet bulb glob temperature at t_n .

2.2.2. Continuous performance test (CPT)

The test was developed in 1956 by Rosvold et al. [19] and quickly gained widespread acceptance. The main purpose of this test is measuring continuous attention and impulse control. Continuous performance test was used to gauge attention error and sustained attention. A validated Persian version of the instrument was employed in the present study. The test consists of 150 stimuli appearing on the screen; the participants' task was to press the spacebar on their keyboards as soon as the number "4" was displayed on the screen. The presentation time for each stimulus was 150 ms, with an interval of 500 milliseconds (ms) between every two stimuli. The number of correct responses, omission error, commission error, and the response time (in ms) were recorded as the dependent variables [20]. External reliability of this test was obtained for a healthy test with an intergroup correlation coefficient of 0.89 [21].

2.2.3. Working memory test (N-back)

The N-back test, the frequently used test to measure memory, was recruited to assess working memory [22]. The N-back task is a task of measuring executive performance commonly used in neuroimaging studies to stimulate subjects' brain performance. This task was first introduced in 1958 by Krencher [23]. This instrument assesses the ability to process, select, and store information within a very short period of time. A total of 120 digits were displayed one by one on the center of the screen for five minutes, with an interval of 1500 milliseconds (ms). An n-back test can include 1 to N steps. for example in a two steps n-back test, at the first step that is called back-1, Participants were asked to compare the two consecutive digits that appeared on the screen and immediately press a response button on a special keyboard if the two digits were the same. In the second step (back-2), if the stimulus is the same as the

second stimulus before it, the participant is asked to press the desired button. Finally, reaction time and mean correct response were recorded as the dependent variables in this test [20].

3. Statistical analysis

Data analysis was performed using SPSS software version 20. Descriptive measures (mean, standard deviation and frequency) were used to summarize the data. The normality assumption for the data was performed using Kolmogorov-Smirnov test. Subsequently, analysis of variance (ANOVA) was employed to check the research hypotheses. Significance level in data analysis was considered less than 0.05.

4. Ethical considerations

Prior to the project, all its stages were approved by the Ethics Committee of the Vice Chancellor for Research, Kerman University of Medical Sciences and Health Services (Project Ethics Code: IR.K-MU.REC.1397.393). Before starting the measures, the necessary explanations about this study were given to the workers and their written consent was obtained to participate in this study. Workers were also assured that their personal information would be kept confidential.

5. Results

5.1. Demographic information

Table 1 shows the participants' demographic information in the three groups.

5.2. Time-weighted average of heat stress index (WBGT_{TWA})

According to the results displayed in Table 2, the highest weighted mean time of heat stress index belongs to the case group exposed to WBGT_{TWA} 29.29 ± 3.31 °C. The WBGT_{TWA} differences between the three groups were statistically significant at the beginning, in the middle and at the end of the shift ($P < 0.05$).

5.3. Determining workers' cognitive performance using continuous performance testing (CPT)

Figures 1, 2, and 3 show the commission error, omission error and response time of workers in the three groups at the beginning, in the middle and at the end of the shift. According to figures, the commission error, the omission error and the response time of the workers increased at the end of the shift and the largest change in cognitive performance was related to the case group exposed to WBGT_{TWA} 29.29 ± 3.31 °C.

5.4. Determining the relationship between time weighted average heat stress index (WBGT_{TWA}) and continuous performance test (CPT)

Effects of the time-weighted average of heat stress index on the continuous performance of workers are shown in Table 3. According to this table, heat stress has a significant effect on the commission error. Furthermore, at the end of the shift, the commission error is significantly affected by the shift time ($P < 0.05$). Moreover, heat stress had a statistically significant effect on response time. With respect to the response time, significant differences were detected between the three groups at the end of the shift ($P < 0.05$). In contrast, increasing or decreasing WBGT did not cause a statistically significant difference in the omission error of workers.

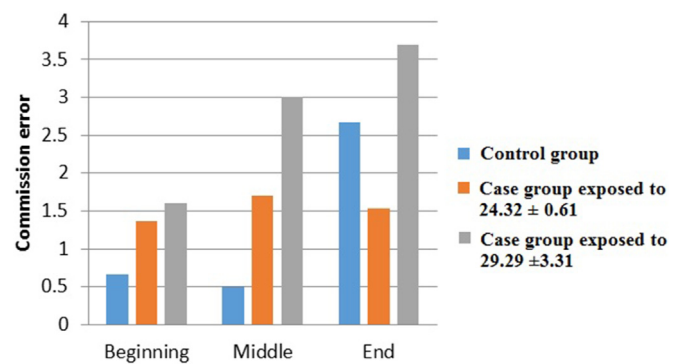


Figure 1. Cognitive performance of workers according CPT-commission error.

Table 1. Participants' demographic information (n = 90).

Variables	Control group exposed to WBGT _{TWA} 21.39 ± 1.11 °C (n = 30)	Case group exposed to WBGT _{TWA} 24.32 ± 0.61 °C (n = 30)	Case group exposed to WBGT _{TWA} 29.29 ± 3.31 °C (n = 30)	Total (n = 90)	P-value*
	M±SD	M±SD	M±SD	M±SD	
Age (year)	34.23 ± 2.75	30.03 ± 3.51	30.03 ± 3.51	31.43 ± 3.80	0.13
BMI(kg/m ²)	25.27 ± 1.55	25.89 ± 2.41	30.12 ± 1.80	27.09 ± 2.90	0.06
Experience (year)	9.20 ± 2.05	7.03 ± 2.60	7.03 ± 2.60	7.75 ± 2.619	0.09
metabolism (W/m ²)	100.7 ± 1.11	164.4 ± 1.32	180 ± 1.25	148.36 ± 34.51	<0.0001
Educational level	19.00 ± 63.3	19.00 ± 63.3	19.00 ± 63.3	19.00 ± 63.3	0.11

*Significance level was considered as p-value <0.05.

Table 2. Comparison of time-weighted average of heat stress (°C) in the three groups of workers at the beginning, in the middle and at the end of the shift (n = 90).

Variables	Time	Control group exposed to WBGT _{TWA} 29.29 ± 3.31 °C (n = 30)	Case group exposed to WBGT _{TWA} 24.32 ± 0.61 °C (n = 30)	Case group exposed to WBGT _{TWA} 29.29 ± 3.31 °C (n = 30)	P-value
		M± SD	M± SD	M± SD	
WBGT _{TWA}	Beginning	21.14 ± 1.07	23.24 ± 0.52	26.07 ± 4.8	*<0.0001
	Middle	22.15 ± 1.05	26.47 ± 0.78	34.72 ± 0.33	*<0.0001
	End	20.90 ± 1.23	23.27 ± 0.53	27.08 ± 4.8	*<0.0001
	Total	21.39 ± 1.11	24.32 ± 0.61	29.29 ± 3.31	*<0.0001

*Significance level was considered as p-value <0.05.

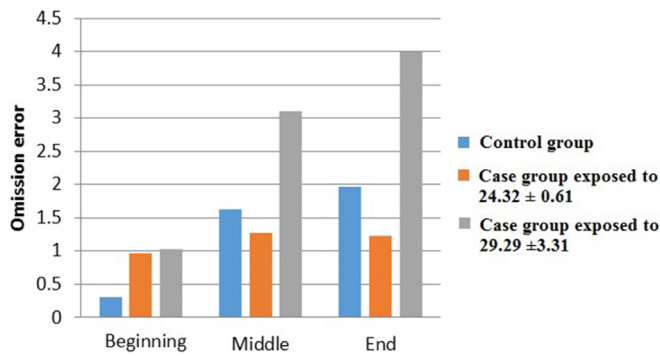


Figure 2. Cognitive performance of workers according CPT-omission error.

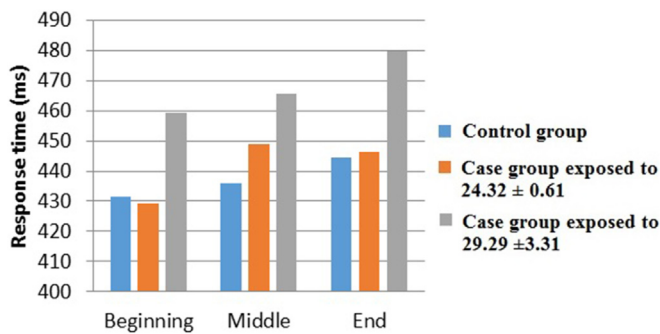


Figure 3. Cognitive performance of workers according CPT-response time.

However, the omission error was affected by shift time and there was a statistically significant difference in the middle and at the end of the shift. It was also found that the response time of the case group exposed to WBGT_{TWA} 29.29 ± 3.31 °C was statistically significant ($P < 0.05$).

5.5. Determining the cognitive performance of workers using working memory performance test (N-back)

The highest reaction time and the lowest average correct response are related to the case group exposed to WBGT_{TWA} 29.29 ± 3.31 °C, which is

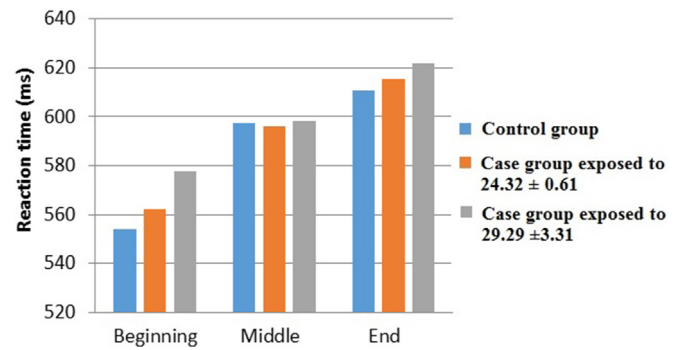


Figure 4. Cognitive performance of workers according N-back test-reaction time.

confirmed according to Figures 4 and 5. Also, according to the following figures, the average reaction time of individuals at the end of the shift went up, while their average correct response declined.

5.6. Determining the relationship between time-weighted average of heat stress index (WBGT_{TWA}) and working memory performance test (N-Back)

Table 4 indicates the effect of the time-weighted average of heat stress index on participants' working memory. Accordingly, heat stress did not significantly affect workers' reaction time. However, workers' reaction time was influenced by shift time, with the results being statistically measurable in the middle and at the end of the shift. Additionally, temperature change caused significant shift in the mean of the correct response ($P < 0.05$). Statistical analysis also showed that the mean scores of the correct response in the middle and at end of the shift were significantly different ($P < 0.05$). According to Table 4, the highest reaction time and the lowest average correct response were associated with the workers of the case group exposed to WBGT_{TWA} 29.29 ± 3.31 °C. Statistical analysis also indicated significant differences in the three groups' mean scores in terms of the correct response during the shift ($P < 0.05$).

6. Discussion

Despite many changes in technology, many processes and activities such as oil and gas industries, space base control centers, power plants

Table 3. The effect of time weighted average heat stress index and shift time on continuous performance of the three groups (n = 90).

Variables		Commission error			Omission error			Response time		
		Standard deviation	P-value	Confidence interval 95 %	Standard deviation	P-value	Confidence interval 95 %	Standard deviation	P-value	Confidence interval 95 %
Constant		0.49	* <0.0001	(-3,-1.1)	0.41	* 0.0004	(-1.9, -0.4)	12.6	* <0.0001	(367.9, 417.4)
Middle		0.25	0.76	(-0.6, 0.4)	0.35	* 0.002	(0.1, 1.5)	4.62	0.78	(-7.8, 10.3)
End		0.37	* 0.001	(0.2, 1.6)	0.27	* <0.0001	(0.6, 1.6)	4.48	* 0.0002	(6.2, 27.7)
Case group exposed to WBGT _{TWA} 24.32 ± 0.61 °C	WBGT _{Beginning} = 23.24 ± 0.52 °C	0.55	0.52	(-1.4, 0.72)	0.2	0.1	(-0.7, 0.06)	9.83	0.54	(-25.3, 13.3)
	WBGT _{Middle} = 26.47 ± 0.78 °C									
	WBGT _{End} = 23.27 ± 0.53 °C									
Case group exposed to WBGT _{TWA} 29.29 ± 3.31 °C	WBGT _{Beginning} = 26.07 ± 4.8 °C	0.59	0.33	(-0.6, 1.7)	0.32	0.055	(-0.01, 1.3)	12.94	* 0.0049	(0.2, 50.89)
	WBGT _{Middle} = 34.72 ± 0.33 °C									
	WBGT _{End} = 27.08 ± 4.8 °C									
WBGT _{TWA}		0.02	* <0.0001	(0.04, 0.14)	0.02	0.15	(-0.01, 0.07)	0.53	* 0.0001	(0.8, 2.8)

*Significance level was considered as p-value <0.05 .

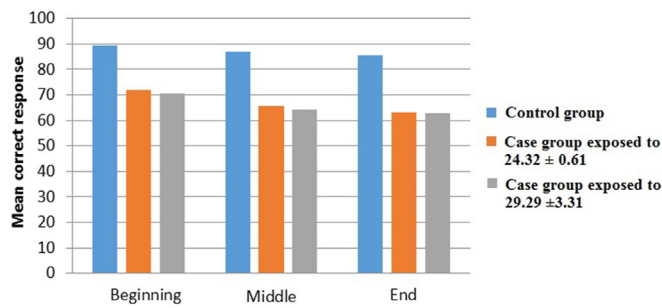


Figure 5. Cognitive performance of workers according N-back test-mean correct response.

and nuclear industries, driving, locomotive, flight control and control centers and watchtowers highly depend on the human factor. It is clear that the most important issue in process control tasks by humans at the topic of "cognition" is understanding, analyzing and responding to the main component of the job in terms of human factors to achieve the desired result of the assigned tasks and prevent human error. In the process of human-machine perception, cognitive activities are considered as structural elements [24]. The results of the present study revealed that the rise or fall of WBGT has a significant effect on the commission error and response time of subjects. In general, it was observed that with continuous increase or decrease of WBGT, the performance of the case group exposed to WBGT T_{WA} 29.29 ± 3.31 °C significantly reduces ($P < 0.05$). Investigating the effect of thermal protective clothing on cognitive responses concluded that human error increases in hot conditions [25]. Also Amiri et al. and Zamanian et al., who explored the effect of temperature on memory, concluded that high temperatures (32 and 38 °C) weaken data storage capacity and reduce the ability to store information compared [26,27]. Hemmatjo et al. (2017) examined the effectiveness of cooling strategies on cognitive function and physiological strain during firefighting activities while wearing protective clothing in the smoke-diving room. They found that the participants' response time (RT) and correct response (CR) improved when using cooling vests (CV) [28]. In another study, Hemmatjo et al. (2020) investigated firefighters' cognitive functions with visual and auditory cognitive function tests before and after the simulated live-fire. They concluded that visual cognitive performance test (VCPT) and auditory cognitive performance

test (ACPT) scores were lower after the activity relative to baseline [29]. Hemmatjo et al.'s findings are consistent with the results of this study, but in their study heat did not have a significant effect on the omission error of people. Nonetheless, the continuous performance of subjects during the shift decreased and there was a significant correlation between shift time and omission error, which can be attributed to work-related fatigue. Mohammadzadeh et al. (2020) investigated the effect of cognitive fatigue on the neural efficacy of the executive control network among athletes adopting a dual regulation system model. It was concluded that cognitive fatigue caused by long periods of required cognitive activity increases error rate and decreases accuracy [30]. Karami et al. [31] also discovered that there was no statistically significant relationship between the WBGT index and the variables of commission error and response time, but omission error was statistically significant. The results of the present study indicated that despite the decline in the working memory of subjects during the shift, raising or lowering WBGT did not change the reaction time of subjects significantly ($P < 0.05$). This conflicts with the findings reported by Mazlumi et al. (2014), who demonstrated a positive and significant correlation between WBGT and reaction time in stroop test [32], a finding that was in line with the study of Karami et al. [32]. The results of the latter study indicated that WBGT index does not have a significant effect on reaction time. But in general, both studies confirmed that working memory performance decreases at the end of the shift. The results of the present study indicated that the mean of the correct response of subjects had statistically significant changes while increasing or decreasing of WBGT ($P < 0.05$). It was observed that the highest decline in working memory performance (i.e. increase in reaction time and decrease in correct response) is related to the case group exposed to WBGT T_{WA} 29.29 ± 3.31 °C. In the case of heat stress, Qian observed that the blood flow to the brainstem goes up, hence increasing the reaction time [33]. Patterson et al. concluded that when workers are exposed to heat stress, the reaction time varies depending on the simplicity or complexity of the task. When the temperature increases from 21 °C to 35 °C, the reaction time also goes up [34]. Kazemi et al. (2016) investigated the impacts of shift work on cognitive performance, sleep quality and sleepiness among petrochemical control room operators. They found that the reaction time and the number of commission errors in the CPT test increased at the end of both shifts. Further, the number of correct responses in the n-back test went down, and the reaction time rose at the end of both shifts (21). Finally, Haidarimoghadam

Table 4. The effect of time weighted average heat stress on working memory performance of the three groups (n = 90).

Variables	Reaction time			Mean correct response		
	Standard deviation	P-value	Confidence interval 95 %	Standard deviation	P-value	Confidence interval 95 %
Constant	30.56	* <0.0001	(626.4, 506.6)	6.48	* <0.0001	(80.6, 106)
Middle	9.72	* <0.0001	(53.4, 15.4)	1.18	* <0.0001	(-6.8, -2.2)
End	9.4	* <0.0001	(32.8, 69.7)	1.2	* <0.0001	(-9.1, -4.3)
Case group exposed to WBGT T_{WA} 24.32 ± 0.61 °C	WBGT _{Beginning} = 23.24 ± 0.52 °C WBGT _{Middle} = 26.47 ± 0.78 °C WBGT _{End} = 23.27 ± 0.53 °C	35.39	0.89	(-64.3, 74.4)	6.93	*0.0004 (-33.7, -6.5)
Case group exposed to WBGT T_{WA} 29.29 ± 3.31 °C	WBGT _{Beginning} = 26.07 ± 4.8 °C WBGT _{Middle} = 34.72 ± 0.33 °C WBGT _{End} = 27.08 ± 4.8 °C	33.99	0.54	(-45.8, 87.5)	7.01	*0.0004 (-34.2, -6.7)
WBGT T_{WA}		0.91	0.69	(-2.1, 1.4)	0.15	0.47 (-0.4, 0.2)

*Significance level was considered as p-value <0.05 .

et al. (2017) explored the effects of consecutive night shifts and shift length on cognitive performance and sleepiness, concluding that shift length (SL) had negative effects on the three studied cognitive functions, i.e. working memory, attention and reaction time [35], which is in alignment with the findings of the current study.

7. Conclusion

In general, the results of the present study indicated that the amount of WBGT index in the three times (at the beginning, in the middle and at the end of the shift) affects the components of continuous performance test (CPT) and working memory performance (N-back). In the continuous performance test, heat stress caused a significant increase in the commission error and response time of subjects, whereas in the working memory performance test, heat significantly reduced the average number of correct responses. On the other hand, the effect of shift length along with WBGT index caused a significant decrease in cognitive performance, so that the greatest decrease was seen at the end of the shift and in the case group exposed to WBGT_{TWA} 29.29 ± 3.31 °C. Due to high job sensitivity of petrochemical workers, number of workers, exposure to various harmful agents and the hard environmental conditions, their cognitive dysfunction can be very dangerous in terms of safety and control strategies. Thus, these variables deserve to receive due attention. It is recommended to use control methods such as proper work - rest cycle or body cooling methods to prevent workers' cognitive dysfunction and consequently increase productivity, efficiency and safety. As a result, findings of the present study can be useful and applicable for safety and health managers.

Declarations

Author contribution statement

Zahra Rastegar: Performed the experiments; Wrote the paper.
 Mohammad Reza Ghotbi Ravandi: Contributed reagents, materials, analysis tools or data.
 Sajad Zare: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.
 Narges Khanjani: Analyzed and interpreted the data.
 Reza Esmaeili: Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

The data that has been used is confidential.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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