Original Article

The Simultaneous Effect of Ambient Temperature and Light Intensity on Performance: A Cross-Sectional Study

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Abstract

Aims: Environmental conditions affect workers health and performance. The present study aimed to investigate the simultaneous effect of ambient temperature and light intensity on human error. **Materials and Methods:** This cross-sectional study was conducted on 50 students from Shiraz University of Medical Sciences. Each participant performed 9 tests in 5 min at 3 different temperatures (20°C, 25°C, and 30°C) and 3 lighting conditions (50, 500, and 1000 lux). The participants were asked to select a text randomly. Participants asked to read the text in just 6 min and identify the mistakes. In each step, the number of remaining lines, number of spelling mistakes found, and task completion time were estimated. **Results:** There was no significant relationship between the temperature and the number of remaining lines, the number of spelling mistakes, and the task completion time ($P > 0.05$). However, the relationship between different light intensity and the number of remaining lines and number of spelling mistakes was statically significant ($P < 0.05$). At a lighting of 500, 1000 lux, and a temperature of 25°C, male subjects performed better. Unlike men, women's performance was not affected that much by the light intensity and only declined slightly in the 1000 lux and at 20°C. **Conclusions:** The results showed that light intensity could be important to create a suitable environment for reducing human error. If the temperature could not increase in an environment due to the nature of a job or economic issues, reducing human errors could achieve by increasing light intensity.

Keywords: Ambient temperature, ergonomics, human error, light intensity

Introduction

Environmental conditions affect workers health, performance, and human error in many industrials including petrochemical, steel, glass, laundromat, and kitchens.[1,2] The monotonous works in which performed in warm environments, decreased individuals performance over time.[3] In 2010, Haldi *et al*. found that the average temperature of 20°C in comparison with 26°C increased efficiency by 6%.[4] In general, occupational stressors, including working environment temperatures, can result in unsafe behaviors among employees through reducing concentration, distraction, and memory impairment.[5-7] Heat and temperature are also associated with human physiological changes. Hence, it can directly or indirectly affect employees' metabolism, body temperature, heart rate, and blood pressure.[8] Previous studies showed that increasing the ambient temperature and heart rate increased the incidence of human error.[8,9] Tatterson *et al*., in a study on the effects of heat on physiological factors, showed that heart rate at 32°C was significantly higher than 23°C during jogging.[9]

On the other hand, lighting is an effective factor in making workers feel comfortable. Good lighting makes people work

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accurately, quickly, and effortlessly.[10] Several studies were conducted on the effect of lighting on performance and visual comfort; for example, Shin *et al*. showed that the light intensity from a computer monitor had a significant effect on people's dissatisfaction. Furthermore, studies showed that environmental lighting can be an effective factor in human error.[11] Buchanan *et al*. examined the effect of changing the light intensity on the rate of human error, and their results showed that by increasing light intensity from 485 lux to 1570 lux, human error rate decreased from 3.9% to 2.6%.[12] According to studies by the Lighting Engineers Association (IES), by increasing the brightness from 65 lux to 170 lux, it reduced human errors by 20%.[13] Furthermore, Amiri *et al*. showed that lighting is a determinant factor in job performance, such as increasing errors and accidents and reducing quality and productivity.[14]

As mentioned, the independent effects of light intensity and ambient temperature on individuals' performance have been somewhat investigated in previous studies. Due to the direct and important effects of these environmental factors on workers' performance, it is important to adjust the environmental conditions, so that people work with the best performance and the least error. However, it is not clear whether the simultaneous effects of these environmental factors change their independent effects on individuals. The simultaneous presence of different environmental factors can have a cumulative effect on humans' cognitive, mental, and physiological functions. Some of these effects can be considered as important, due to reduced comfort, performance, and health status.[15] To study the simultaneous effects of environmental factors, it is necessary to first conduct studies to examine the simultaneous effects of two factors to identify the effects of factors on each other to be fully identified. Then, in future studies, by adding other environmental factors, more complex simultaneous effects were investigated. However, limited studies were conducted to examine the simultaneous effects of environmental factors on mental parameters. Monazzam *et al*. investigated the simultaneous effect of vibration and light intensity on reaction time, heart rate, and discomfort. It was stated that vibration alone had a significant effect on heart rate, discomfort, and reaction time, whereas the combination of light intensity and vibration did not significantly change heart rate and reaction time, and it only had a significant effect on discomfort.[10]

So far, no study has been conducted to investigate the simultaneous effect of brightness and workplace temperature on performance and error. It is not clear that with increasing light intensity, the positive effects of ambient temperature improve or decrease. Therefore, the aim of this study was to investigate the simultaneous effect of light intensity and ambient temperature on performance.

Materials and Methods

This was a cross-sectional study, conducted in the faculty of health at Shiraz University of Medical Sciences, Iran. All phases were performed at the Thermal laboratory of the faculty. Based on the Previous studies, the 3 temperature modes (Mode 1: Low temperature 20°C, Mode 2: Normal temperature 25°C, and Mode 3: High temperature 30°C) and 3 lighting modes (Mode 1: Low intensity 50 Lux, Mode 2: Standard intensity 500 lux, and Mode 3: High intensity 1000 lux) were considered. The amount of light and temperature was selected based on the occupational exposure limit for office jobs, which is 500 lux and 25°C, and to create conditions other than that, two very high and very low ranges were selected compared to the standard conditions.

An air-conditioning system was used to create different temperatures. To eliminate the interference effect of other environmental factors, air velocity and humidity in the ventilation system were set at 30 feet/min and 50%, respectively. At each test, air humidity and airflow velocity were measured by a digital humidity meter (Beurer HM16 Hygrometer) and an anemometer (Amprobe TMA10A Anemometer with Flexible Precision Vane), respectively, to ensure that these factors did not have an interfering effect at all stages of the research. To ensure the accuracy of temperature, it was measured with a mercury thermometer. The lighting was provided by two 55W compact fluorescent lamps (optical flux of 4400 lumens and 75 lumens per watt and 6000° Kelvin) and 4 fluorescent lamps of 60 watts and a dimmer to adjust the brightness. The arrangement of lamps was so that no dazzling effect was created. To measure the light intensity, the Hagner digital photometer (model TP200) was used.

At first, each participant sat on a chair in the most comfortable position. Next, they were asked to select a text randomly (between nine text) that each had 1000 words. Then, to evaluate the participants' performance and rate of error, 60 spelling mistakes were deliberately made in each text, and each participant had to read the text in just 6 min and identify the mistakes. If a participant was not able to read the whole text at the end of 6^{th} min, the number of mistakes found and the number of remaining lines were recorded. As it was mentioned before, there were 9 experimental modes, 3 temperature modes (20°C, 25°C, and 30°C), and 3 lighting modes (50, 500, and 1000 lux). Three lighting and ambient temperatures were also studied separately. When examine the effect of light intensity on human error singly, the ambient temperature was set in the normal state (25°C), and when examine the effect of the temperature on human error, light intensity was set at 350 lux (intensity needed for reading). After each test, 15 min rest was considered. To avoid bias and fatigue after each stage, these 9 steps were randomly selected by each participant.

This design is called before–after comparison or within patient comparison in a single group of subjects. In this experimental design, the comparative nature of the experiment is respected.

The study population consisted of 10 students (5 males and 5 females) with a mean age 24.10 years (standard deviation [SD] = 1.19). The inclusion criteria were lake of any eye diseases (acute problems with vision and color blindness), cardiovascular disease, mental illness, and sleep disorders.

Finally, SPSS version 22 (IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp) was used to analyze the data, and the results were presented as descriptive and analytic. Mann–Whitney test (difference between two variables) and Kruskal–Wallis (the difference between several variables) were used for statistical analysis between the study conditions. The significance level for performing statistical tests was ($P < 0.05$).

Results

Table 1 shows the effect of different temperatures on the number of remaining lines, the number of spelling mistakes found, and task completion time. However, there was no significant relationship between different temperatures and the studied variables ($P > 0.05$).

The relationship between different light intensity with the number of remaining lines, number of spelling mistakes found, and task completion time, showed that changes in the light intensity on the number of spelling mistakes found and the number of remaining lines had a significant relationship ($P < 0.05$), but the light intensity on task completion time did not have a significant effect ($P = 0.425$) [Table 1].

Table 2 shows mean ± SD for the number of remaining lines, the number of spelling mistakes found, and task completion time in the interactive conditions of the temperature and light intensity. The minimum number of remaining lines was at 25°C and 1000 lux, and the highest number of remaining lines was at 20°C and 30°C, at intensity of 50 lux. The lowest error rate was found at 25°C and 50 lux, and the highest error rate was found at 25°C and 1000 lux. The minimum task completion time was at 30°C and 1000 lux, and the highest task completion time was at 20°C and 50 lux. As seen, there was significant differences in number of remaining lines, error rate, and task completion time at all lighting levels for each temperature level.

The simultaneous effect of ambient temperature and light intensity was investigated in two by two comparison and their effect on the studied variables [Table 3]. The results showed that in condition 20°×50 lux compared to conditions 25°×1000 lux, 30°×500 lux and 30°×1000 lux, condition 20°×500 lux compared to conditions 25°×50 lux, 25°×1000 lux, condition 20°×1000 lux compared to conditions 25°×50 lux, 25°×500 lux, 25°×1000 lux, 30°×500 lux and 30°×1000 lux, condition 25°×50 lux compared to conditions 25°×500 lux, 25°×1000

Table 1: Relationship between different temperatures and light intensity and the number of remaining lines, the number of spelling mistakes found and task completion time (at 350 lux)

	The number of remaining lines		The number of spelling mistakes found		The task completion time (s)	
	Mean±SD	*P**	Mean±SD	*P**	Mean±SD	*P**
Temperatures (°C)						
20	3±3.43	0.863	50.30±4.85	0.127	324.30±41.78	0.736
25	2.30±2.75		52.70±3.62		321±43.12	
30	1.80±1.55		54.30±3.94		336.10±27.81	
Light intensity (lux)						
50	6.10±4.72	0.020	43.10±9.87	0.005	346±21.01	0.425
500	1.20±1.31		55.10±3.98		314.10±50.89	
1000	1.40±1.35		56±2.83		321.20±49.52	

*Kruskal–Wallis test (significance level 0.05). SD: Standard deviation

Table 2: Mean±standard deviation for the number of remaining lines, the number of spelling mistakes found, and task completion time between interactive temperature and light intensity

Temperatures (°C)	Light intensity (lux)	The number of remaining lines		The number of spelling mistakes found		The task completion time (s)	
		Mean±SD	*P**	Mean±SD	*P*	Mean±SD	*P*
20	50	6.90±5.53	0.021	43±12.19	0.032	350.50±18.96	0.026
	500	2.90±3.07		54.50±3.72		327.40±35.92	
	1000	1.70±1.83		51.90±3.14		332.20±32.57	
25	50	5.50±5.15	0.014	42.70±8.43	0.025	343.60±19.01	0.042
	500	1.30±1.42		55.10±4.04		327.30±41.81	
	1000	1.00±1.25		57.00±2.79		336.20±27.88	
30	50	6.90±4.91	0.017	43.80±12.37	0.031	338.60±25.18	0.037
	500	2.20±2.48		56.20±2.44		343.40±26.30	
	1000	2.20±1.81		55.70±2.45		319.40±45.42	

*Kruskal–Wallis (significance level 0.05). SD: Standard deviation

Table 3: Comparing the simultaneous effect of ambient temperature and light intensity on the number of remaining lines, the number of spelling mistakes found, and task completion time

Conditions	A	B	C	D	E	F	G	H	I
A (20°×50 lux)	-								
B (20°×500 lux)	0.030[a],*	-							
	0.083[b]								
	0.116[c]								
C (20°×1000 lux)	0.324	0.110	-						
	0.031*	0.310							
	0.160	0.808							
D (25°×50 lux)	0.820	0.003*	0.019*	-					
	0.403	0.121	0.122						
	0.385	0.353	0.518						
E (25°×500 lux)	0.020*	0.434	0.034*	0.001*	-				
	0.014*	0.310	0.511	0.104					
	0.160	0.968	0.904	0.545					
F (25°×1000 lux)	0.003*	0.043*	0.004*	0.001*	0.182	-			
	0.007*	0.424	0.632	0.057	0.749				
	0.186	0.428	0.716	0.628	0.747				
G (30°×50 lux)	0.791	0.103	0.305	0.989	0.041*	0.018*	-		
	0.908	0.051	0.016*	0.304	0.008*	0.002*			
	0.215	0.492	0.600	0.777	0.657	0.808			
H (30°×500 lux)	0.008*	0.379	0.007*	0.001*	0.786	0.284	0.034*	-	
	0.047*	0.844	0.723	0.221	0.407	0.272	0.024*		
	0.443	0.363	0.432	0.804	0.456	0.620	0.679		
I (30°×1000 lux)	0.015*	0.564	0.019*	0.001*	0.538	0.165	0.044*	0.788	-
	0.078	0.555	0.426	0.267	0.180	0.169	0.039*	0.698	
	0.098	0.628	0.628	0.313	0.777	0.492	0.396	0.321	

*Spearman correlation test, $P<0.05$, [a]The number of spelling mistakes found, [b]The number of remaining lines, [c]The task completion time

lux, 30°×500 lux and 30°×1000 lux, condition 25°×500 lux compared to condition 30°×50 lux, condition 25°×1000 lux compared to condition 30°×50 lux, and condition 30°×50 lux compared to condition 30°×500 lux and 30°×1000 lux, were significantly different in the number of spelling mistakes found. Also, condition 20°×50 lux compared to conditions 20°×1000 lux, 25°×500 lux, 25°×1000 lux and 30°×500 lux, condition 20°×1000 lux compared to condition 30°×50 lux, condition 25°×500 lux compared to condition 30°×50 lux, condition 25°×1000 lux compared to condition 30°×50 lux, and condition 30°×50 lux compared to conditions 30°×500 lux and 30°×1000 lux, in the number of remaining lines was significantly different. For task completion time, no significant difference was observed in neither of the two by two comparisons.

In Figure 1, the simultaneous effect of different ambient temperature and light intensity is shown separately for the studied variables among men and women, respectively. As shown in Figure 1a, men's performance (finding the spelling mistakes in the text) had diminished sharply at 50 lux at all temperatures. However, at a lighting of 500, 1000 lux, and a temperature of 25°C, men performed better. Unlike men, women's performance was not affected that much by the light intensity and only declined slightly in the 1000 lux and at 20°C.

Women at 500 and 1000 lux at 20°C and 25°C could read the full text, leaving only 1 line at 30°C. However, in 50 lux, they performed weaker, especially at 20°C and 30°C. Among men, the number of remaining lines (the ability to complete the task) was heavily influenced by the light intensity. At 50 lux, the number of remaining lines was more than 10 lines at all temperatures. In light intensity of 500 and 1000 lux, men performed better, but in these conditions, a weak performance was observed at 20°C [Figure 1b].

According to Figure 1c, men used the maximum allowed time (6 min) in all combinations of temperature and lighting. However, in different conditions, women had different speeds in carrying out the task. Women at 50 lux and 20°C had the slowest performance, and with a brightness of 1000 lux and a temperature of 30°C, the fastest performance.

Discussion

In this study, the effect of temperature and light intensity and their simultaneous effect on human error was investigated. To investigate the effect of lighting on human error, participants were asked to identify spelling mistakes in a text (60 mistakes). The results showed that by changing light intensity from 50 lux to 1000 lux, the number of mistakes found and the number of remaining lines significantly decreased, which might be due to that increasing light intensity can increase the participants' alertness.

In the light intensity of 50 lux, each participant was forced to read the text more carefully, which led to reduced reading

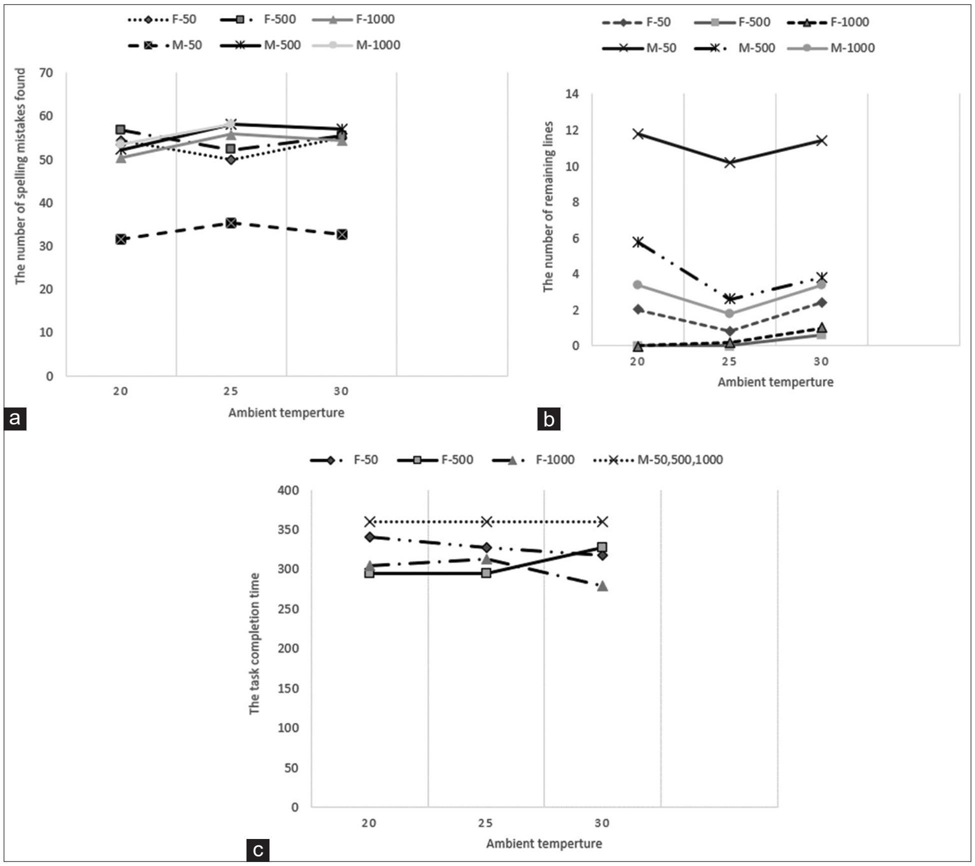

Figure 1: The simultaneous effect of temperature and light intensity on the number of spelling mistakes found (a), the number of remining lines (b), and task completion time (c) according to gender. F: Female, M: Male

speed; hence, the individual could not finish the task on time. Zare investigated the effect of light intensity on visual, cognitive, and subjective performance, showing that by increasing the light intensity from 200 lux to 400 lux, the individua's visual ability to perform tasks and satisfaction of individuals significantly improved.[7,16,17] Also, previous studies and working standards show that the best light intensity for office tasks and text reading is between 300 and 500 lux, which leads to better awareness and better visibility.[18,19] Schlangen *et al*. stated that high levels of light intensity can increase human performance and reduce errors, which is in line with the results of this study.[19-21] Several studies showed that increased light intensity increases eye activity, resulting in increased reading speed and improved performance.[22-24]

Regarding the simultaneous effect of temperatures and lighting on human error, no study has been performed so far. Moreover, the present study results can only be interpreted according to the available conditions; hence, it is not possible to compare it with any other study.

According to the results in Table 2 and comparison between the two test conditions in Table 3, the number of spelling mistakes found (higher number means the individual performance was the better) in most conditions. This showed a significant difference between the conditions, which was due to light intensity, but by comparing condition 20°×1000 lux to 25°×500 lux and 30°×500 lux, it showed that by decreasing light intensity in the two mentioned conditions in comparison with condition 20°×1000 lux, the number of spelling mistake fund in conditions 25°×500 lux and 30°×500 lux had significantly increased, which is an indication for the effect of temperature. Regarding the number of remaining lines, indicating an individual performance in completing the task, in all conditions, increasing the light intensity, their performance improved and the remaining lines decreased. To confirm to see if temperature had less effect, results of 30°×50 lux condition in comparison with conditions 30°×500 lux and 30°×1000 lux that had the same ambient temperature (30°C), number of remaining lines were significantly less in 30°×500 lux and 30°×1000 lux conditions, and the participant's performance had improved.

By comparing the results between men and women, it showed that men had a very low performance in light intensity of 50 lux and their error rate increased with decreasing light intensity. The temperature and light intensity did not have any effect on performing tasks speed in men, but women showed higher reading speed at 30°C, and their accuracy in doing the task was not affected much by changes in lighting.

Therefore, it can be concluded that interaction between ambient temperature and light intensity had a significant effect on human errors. Hence, at a certain temperature, changing the light intensity can have different effects on human error. In addition, at a certain light intensity, rate of errors increased as the ambient temperature increased. In general, it can be inferred that the effect of ambient temperature on human error rate might depends on the light intensity rather than the ambient temperature.

The study had some limitations. The most important one is the low study population due to lack of financial assistance. Therefore, it is suggested that in future studies, increase the number of participants, as well as adding other environmental factors, to reach a better conclusion.

Conclusions

The results of this study showed that to create a suitable environment for reducing human errors and improving safety, an environment with higher light intensity and temperate is warranted. Furthermore, if the temperature cannot be increased in an environment due to the nature of a job or economic issues, the present study showed that reducing human errors can be achieved by increasing light intensity. It seems that adjusting environmental conditions based on the simultaneous effects of variables can improve work environment conditions more effectively. However, a definite statement in this case depends on examining the effects of other environmental variables and examining the relationship between these factors. However, the very high complexity of this type of research has slowed the process.

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Conflicts of interest

There are no conflicts of interest.

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