Original Article

The Impacts of Heat Stress on the Cognitive Performance Parameters of Taxi Drivers

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Abstract

Aim: Cognitive function factors have been reported as an effective factor in the incidence of traffic accidents. The aim of this study was to investigate the effect of heat stress on the cognitive performance parameters of taxi drivers. **Materials and Methods:** This prospective cohort study was performed on 29 taxi drivers in both winter and summer. The parameters studied in this study were precision, speed of work, attention, short-term auditory memory, concentration skills, mental fatigue, the wet bulb glob temperature index, and the thermal comfort parameters. **Results:** The mean and standard deviation of drivers age was 52.24 ± 8.28 years. People's performance in terms of speed, precision, number of errors, and attention in the summer morning shift was better than the winter evening shift, but these parameters dropped sharply in the evening shift in the summer. There was a statitistically significant difference between these parameters in the morning and evening of summer ($P < 0.05$). **Conclusion:** The results of this study showed that heat stress reduces the precision, speed of work and attention and increases the number of errors and mental fatigue of drivers. Therefore, it is necessary to plan to improve the working conditions of drivers to prevent the reduction of drivers' cognitive performance and improve driving conditions.

Keywords: Cognitive function, heat stress, taxi drivers, wet bulb glob temperature index

Introduction

It has been reported that the temperature is the third factor among the effective factors contributing to road accidents.[1] High temperature is recognized as an important factor in reducing human ability and performance and increasing the risk of road accidents. Studies conducted in a number of countries have shown that a 1°C increase in air temperature per month increases the number of accidents by 1%–2% in the same month.[2] The factors such as human, vehicle, road, and environmental have been reported as the main factors responsible for road traffic accidents, which the main factor in the occurrence of such incidents is human error or human factor.[3] In the study of factors affecting traffic accidents, cognitive functions were mentioned as effective factors for the occurrence of traffic accidents[4] Cognitive performance is defined as a multidimensional ability, including learning, thinking, logic, attention, memory, and the ability to solve problems and make decisions[5] Mental performance of people in the work environment is influenced by several factors, including the environment, one of which is heat stress.[6] Heat stress is defined as an increase in core body temperature and heart rate due to exposure to excessive temperatures and the body's inability to get rid of excess body heat, which leads to negative effects on the body.[7] Heat stress affects cognitive performance differentially, depending on the type of cognitive task, duration of exposure, skill, and level of adaptation to heat. Study conducted by Nofal and Saeed showed that driving at high temperatures in summer reduces driving performance and increases stress, which should be considered as an important factor in increasing the incidence of road accidents.[8]

Driving has been introduced as a complex task, while driving multiple senses, cognitive skills, and motor ability of people

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are involved.[9] One of the aspects used in driving is the driver's cognitive performance so that when it decreases, including the effect of age on cognitive performance, the rate of errors and driving accidents also increases.[10,11] Road traffic accidents cause considerable economic losses to individuals, their families and to society as a whole, which cost most countries 3% of their gross domestic product. These accidents have reduced the productivity of the victims.[12] No studies have been conducted so far in Iran to investigate the cognitive performance of drivers and their thermal comfort in confronting with heat stress and few real-world studies have been examined the mental performance of the individuals. Therefore, this study was conducted to investigate the effect of heat stress on cognitive performance parameters in taxi drivers.

Materials and Methods

This prospective cohort study was performed on 29 taxi drivers in Isfahan City in the morning and evening in the winter and summer of Iran (February, March, June, and July 2021). Initially, due to the lack of a list of taxi drivers with the coordination of the Taxi Organization and the supervisors of the taxi lines, 30 drivers were selected from the eight taxi lines in accordance with the inclusion criteria. However, one of the drivers was excluded from the study in the second part of the study in the summer due to a problem happened to him. Inclusion criteria for participating in the study were having general health and getting adequate sleep the night before the test, no history of cardiovascular disease, mental disorders, diabetes, thyroid, MS, and satisfaction of research participants to enter the study. Exclusion criteria were the unwillingness of the participants to continue cooperation and problems in completing the questionnaires.

The cognitive performance parameters of taxi drivers were measured in late winter and in the absence of heat, then the subjects were followed and the cognitive performance changes of the same subjects in the summer and in the presence of heat were examined again. All the parameters were measured inside the car and during half an hour in each time of the test. General health of individuals was assessed using the general health questionnaire and after reviewing the questionnaires and obtaining a mental health score above 22, they entered the study. This questionnaire included 28 questions in 4 sections (physical, anxiety, social dysfunction, and depression) whose reliability and validity have been investigated by Taghavi.[13] Other inclusion criteria were assessed by asking questions of participants.

Cognitive performance parameters studied in this study included mental fatigue, concentration skills, short-term auditory memory, speed of work, precision, attention and number of errors, and temperature and thermal comfort parameters studied by wet bulb glob temperature (WBGT), the predicted percentage of dissatisfied (PPD) and the predicted mean vote (PMV). Mental fatigue was measured using a mental fatigue questionnaire. This questionnaire includes 15 dimensions of fatigue, inability to perform an operation, mental fatigue, recovery of mental fatigue, concentration problems, memory problems, mental sluggishness, sensitivity to stress, emotional arousal, irritability, sensitivity to light, sensitivity to noise, sleep deprivation at night, increased sleep, and 24-h changes.[14] Concentration skills were measured using a concentration and focus skills test. This questionnaire included two subscales of voluntary concentration skills (8 questions) and involuntary concentration skills (5 questions). Voluntary concentration skill is a part of concentration skill and is defined as people's awareness of external and internal stimuli and the occurrence of an appropriate response. The skill of involuntary concentration refers to intellectual and mental activities and several parameters that disrupt concentration.[15]

Auditory short-term memory consists of at least two components, active working memory and sensory effect, and remembering information for a short period.[16] Participants' short-term auditory memory was measured using Wechsler test. This test consists of 7 subtests, each of these tests examines a part of memory. In this study, only the sub-test of digit span was used. The test consisted of two columns of 3–9-digit numbers. At first, the numbers in the first column were read aloud by the examiner to the participant and then immediately after hearing the numbers, participants were repeated numbers in the same order as read aloud by examiner. At this point, the test ended when participants mistakenly recalling the numbers or finishing reading the whole row of numbers and the score of this step was recorded. Then in the next step, the 3–9 digit numbers of the next column were read to the participant in the same way and immediately after hearing the numbers, participants repeat the numbers in the reverse order of that presented by the examiner. This stage ended when participants mistakenly recalling the numbers or finishing reading the whole row of numbers and the score of this step was recorded. The numbers of two stages were added together and the total score of the participant was recorded. The validity of this test has been confirmed in many studies.[17,18] The parameters of precision, speed of work, attention, and number of errors were measured using the Toulouse–Pieron accuracy test. This test content consisted of a number of repetitive comet squares with three selected patterns at the top of the page. The participant had 5 min to complete the test and identify three selected patterns (selected comet squares) among the comet squares from right to left and then align the squares of the specified pattern. At the end of the test, the number of incorrect choices along with each missed choices that were not selected according to the pattern were recorded as the number of individual errors. The number of correct answers representing the speed of the subject and the number of incorrect and forgotten answers indicates their inaccuracy and decentralized. Participant's precision is also recorded by subtracting the correct choices from the incorrect choices divided by the correct choices multiplied by one hundred as a percentage. Then, for each correct choice, one

positive score and for each wrong or missed choice, negative 0.5 score is considered. Moreover, from the algebraic sum of the resulting numbers, people's attention was recorded.[19-22]

In this study, thermal comfort indices of the PMV and the PPD were used. The PMV index was selected to predict the mean value of votes of participants on a seven–point thermal sensation scale of cold, cool, slightly cool, neutral, slightly warm, warm and hot, and according to the selected situation, the values of −3,−2,−1, 0, +1, +2, +3 were assigned to them, respectively. In general, to calculate the PMV, the total number of people in each degree of the scale was multiplied by the PMV value, and then, the results are added together and then divided by the total number of participants. However, considering that the number of people present in each taxi was one person and the number of measurements in each turn was three times, the amount of each PMV index in each measurement was equal to the value of the selected scale and finally the average PMV index was calculated from the results obtained from three measurements in each turn. The PPD index was also calculated by the following formula.[23]

$$PPD = 100 - 95 \times e^{-(0.03353 \times PMV^4 + 0.02179 \times PMV^2)}$$

WBGT index was measured using WBGT device (cassella model). The steps of the execution method are shown in Figure 1.

Qualitative data were described using percentage and number indices and quantitative data were reported using mean and standard deviation indices. Paired *t*-test was used for comparison between normal data and Wilcoxon nonparametric test was used for comparison between abnormal data. SPSS software version 26 (IBM corp, Armonk, New York) was used to check all statistical analysis.

Results

The study was performed on 29 taxi drivers. Mean and standard deviation of age, work experience, and body mass index of the drivers in the study were 52.24 ± 8.28 years, 17.69 ± 8.19 years, 26.94 ± 2.81 Kg/m^2, respectively. The mean and standard deviation index of drivers' general health was 18.41 ± 4.66 in winter and 18.27 ± 6.29 in summer.

Comparison of cognitive performance and temperature parameters of drivers in the morning and evening in winter and summer

Winter

There was no significant difference between the parameters of cognitive performance of speed, number of errors, attention, voluntary concentration, involuntary concentration, and mental fatigue in the morning and evening ($P > 0.05$). Precision parameter data had an abnormal distribution in winter, therefore Wilcoxon test was used to compare the morning and evening shifts. There was a statistically significant difference between the precision parameter in the morning and evening shifts ($P < 0.05$). The obtained data of PPD and PMV thermal comfort indices had an abnormal distribution, so nonparametric Wilcoxon test was used to compare the data between morning and evening shifts. There was no statistically significant difference between WBGT temperature parameter and PPD

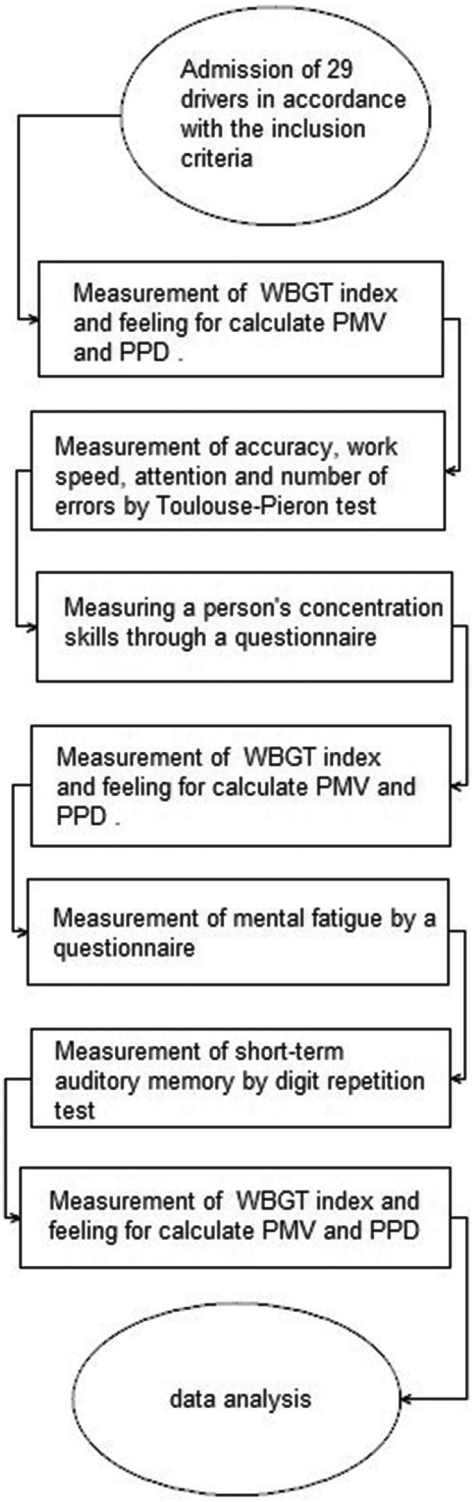

Figure 1: Measurement steps of parameters in winter and summer in the morning and evening (Measurement duration = 30 min)

and PMV thermal comfort parameters in the morning and evening ($P > 0.05$).

Summer

There was a significant difference between the parameters of cognitive function, number of errors, attention, precision in the morning and evening ($P < 0.05$). There was also no significant difference between voluntary concentration, involuntary concentration, mental fatigue, and short-term auditory memory in the morning and evening ($P > 0.05$).

There was a significant difference between WBGT temperature parameter and PPD and PMV thermal comfort indices in the morning and evening ($P < 0.05$). Further details are provided in Tables 1, 2 and Figure 2 (in this table, due to the abnormal distribution of some data and the use of nonparametric Wilcoxon test for these data, the mean difference is not reported).

Comparison of cognitive performance and temperature parameters of taxi drivers in winter and summer mornings

There was a significant difference between the two morning shifts on cognitive performance parameters of work speed, precision, attention, number of errors, mental fatigue and short-term auditory memory ($P < 0.05$). There was no significant difference between voluntary concentration skills and involuntary concentration skills between the two morning shifts ($P > 0.05$). Temperature and thermal comfort parameters of WBGT, PPD, PMV were significantly different between the two morning shifts ($P < 0.05$).

Comparison of cognitive performance and temperature parameters of taxi drivers in winter and summer evenings

There was no significant difference between the two evening shifts on cognitive performance parameters of work speed, precision, attention, number of errors, mental fatigue and short-term auditory memory ($P > 0.05$). There was a significant difference between voluntary concentration skills and involuntary concentration skills between the two evening shifts ($P < 0.05$). Temperature and thermal comfort parameters of WBGT, PPD, PMV were significantly different between the two evening shifts ($P < 0.05$).

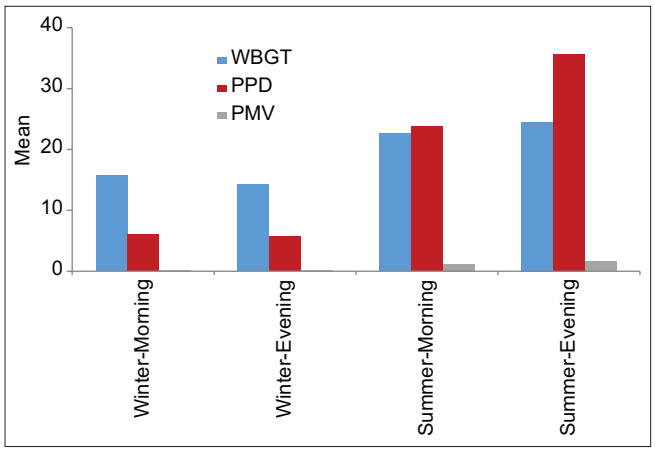

Figure 2: Comparison of mean parameters of WBGT, PPT PMV in summer and winter in the morning and evening. WBGT: Wet bulb glob temperature, PMV: Predicted mean vote, PPD: Predicted percentage of dissatisfied

Comparison of drivers' cognitive performance and temperature parameters in winter and summer

Cognitive performance parameters of work speed, number of errors, attention and mental fatigue were significantly different between the two seasons ($P < 0.05$) and there was no significant difference between the parameters of precision, voluntary concentration skills, involuntary concentration skills and short-term auditory memory ($P > 0.05$). There was a significant difference between temperature and thermal comfort parameters of WBGT, PPD and PMV between the two seasons ($P < 0.05$). Further details can be seen in Table 3 (in this table, due to the abnormal distribution of some data and the use of nonparametric Wilcoxon test for these data, the mean difference is not reported).

The relationship between mental performance parameters and WBGT index and PPD and PMV thermal comfort parameters were investigated using Pearson and Spearman correlation coefficients. There was no significant relationship between all mental performance parameters and temperature parameters ($P > 0.05$).

Discussion

The aim of this study was to investigate the effect of heat stress on the cognitive performance parameters of taxi drivers. The percentage of dissatisfied persons with the temperature conditions in summer compared to winter had increased sharply, so that this rate had exceeded the standard of ISO7730.[24] The results of the present study showed that heat stresses affect the speed of work, precision, attention

Table 1: Investigating the number and percentage of concentration skill parameters and mental fatigue in winter and summer

Parameter	Winter		Summer	
	Morning, *n* (%)	Evening, *n* (%)	Morning, *n* (%)	Evening, *n* (%)
Mental fatigue				
Without problems	10 (34.5)	12 (41.4)	8 (27.6)	10 (34.5)
Minor problems	18 (62.1)	16 (55.2)	19 (65.5)	16 (55.2)
Relatively minor problem	1 (3.4)	1 (3.4)	2 (6.9)	3 (10.3)
Focus skills				
Voluntary				
>Mean	14 (48.3)	13 (44.8)	17 (58.6)	15 (51.7)
<Mean	15 (51.7)	16 (55.2)	12 (41.4)	14 (48.3)
Involuntary				
>Mean	12 (41.4)	12 (41.4)	11 (37.9)	12 (41.4)
<Mean	17 (58.6)	17 (58.6)	18 (62.1)	17 (58.6)

Table 2: Mean and standard deviation of cognitive and temperature performance parameters and comparison of cognitive and temperature performance parameters in two shifts in the morning and evening in winter and summer (n=29)

Parameter (morning)	Mean±SD		MD	*P**
	Morning	Evening		
Winter				
Speed of work	80.2±23.1	77.4±23.8	2.7	0.059
Number of errors	121.3±23.2	123.6±23.8	−2.3	0.182
Attention	18.3±34.6	12.3±38.8	6	0.073
Precision (%)	−76.3±100.4	−92.9±108.5	-	0.027
Voluntary concentration skills	26.5±6.5	26±6	0.5	0.499
Involuntary Concentration skills	12.7±3.9	13.3±3.5	−0.5	0.418
Mental fatigue	10±5.5	10.1±6.5	−0.1	0.827
Short-term auditory memory	8±1.9	7.8±1.7	-	0.380
WBGT (°C)	15.6±3.4	14.2±2.1	1.4	0.059
PPD	6±1.5	5.7±1.4	-	0.206
PMV	0.1±0.3	0.1±0.3	-	0.793
Summer				
Speed of work	100.7±27.5	74.7±18.8	25.9	<0.001
Number of errors	102.6±30.9	129.3±21	−26.6	<0.001
Attention	45.7±40	5.2±28.5	40.4	<0.001
Precision (%)	−20±63.2	−110.9±110.6	-	<0.001
Voluntary concentration skills	24.7±6.7	24.4±6.8	0.6	0.661
Involuntary concentration skills	13.2±4.3	12.7±4	0.6	0.612
Mental fatigue	12.1±6.3	11.7±7.3	0.4	0.413
Short-term auditory memory	7.3±2.2	7.7±2.3	0.2	0.230
WBGT (°C)	22.6±2.6	24.5±1.6	−1.9	0.004
PPD	23.7±19.5	35.6±18.9	-	0.028
PMV	1.1±0.7	1.5±0.6	-	0.029

**P* <0.05. SD: Standard deviation, MD: Mean difference, WBGT: Wet bulb glob temperature, PPD: Predicted percentage of dissatisfied, PMV: Predicted mean vote

Table 3: Comparison of cognitive function and temperature parameters of individuals between two shifts in the morning, two shifts in the evening and in winter and summer (n=29)

Parameter	Morning		Evening		Winter-summer	
	MD	*P**	MD	*P**	MD	*P**
Speed of work	20.5	<0.001	-2.6	0.479	-8.9	0.009
Number of errors	−18.6	<0.001	5.6	0.135	6.4	0.05
Attention	27.3	<0.001	−7	0.260	−10.1	0.044
Precision	-	<0.001	-	0.315	-	0.325
Voluntary concentration skills	−1.7	0.158	−1.6	0.2	1.7	0.124
Involuntary concentration skills	0.4	0.593	-	0.449	0.03	0.962
Mental fatigue	2	0.008	1.5	0.049	−1.8	0.012
Short-term auditory memory	-	0.032	-	0.611	0.4	0.122
WBGT	−6.9	<0.001	−10.2	<0.001	−8.5	<0.001
PPD	-	<0.001	-	<0.001	-	<0.001
PMV	-	<0.001	-	<0.001	-	<0.001

**P* <0.05. MD: Mean difference, WBGT: Wet bulb glob temperature, PPD: Predicted percentage of dissatisfied, PMV: Predicted mean vote

and number of errors of drivers, however, according to the results of statistical analysis, this relationship is not direct. In other words, there is no linear relationship between temperature and mental performance of the subjects present in the study and the mental performance of drivers is more affected by the duration of their activity in a high temperature environment.

Although the precision, speed of work and attention of people was higher and the number of error was lower in the summer morning shift than the winter morning shift, these parameters changed drastically in the summer evening shift so that the precision, speed of work and attention of drivers was declining and the number of their errors increased. In other words, the results showed that although the cognitive

performance parameters of individuals at the beginning of the shift in summer were better than the winter season, during the working hours and due to exposure to heat stress, the cognitive performance of these people decreased sharply. The precision of the subjects in both seasons in the evening shift had decreased, in part because they are tired in the evening shift. However, this difference was so large in summer compared to winter that it can be concluded that exposure of taxi drivers to heat in summer can cause this large difference. In a study conducted by Habibi *et al*. Showed that heat reduces the Precision and performance of people but does not affect the speed of work.[25] Part of the mentioned study is consistent with the present study and the other part of that study is contrary to the results of the present study, which may be due to differences in the age group of participants and environmental conditions between the two studies. Another study conducted by Bidel *et al*., which was in line with the present study showed that prolonged exposure to extreme temperature reduces participants' attention and concentration while performing their assigned tasks.[26] In a study conducted by Choi *et al*., which examined the subjects' attention abilities on a seven-point PMV thermal comfort sensation scale (−3 to + 3), it was shown that the individuals' lowest attention is in high temperature conditions and in the scale of + 3 and + 2.[27] The results of the study of Mazloumi *et al*. showed that exposure to heat stress increases the reaction time and the number of errors[6] Finally, according to the above mentioned studies and the present study, it can be said that heat stress reduces Precision, speed and attention and increases the number of errors.

The results of the present study showed that mental fatigue in summer is more than winter and there is a significant difference between the results of the two seasons, in other words, heat stress can be one of the important factors in increasing the mental fatigue of taxi drivers. The study is consistent with a study conducted by Qian *et al*. that showed that during heat exposure when people are performing tasks that require constant attention, mental fatigue increases[28] According to the results of the present study and other studies, it can be said that heat stress increases mental fatigue.

The results of the present study showed that there is no significant difference between the concentration skills of individuals in the summer and winter. In other words, heat stress has not affected the Concentration skills. The results of this study were contrary to part of the results of Bidel *et al*., which showed that exposure to heat causes a decrease in cognitive performance, including attention and concentration. This difference in the results of the two studies can be due to the difference in exposure to heat in the participants of both studies.[26] The results of the present study also showed that there is no significant difference between short-term auditory memory of taxi drivers in summer and winter. In other words, heat stress has not affected the short-term auditory memory of individuals and heat stress is not an effective factor in short-term auditory memory. This study is consistent with a study conducted by Yang with three temperature conditions of 26, 28 and 30°C that showed that short-term memory is not affected by ambient temperature.[29]

One of the limitations of this study was the withdrawing of one of the subjects from the study in the summer and the lack of cooperation of some drivers to participate in the study. It is suggested that in future studies, along with cognitive performance parameters, the number of drivers' accidents in two seasons be recorded to make the relationship between the parameters clearer. It is also recommended to use a larger sample in the research study and longer follow-up period to be considered.

Conclusion

The results of this study showed that heat stress reduces the precision, speed of work and attention and increases the number of errors and mental fatigue of taxi drivers, but has no effect on concentration skills and short-term auditory memory of drivers. The results also showed that the prolonged exposure to heat stress has a significant effect on reducing cognitive performance and reduces the thermal comfort of drivers in summer. Therefore, it is necessary to plan to improve the working conditions of taxi drivers to prevent drivers' cognitive performance decline and improve driving conditions and reduce traffic accidents.

Ethics code

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Conflicts of interest

There are no conflicts of interest.

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