

Research Paper:



Investigating the Combined Effects of Heat and Light Color Temperature on Precision and Speed in Female Students in Laboratory Conditions

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<u>ABSTRACT</u>

Background & Aims of the Study: Cognitive functions, such as precision and speed, significantly affect human errors and incidents. The temperature of light color and heat can impact cognitive functions. Therefore, the present study examined the effect of heat and color temperature on the speed and precision of work in the laboratory.

Materials and Methods: This study was conducted on 10 female students in the Laboratory of Atmospheric Medical School of Isfahan University of Medical Sciences in Isfahan City, Iran. Piron v-vibrometer and precision and target vibrometer devices were used to measure accuracy and speed. The test was held in 4 turns, each time for 1 hour. The first turn, 22°C, and color temperature 3000°K, the second turn 22°C and color temperature 6000°K, the third turn 36°C and color temperature 6000°K, adjusted.

Results: Based on the obtained results, precision measurement with precision and target vibrometer was significant in two cases with a color temperature of 3000 and temperatures of 22° C and 36° C (P<0.05); thus, with increasing temperature, the frequency of errors enhanced, and consequently the precision decreased. Furthermore, the speed measurement with the precision and target and Piron v-vibrometer in color temperature state 6000 and temperatures of 22° C and 36° C and the color temperature of 3000 and temperatures 22° C and 36° C were significant (P<0.05). In other words, with increasing temperature, the time of work decreased, and as a result, the speed of work increased, and in other cases, no significant relationship was observed (P>0.05).

Conclusion: In general, the present study results indicated that the precision of work at 36°C is less than exposure to 22°C; the speed of work is higher, and changing the color temperature of light has no significant effect on increasing the precision of work. Therefore, it is suggested to use control strategies to reduce the temperature in environments with temperatures higher than comfort.

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1. Introduction

ser's air quality affects humans' health, satisfaction, and performance [1, 2]. A common risk factor in various activities concerning mining, agriculture, production, firefighting and other emergency activities, outdoor sports, and military

jobs is heat [3]. Heat causes heat stress and dysfunction in work environments [4]. Increasing human body temperature leads to behavioral responses such as decreased physical activity, removing clothing, distance from the heat source, and cognitive responses, such as reduced concentration and increased error [5]. Prolonged exposure to high temperatures and humidity can lead to health hazards, such as syncope, heatstroke, and heart attack. It also leads to increased accidents, decreased productivity in the workplace, and changes in cognitive functions. Costello et al. (2019) investigated the effects of heat stress on cognitive function; accordingly, the heat did not affect precision [6]. According to Mazloumi et al. in 2017, heat stress led to increased stress hormones, resulting in impaired cognitive function [7]. Habibi et al. in 2016 documented that heat reduces the precision of work [8].

Artificial lighting, another essential physical factor in office and educational environments, can affect employees' mental health, behavior, and performance [9, 10]; lighting conditions in the workplace are related to job satisfaction, productivity, and well-being [11]. Lighting is a potent modulator for non-visual activities, such as improving consciousness and cognitive functions of the brain [9, 12]. According to research, different light intensity and color temperature values are the main parameters in lighting that lead to various psychological effects [13].

Color temperature is usually measured in Kelvin degrees. Like the wavelengths of light shorten, the corresponding color temperature increases. Light with a higher color temperature is considered "cooler," and light with a lower color temperature appears "warmer" [14]. According to laboratory studies, exposure to light at cool color temperatures improves mood and alertness, attention, and memory. However, the full range of these effects is not well understood [15].

Moreover, using white light can improve cognitive functions [16]. In the office environment, fluorescent lamps with high color temperature can improve health and productivity the environment [17]. High color temperature improves attention [18]. In a study of US military personnel, using LED lamps with cold light increased the performance of individuals [19]. Amoozadeh et al. in 2018 stated an improvement in typing performance and an increase in speed and reduction of error at a color temperature of 4000°K, compared to 3000°K [20].

The effects of temperature on physiological function, such as depth and skin temperature increase, human sweating, and heart rate, have been well studied. However, the effect of temperature on cognitive abilities can lead to error and increase the odds of unsafe behavior has less been examined [21]. Most studies reported a decrease in cognitive function in heat; however, some report no effect, while others indicate improved cognitive function [22]. Furthermore, research on lighting has mainly been about the visual aspects of light. Accordingly, despite the studies conducted on cognitive processes and the importance of attention to these functions, the effects of heat and light color temperature on the cognitive functions of precision and speed, due to their role in errors and incidents, are rarely addressed. Therefore, this study aimed to determine the effects of exposure to different levels of heat and lamps with different color temperatures in a controlled laboratory environment on the precision and speed of female students.

2. Materials and Methods

The present interventional study was performed in 2020 on 10 female students of Isfahan University of Medical Sciences with an average age of 20-30 years. The number of samples tested was selected based on studies performed by Mac, Corbet, and Okamoto, i.e., conducted on 8 women, 9 office staff, and 8 subjects, respectively. We intended to investigate the effects of color temperature on consciousness and cognitive function [22-24].

The study samples were selected by the convenience sampling method in this study. The inclusion criteria were the lack of uncorrected visual impairment, no history of cardiac drug use, hypoglycemic, antidepressant, sedative, and other drugs, and no history of cardiovascular disease and sleep disorders. Besides, the exclusion criterion was an unwillingness to continue cooperation [8].

All experiments were performed in a chamber with controlled weather conditions. The chamber was intended for 3 in 4 experiments with a height of 2.8 meters; it was equipped with an intelligent cooling and heating system. Inside the room, an ergonomic table and chair were installed for the participant to sit on. The location of the LED lamps with a power of 100 watts and the color temperature of 3000°K and 6000°K was considered according to the position of the subjects to provide a light intensity of 500 lux. Beheshti et al. explored the



effects of light color temperature on selective attention, error rate, and reaction time. Accordingly, the relevant results suggested an increased correct response in using light with a color temperature of 6500, compared to 3500; two-color temperatures of 3000°K and 6000°K were selected for comparison [25].

Electric radiators and heaters were applied to regulate the dry temperature. Besides, suction blowing fans installed in the chamber were implemented in case of temperature change. Piron v-vibrometer and precision and target vibrometer were used to measure precision and speed. The v-piron vibrometer has two metal branches with an angle, i.e., calibrated, and the individual must move the metal pen between this angle without hitting its wall. In the case of hitting, an error is calculated; the number of errors indicates precision, and the test time indicates the speed. In the precision and objective vibrometer, the subject must insert and remove the metal pin in the holes from the most significant hole to the smallest gap, respectively. In this test, hitting the pen with the wall of the holes is considered an error [8]. The chamber temperature was measured with the WBGT Cassella model made in England to ensure the same environmental conditions. The color temperature of 3000°K and 6000°K was measured with a Kelvin meter.

Considering the Coronavirus Disease 2019 (COV-ID-19) pandemic, the respiratory mask was delivered to them while disinfecting all surfaces, tools, and devices before entering the room. Their hands were disinfected, and a digital thermometer measured their body temperature, and if the body temperature was higher than 37.7°C, the subjects were not allowed to enter. Then, the study subjects entered a room outside the atmospheric chamber. While fully explaining how to perform the test, a written informed consent form was delivered to the participants and after completion. Furthermore, they were given 30 minutes of rest to return the physiological parameters of the individuals to their normal state. During that time, individuals were served with sweet substances to help quickly return this cycle. All tests were performed in the morning and from 9 AM to 10 AM. The trial was held in 4 rounds, each 1 hour. The first turn, 22°C, and color temperature 3000°K, the second turn 22°C and color temperature 6000°K, the third turn 36°C and color temperature 3000°K and the fourth turn 36°C and color temperature 6000°K, adjusted.

Each one-hour shift was divided into four 15-minute periods. At the end of every 15 minutes, the participant began to perform the test with the examiner's command. The researcher recorded the number of mistakes made (precision measurement) and the duration of the test (speed measurement). To describe and analyze the obtained data, SPSS v. 25 was used. To illustrate the data from the central indicators and dispersion and for analysis using the Wilcoxon test. Furthermore, the relationship between exposure to color temperature and heat was evaluated in different modes.

3. Results

The Mean±SD age, weight, and Body Mass Index (BMI) of the study participants were measured as 25.3 ± 1.3 years, 60.5 ± 5.2 kg, and 21.4 ± 1.6 kg/m2, respectively. The mean and standard deviation values of the number of errors of individuals as the precision of work are shown in Table 1.

After using the Kolmogorov-Smirnov test to determine the distribution type and achieve the value (P < 0.05) to analyze the data, the Wilcoxon non-parametric test was used to investigate the relationship between the intensity of exposure to color temperature and heat in different conditions.

Based on the results, precision measurement and target vibrometer were significant in two cases with a color temperature of 3000 and temperatures of 22°C and 36°C (P<0.05). Moreover, no significant relationship was observed in other cases (P<0.05). These results are presented in Tables 2 and 3.

The Mean±SD values of test time as the speed of work are presented in Table 4. Based on the relevant results, speed measurement with precision and target vibrometer and piron v were significant at a color temperature of 6000°C and 22 and 36°C and color temperature of 3000°C and 22°C and 36°C (P<0.05). No significant relationship was observed (P<0.05). These results are listed in Tables 2 and 3.

4. Discussion

Heat is among the major risk factors affecting cognitive functions, such as reducing individuals' precision and reaction time [8, 26]. Exposure to different types of light can also alter the cognitive functions of individuals in addition to changes in circadian rhythms and mood [14]. Maintaining and managing cognitive functions is vital for employees. This is because it plays a prominent role in accidents caused by human error [10]. Therefore, this study investigated the combined effects of heat and color temperature on the precision and speed of 10 female students of Isfahan University of Medical Sciences



Table 1. Mean±SD frequency of errors of individuals when performing Piron v-vibrometer and precision and target vibrometer tests

Tests	Mean±SD			
Experiment Modes	Precision and Target Vibrometer	Piron v		
Color temperature 6000 and temperature 36°C	2.8±9.5	1.45±3.6		
Color temperature 3000 and temperature 36°C	2.5±9.33	1.5±3.5		
Color temperature 3000 and temperature 22°C	0.93±6.22	0.79±2.8		
Color temperature 6000 and temperature 22°C	3.22±8.03	1.24±3.1		
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Table 2. Significance level of difference in mean precision and speed at fixed temperatures and temperatures of different colors

Parameter	Precision				Speed			
	Temperature 22°C		Temperature 36°C		Temperature 22°C		Temperature 36°C	
Tests	Color temperature 3000	Color temperature 6000	Color temperature 3000	Color temperature 6000	Color temperature 3000	Color temperature 6000	Color temperature 3000	Color temperature 6000
Precision and target vibrometer	86	5.0	148.0		438.0		567.0	
Piron v	69	8.0 365.0		121.0		877.0		
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in laboratory conditions. The present study results indicated that increasing the heat from 22°C to 36°C reduces work time; thus, it increases work speed, and the temperature of different colors can not change the result. Habibi et al., in 2016, determined the effects of heat intervention on the precision and speed of work in men using a set of job skills assessment tests in the laboratory. They concluded that temperature increase does not affect work speed, i.e., not consistent with the present study results. In explaining this finding, we can point to the difference between the sexes of the samples in the two studies and the number of samples. Other study results included increasing the frequency of errors; thus, reducing the precision of work due to increasing temperature. The results are consistent with the study of Naserpour et al. in 2014. Their analysis was performed on 33 individuals. Their results signified a decrease in cognitive functions in the face of 33°C, compared to 29°C, 22°C, and 18°C. Moreover, a 2017 study by Mazlumi et al. identified heat stress as affecting the increasing levels of stress hormones, causing cognitive dysfunction [7, 26].

Table 3. Significance level of difference in mean precision and speed at fixed color temperatures and different temperatures

Parameter	Precision			Speed				
Tasta	Light color temperature 3000°K		Light color temperature 6000°K		Light color temperature 3000°K		Light color temperature 6000°K	
Tests	temperature 22°C	temperature 36°C	temperature 22°C	temperature 36°C	temperature 22°C	temperature 36°C	temperature 22°C	temperature 36°C
Precision and target vibrometer	0.0	009	0.407		0.005		0.028	
Piron v	0.2	249	0.281		0.006		0.020	
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Tests	Mean±SD			
Experimental modes	Precision and target vibrometer	Piron v		
Color temperature 6000 and temperature 22°C	12.06±5.2	6.61±3.46		
Color temperature 3000 and temperature 22°C	11.45±3.11	5.8±2.4		
Color temperature 3000 and temperature 36°C	6.62±1	3.7±1.22		
Color temperature 6000 and temperature 36° C	6.73±1.02	3.7±1.5		
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Table 4. Mean±SD values of the test time as the speed of work when performing the precision and target vibrometer tests and v piron

Moreover, in a 2016 study on 19 firefighters, William reported decreased cognitive function when individuals increased body temperature to 38.5°C due to increased complexity of activity [27]. In 2019, Costello et al. investigated the effects of heat stress on cognitive function in 12 men. Accordingly, they concluded that the heat did not affect accuracy. This finding is inconsistent with those of the present study. The difference in the sex of the samples and the tools and methods of testing may be the cause of this difference [6].

After examining the effect of 3000°K and 6000°K color temperatures on cognitive functions, no significant relationship was observed between the precision and speed of work in the face of different color temperatures. This result was in contract with the study of Amoozadeh et al. in 2018; it was conducted to investigate the effect of cold and hot light of LED lamps on the typing performance of 24 students. In Amoozadeh's study, students' typing was measured in two conditions of the color temperature of 3000°K and 4000°K. The reason for the discrepancy is the difference in the tools and methods of testing [20].

In a 2015 study, Hong examined the effect of color temperatures of 2700°K, 4300°K, and 6500°K on sustained attention. The color temperature of 4300°K caused considerable sustained attention. It seems that the color temperature of 4000°K, compared to 3000°K and 6000°K, has a positive and significant effect on cognitive functions [17].

In the study of Mills et al., a significant improvement in individuals' well-being, alertness, and work performance when using lamps with a color temperature of 17000°K, compared to 2900°K, was observed [16]. This result is inconsistent with the present study, which could be due to the large amount of color temperature used in the Mills study. In the present study, the experiments were performed in autumn and morning. This has probably contributed to the lack of significance in the results of color temperature change. In a study, light effects were observed only when participants

were tested in the spring and afternoon, and no effects were reported in the fall or the morning, indicating a change in participants' sensitivity to the effects of color temperature change; it can be due to differences in melatonin levels at different times of the day or the extent of sun exposure [14].

5. Conclusion

The present study data revealed that the effect of heat on the cognitive functions of individuals is more important than environment color temperature. In warm environments, improving the color temperature of lamps cannot significantly affect the cognitive functions of individuals. Therefore, in environments with temperatures above the comfort level, maintaining the speed, precision, and cognition of individuals is essential. It is recommended to design and implement control strategies to reduce the temperature. One of the study's limitations is the lack of access to students due to the spread of coronavirus and the need to follow health protocols. In this study, only the combined effect of heat and color temperature on the speed and precision of work in females was investigated, which is another limitation of this study. Therefore, it is suggested that in future studies to determine the exact effect of simultaneous exposure to heat and color temperature on the speed and precision of work, this method with more participants and the presence of both sexes, to be repeated and compared the results with the present study.

Ethical Considerations

Compliance with ethical guidelines

The Ethics Committee approved this study of Isfahan University of Medical Sciences (Code: IR.MUI.RE-SEARCH.REC.1398.407).

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Authors' contributions

Conceptulization and supervision: Ehsanollah Habibi; Methodology: Habibollah Dehghan; Investigation and writing: Mahsa Jahadi Naeini; Data collection: Mahsa Jahadi Naeini, Parnian Illbag; Data analysis: Seyed Mahdi Mousavi; Review & Editing: Seyed Mahdi Mousavi, Mahsa Jahadi Naeini.

Conflict of interest

The authors declared no conflicts of interest.

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