Effect of Environmental Temperature on Working Memory in Military Personnel

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Abstract

Background: Working memory is one of the essential cognitive functions. Achieving the highest cognitive performance is especially important in critical jobs such as military and crisis management-related jobs. The thermal environment can cognitive functions. Humans have different thermal sensations in the same fixed temperature environments.

Objectives: This study was conducted to determine the effect of thermal environment and thermal sensation on working memory.

Methods: Each of 20 male adult participants, physically and mentally healthy aged 19 - 29 years, experienced seven thermal conditions (office room climate: 14°C, 17°C, 20°C, 23°C, 26°C, 29°C, and 32°C) over four months. Before the test, they waited 40 minutes in the room for adaptation. The thermal sensation questions were asked from them, and working memory was measured with the n-back test.

Results: In this experiment, 140 working memory data were collected. The relationship between air temperature and working memory was significant in two of six conditions. The relationship between thermal sensation and working memory was significant in all six conditions. Participants had various thermal sensations in the same fixed thermal environment.

Conclusions: Thermal sensation significantly affected the working memory of the environment users. Working memory was more related to changes in people's thermal sensation than changes in ambient temperature. Adjusting the ambient temperature based on the user’s thermal sensation increases cognitive performance and prevents working memory loss.

Keywords: Working Memory, Thermal Environment, Thermal Sensation

1. Background

Work-related accidents are among the most critical reasons for morbidity and mortality worldwide. The International Labor Organization reported that at least 1.9 million people die from work-related accidents, and 90 million years of life are estimated for people with disabilities caused by occupational accidents (1). Studying major events such as the Three Mile Island in the United States, Bhopal in India, Chornobyl in the former Soviet Union, and thousands of other incidents shows that in more than 70% of accidents, unsafe behaviors and human errors have been the critical factors (2, 3). Human errors often result from reduced focus, attention, and working memory.

The increasing complexity of today's industrial and military systems has significantly imposed a mental workload and increased pressure on human labor (4), increasing the likelihood of human error. Since preventing human error is essential, studying cognitive functions under different thermal conditions is significant for determining workplace design parameters in environments where most work is cognitive.

Previous studies show that the thermal environment is often associated with cognitive functions (5-7). Achieving the highest cognitive performance is especially important in critical jobs such as military jobs, rescue teams, or crisis management-related jobs, as military personnel may work in environments with extra hot or extra cold temperatures.

In this research, we studied the effect of the thermal environment on working memory as one of the cognitive functions. Working memory is a cognitive system with a limited capacity. This system can hold information temporarily and for a limited time (8). Active memory is essential for guiding decisions, reasoning, and behavior (9, 10). Research about the effect of environmental temperature on memory has shown mixed results. In some cases, the researchers found a relationship between temperature...
and memory (11-13), and in some other cases, no significant results were found (14-17). Since in previous studies, the relationship between thermal sensation (18, 19) and its effect on cognitive functions were assessed, this issue was also examined in this study. People in a stable temperature environment have different thermal sensations due to individual differences such as age, gender, basal metabolic rate, type of clothing, and metabolic rate.

2. Objectives

This research investigated the effect of environmental temperature and thermal sensation on working memory.

3. Methods

There were 20 adult participants physically and mentally healthy aged 19 - 29 years. Due to the effect of the menstrual cycle on thermal sensation and its consequences, and as the test time lasted more than a month, female subjects were not included in this study. The participants’ demographic information, including gender, height, and body weight, is summarized in Table 1. Individuals with a history of neuropsychiatric diseases such as attention deficit, brain damage, and epilepsy or who were currently taking medication for these mental disorders were excluded from the study. Since the working memory in this experiment was measured with a computer test, all participants were familiar with the computer. There was also a single pattern to cover participants (underwear, T-shirts, pants, ankle boots, and shoes). All experiments were conducted during the daytime. The order of experiments and the time pattern were balanced among the subjects, as shown in Table 2.

All 20 subjects experienced seven conditions (office room climate at seven temperatures of 14°C, 17°C, 20°C, 23°C, 26°C, 29°C, and 32°C) over four months, and each subject was exposed to two conditions per day. Features of the office are shown in Figure 1. All experiments were conducted during the daytime. The participants moved to the office room climate, and their electrodes were connected to a computer. They waited 40 minutes before the test in the room for adaptation and to practice the working memory test. Then, the thermal sensation questions were asked from them. The ASHRAE scale was used to measure the thermal sensation. This scale has seven points, namely, “hot,” “warm,” “slightly warm,” “neutral,” “slightly cool,” “cool,” and “cold.” In this step, the working memory was measured with the n-back test. The mentioned time divisions are presented in Figure 2.

In the n-back test, the subject must determine from a series of stimuli when one stimulus matches the stimulus of the previous n set. This test has three cognitive levels (n = 1 means low workload, n = 2 means medium workload, and n = 3 means high workload). Kirchner introduced this test in 1958 for the first time (20). In recent years, this test has been widely used in various studies to measure working memory (21-23). The institute of behavioral and cognitive science changed this test to the Farsi model in 2014 (24).

4. Results

4.1. Working Memory and Environmental Temperature

Finally, 140 working memory data were reported for 20 participants in seven conditions. The relationship between the ambient temperature and working memory was investigated in seven temperatures. All 21 conditions for comparison are shown in Table 3. The results were significant in eight cases (between 14°C and 20°C, 14°C and 23°C, 14°C and 29°C, 17°C and 32°C, 20°C and 29°C, 20°C and 32°C, 23°C and 32°C, 26°C and 32°C). No significant results were reported for the other 13 conditions.

To achieve more precise results, we divided the temperature conditions into four groups: Extremely hot and extremely cold (14°C, 32°C), hot and cold (29°C, 17°C), mild (20°C, 26°C), and natural (23°C). In these conditions, as seen in Table 4, the changes in working memory between extreme temperatures (14°C, 32°C) and two conditions (20°C and 23 - 26°C) were significant. In the other conditions, the relationships were not significant.

4.2. Working Memory and Thermal Sensation

The relationship between thermal sensation and working memory was investigated. The participants selected one item from seven options describing their thermal sensation after 40 minutes in the office room climate. All 21 conditions for comparison are shown in Table 5. The results were significant in 19 cases and insignificant in two cases (between cool and warm and between slightly cool and slightly warm).

To achieve more precise results, we divided thermal sensation into four groups: Cold and hot, cool and warm, slightly cool and slightly warm, and neutral. In these conditions, as seen in Table 6, the relationships between working memory and thermal sensation of participants in the different thermal environments were significant all the time.
Table 1. Demographic Information of the Individuals

| Variable | Count | Age (y) | Height (cm) | Weight (kg) |
|----------|-------|---------|-------------|-------------|
| Value    | 20    | 24.5    | 179.7       | 79.4        |

Table 2. Order of the Experiments for Each Subject

| Subject | First Time | Second Time | Third Time | Fourth Time | Fifth Time | Sixth Time | Seventh Time |
|---------|------------|-------------|------------|-------------|------------|------------|--------------|
| 1       | 14         | 17          | 20         | 23          | 26         | 29         | 32           |
| 2       | 17         | 20          | 23         | 26          | 29         | 32         | 14           |
| 3       | 20         | 23          | 26         | 29          | 32         | 14         | 17           |
| 4       | 23         | 26          | 29         | 32          | 14         | 17         | 20           |
| 5       | 26         | 29          | 32         | 14          | 17         | 20         | 23           |
| 6       | 29         | 32          | 14         | 17          | 20         | 23         | 26           |
| 7       | 32         | 14          | 17         | 20          | 23         | 26         | 29           |
| 8       | 14         | 17          | 20         | 23          | 26         | 29         | 32           |
| 9       | 17         | 20          | 23         | 26          | 29         | 32         | 14           |
| 10      | 20         | 23          | 26         | 29          | 32         | 14         | 17           |

Table 3. Relationship Between Working Memory and Environmental Temperature in 21 Conditions

| Thermal Sensation (°C) | P Value |
|------------------------|---------|
| 14°C                   |         |
| 17°C                   | 0.511   |
| 20°C                   | 0.13    |
| 23°C                   | 0.009   |
| 26°C                   | 0.059   |
| 29°C                   | 0.042   |
| 32°C                   | 0.951   |
| 17°C                   |         |
| 20°C                   | 0.644   |
| 23°C                   | 0.060   |
| 26°C                   | 0.072   |
| 29°C                   | 0.620   |
| 32°C                   | 0.044   |
| 20°C                   |         |
| 23°C                   | 0.851   |
| 26°C                   | 0.14    |
| 29°C                   | 0.033   |
| 32°C                   | 0.007   |
| 23°C                   |         |
| 26°C                   | 0.722   |
| 29°C                   | 0.052   |
| 32°C                   | 0.045   |
| 26°C                   |         |
| 29°C                   | 0.073   |
| 32°C                   | 0.022   |
| 29°C                   |         |
| 32°C                   | 0.065   |

4.3. Environment Temperature and Thermal Sensation

Figure 3 examines participants’ thermal sensations at different ambient air temperatures. Neutral heat sensation was reported by the participants from 20°C to 29°C. Except for “hot” and “cold” thermal sensations, which were reported twice at extra high or low temperatures, the rest of the thermal sensation options were reported at three or four different temperatures. The greatest variability of response in thermal sensation was reported at 23°C, 26°C, and 29°C (four types of response).

5. Discussion

Thermal sensation and environmental temperature can show different results. People's thermal sensation results from a balance between 2 items, the sensory data from thermal receptors on the human skin caused by environment temperature and the internal body condition. After receiving from skin receptors, the human thermoregulatory system maintains the body’s internal temperature...
with the help of the body's nervous system and determines the body's sense of heat and physiological state (25). The diverse responses to the thermal sensation at the same temperatures indicate that humans have different thermal needs and explain the differences in cognitive function changes for different participants at constant temperatures. Since different people feel “neutral” at different temperatures, we cannot expect all people to have the best cognitive function at a constant temperature. In addition, considering that people have a “hot” or “cold” sensation
in relation to the environment at different temperatures, it can be realized that their cognitive functions can be most damaged at different temperatures. As Table 4 shows, changes in individuals’ working memory at different temperatures were significant only in comparison with temperature ranges with high distances (14 - 32°C with 20°C and 23 - 26°C). In extreme temperatures such as 32°C and 14°C, everyone feels intense heat and cold, but no significant difference was observed in temperatures closer to each other.

However, all relationships were significant in examining the effect of thermal sensation reported by individuals on their working memory (Table 6). This shows that humans’ thermal sensation is not completely consistent with ambient temperatures and working memory has a more significant relationship with thermal sensation than ambient temperature. Building heating and cooling systems with fixed and predetermined temperature settings do not have the required efficiency and do not lead to high satisfaction and the best work efficiency for space users. Therefore, systems with fixed, predetermined settings for controlling environmental temperature may not have the required efficiency. A flexible thermal environment can have better consequences for its occupants. Recent research has a great deal of emphasis on user-based systems. Adjustment of a set point based on occupants’ feedback, using personal equipment to create thermal comfort, and using physiological data of residents can be the most efficient approaches to reach the best cognitive performance with an emphasis on the occupants. Therefore, many approaches have been proposed for station-oriented systems. The use of personal equipment that creates a microclimate next to people, such as heated and cooled chairs (26), floor fans (27), and ceiling fans (28), can increase the temperature range around the person from 15°C to 30°C (29), allowing people to change the thermal environment to the condition with appropriate thermal sensation for them.

5.1. Conclusions

According to experiments, the thermal sensation of humans affects their working memory more than the ambient temperature. The significant relationship between thermal sensation and working memory in all six cases studied indicates that thermal sensation can be essential in determining the ambient temperature to achieve the highest cognitive performance and maximum working memory in individuals. Since the relationship between working memory and ambient temperature was significant in two of the six general cases studied, it is impossible to determine a specific ambient temperature for all people.
Table 5. Relationship Between Working Memory and Thermal Sensation in 21 Conditions

| Thermal Sensation | P Value |
|-------------------|---------|
| Cold | |
| Cool | 0.031 |
| Slightly cool | 0.006 |
| Neutral | 0.001 |
| Slightly warm | 0.030 |
| Warm | 0.042 |
| Hot | 0.020 |
| Cool | |
| Slightly cool | 0.045 |
| Neutral | 0.003 |
| Slightly warm | 0.010 |
| Warm | 0.120 |
| Hot | 0.025 |
| Slightly cool | |
| Neutral | 0.002 |
| Slightly warm | 0.048 |
| Warm | 0.004 |
| Hot | |
| Neutral | |
| Slightly warm | 0.012 |
| Warm | 0.002 |
| Hot | 0.002 |
| Slightly warm | |
| Warm | 0.003 |
| Hot | 0.031 |
| Hot | 0.045 |

Table 6. Relationship Between Working Memory and Thermal Sensation in 6 Conditions

| Thermal Sensation | P Value |
|-------------------|---------|
| Cold and hot | |
| Cool and warm | 0.03 |
| Slightly cool and slightly warm | 0.006 |
| Neutral | 0.0002 |
| Cool and warm | |
| Slightly cool and slightly warm | 0.003 |
| Neutral | |
| Slightly cool and slightly warm | |
| Neutral | 0.003 |

If a certain temperature is set for all humans, some of them will not be in appropriate condition.

Footnotes

Authors’ Contribution: Study concept and design: Esmaeil Zarghami, Faezeh Dadras, Nafiseh Hoseini Yekta, and Seyed Abas Zarghami; acquisition of data: Faezeh Dadras; analysis and interpretation of data: Faezeh Dadras, Esmaeil Zarghami, and Nafiseh Hoseini Yekta; drafting of the manuscript: Faezeh Dadras; revising of the manuscript for important intellectual content: Seyed Abas Yazdanfar; statistical analysis: Faezeh Dadras; administrative, technical, and material support: Faezeh Dadras; study supervision: Esmaeil Zarghami, Nafiseh Hoseini Yekta, and Seyed Abas Zarghami.

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