J Arch Mil Med. 2022 September; 10(3):e128528. https://doi.org/10.5812/jamm-128528.

Published online 2022 September 14. **Research Article**

Effect of Environmental Temperature on Working Memory in Military Personnel

Esmaeil Zarghami [1], Seyed Abbas Yazdanfar [2], Nafiseh Hosseini Yekta [3] and Faezeh Dadras [1,*]

[1]Department of Architecture, Shahid Rajaee Training University, Tehran, Iran
[2]Department of Architecture, Iran University of Science and Technology, Tehran, Iran
[3]Department of Persian Medicine, School of Medicine, AJA University of Medical Sciences, Tehran, Iran

[*]*Corresponding author*: Department of Architecture, Shahid Rajaee Training University, Tehran, Iran. Email: faeze_dadras@yahoo.com

Received 2022 June 18; **Accepted** 2022 August 09.

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.

Table 1. Demographic Information of the Individuals

Count	Age (y)	Height (cm)	Weight (kg)
20	24.5	179.7	79.4

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).

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

Relationship Between Working Memory and Thermal Sensation	
Thermal Sensation (°C)	**P Value**
14°C	
17	0.511
20	0.03
23	0.009
26	0.590
29	0.042
32	0.951
17°C	
20	0.644
23	0.060
26	0.072
29	0.620
32	0.044
20°C	
23	0.851
26	0.14
29	0.033
32	0.007
23°C	
26	0.722
29	0.052
32	0.045
26°C	
29	0.073
32	0.022
29°C	
32	0.065

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 4. Relationship Between Working Memory and Environment Temperature in Six Conditions

Relationship Between Working Memory and Thermal Sensation	
Thermal Sensation (°C)	**P Value**
14 - 32°C	
17 - 29	0.23
23 - 26	0.04
20	0.011
17 - 29°C	
23 - 26	0.62
20	0.089
23 - 26°C	
20	0.80

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

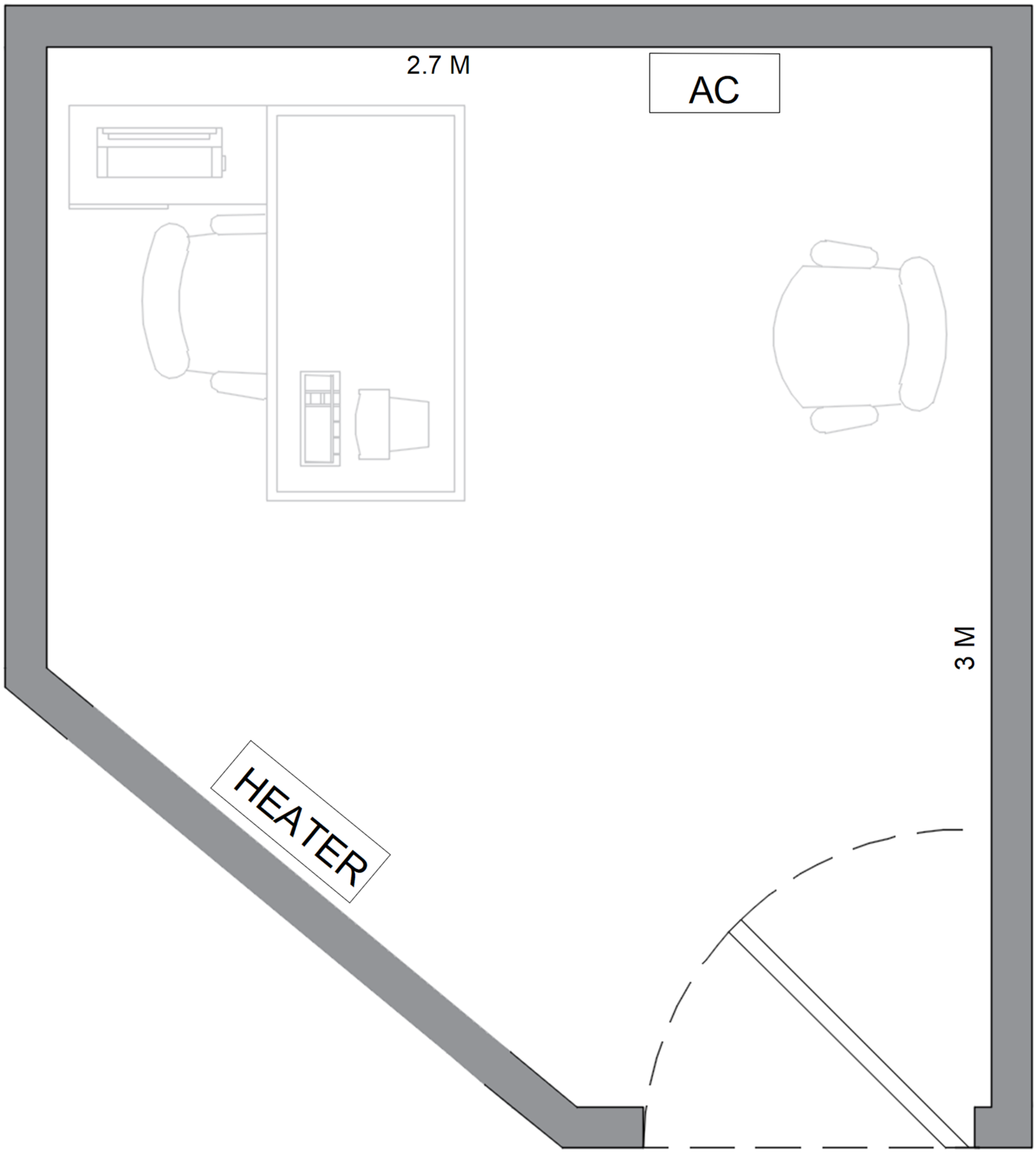

Figure 1. Office layout

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

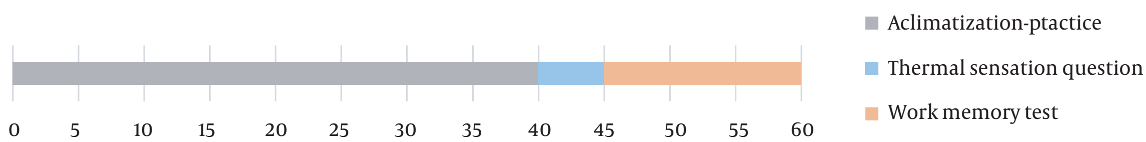

Figure 2. Experimental timeline

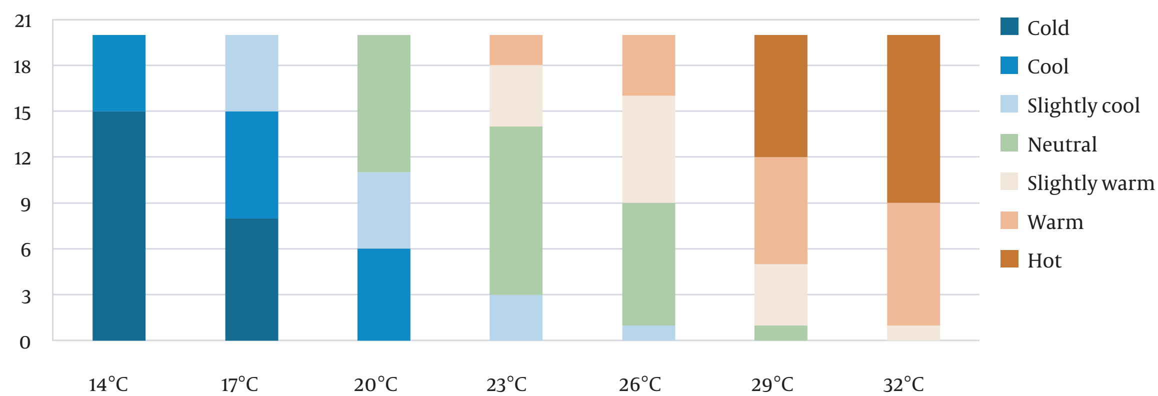

Figure 3. Relationship between environmental temperature and thermal sensation

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

Table 5. Relationship Between Working Memory and Thermal Sensation in 21 Conditions

Relationship Between Working Memory and Thermal Sensation	
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	0.48
Warm	0.048
Hot	0.004
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

Relationship Between Working Memory and Thermal Sensation	
Thermal Sensation	**P Value**
Cold and hot	
Cool and warm	0.03
Slightly cool and slightly warm	0.006
Neutral	0.0012
Cool and warm	
Slightly cool and slightly warm	
Neutral	0.003
Slightly cool and slightly warm	
Neutral	

impossible to determine a specific ambient temperature for all people. 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; critical revision 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.

Conflict of Interests: The authors declare that they have no conflict of interest.

Data Reproducibility: The dataset presented in the study is available on request from the corresponding author during submission or after publication.

Funding/Support: It was not declared by the authors.

References

1. International Labour Organization. *Safety and Health at Work*. Geneva: International Labour Organization; 2022. Available from: https://www.ilo.org.
2. Shaw A, Bluett V, Hopkins A. Behaviour Based Safety Programs. *ACTU Seminar*. May 2005; Melbourne, Australia. Maritime Union of Australia; 2005.
3. Mital A, Kilbom Å, Kumar S. *Ergonomics Guidelines and Problem Solving*. Oxford: Elsevier; 2000.
4. Meshkati N; Hancock. *Human mental workload*. Amsterdam: North-Holland; 1988.
5. Racinais S, Gaoua N, Mtibaa K, Whiteley R, Hautier C, Alhammoud M. Effect of Cold on Proprioception and Cognitive Function in Elite Alpine Skiers. *Int J Sports Physiol Perform*. 2017;**12**(1):69–74. [PubMed ID: 27080805]. https://doi.org/10.1123/ijspp.2016-0002.
6. Watkins SL, Castle P, Mauger AR, Sculthorpe N, Fitch N, Aldous J, et al. The effect of different environmental conditions on the decision-making performance of soccer goal line officials. *Res Sports Med*. 2014;**22**(4):425–37. [PubMed ID: 25295479]. https://doi.org/10.1080/15438627.2014.948624.
7. Sun C, Han Y, Luo L, Sun H. Effects of air temperature on cognitive work performance of acclimatized people in severely cold region in China. *Indoor Built Environ*. 2020;**30**(6):816–37. https://doi.org/10.1177/1420326x20913617.
8. Miyake A, Shah P. *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*. Cambridge: Cambridge University Press; 1999. https://doi.org/10.1017/cbo9781139174909.
9. Diamond A. Executive functions. *Annu Rev Psychol*. 2013;**64**:135–68. [PubMed ID: 23020641]. [PubMed Central ID: PMC4084861]. https://doi.org/10.1146/annurev-psych-113011-143750.
10. Nestler EJ, Hyman SE, Malenka RC. *Molecular Neuropharmacology: A Foundation for Clinical Neuroscience*. New York: McGraw-Hill Medical; 2009.
11. Geng Y, Ji W, Lin B, Zhu Y. The impact of thermal environment on occupant IEQ perception and productivity. *Build Environ*. 2017;**121**:158–67. https://doi.org/10.1016/j.buildenv.2017.05.022.

12. Cui W, Cao G, Park JH, Ouyang Q, Zhu Y. Influence of indoor air temperature on human thermal comfort, motivation and performance. *Build Environ*. 2013;**68**:114–22. https://doi.org/10.1016/j.buildenv.2013.06.012.
13. Muller MD, Gunstad J, Alosco ML, Miller LA, Updegraff J, Spitznagel MB, et al. Acute cold exposure and cognitive function: evidence for sustained impairment. *Ergonomics*. 2012;**55**(7):792–8. [PubMed ID: 22506538]. [PubMed Central ID: PMC3375336]. https://doi.org/10.1080/00140139.2012.665497.
14. Zhang F, Haddad S, Nakisa B, Rastgoo MN, Candido C, Tjondronegoro D, et al. The effects of higher temperature setpoints during summer on office workers' cognitive load and thermal comfort. *Build Environ*. 2017;**123**:176–88. https://doi.org/10.1016/j.buildenv.2017.06.048.
15. Cui W, Cao G, Ouyang Q, Zhu Y. Influence of dynamic environment with different airflows on human performance. *Build Environ*. 2013;**62**:124–32. https://doi.org/10.1016/j.buildenv.2013.01.008.
16. Maula H, Hongisto V, Ostman L, Haapakangas A, Koskela H, Hyona J. The effect of slightly warm temperature on work performance and comfort in open-plan offices - a laboratory study. *Indoor Air*. 2016;**26**(2):286–97. [PubMed ID: 25866136]. https://doi.org/10.1111/ina.12209.
17. Makinen TM, Palinkas LA, Reeves DL, Paakkonen T, Rintamaki H, Leppaluoto J, et al. Effect of repeated exposures to cold on cognitive performance in humans. *Physiol Behav*. 2006;**87**(1):166–76. [PubMed ID: 16309719]. https://doi.org/10.1016/j.physbeh.2005.09.015.
18. Kim M, Chong SC, Chun C, Choi Y. Effect of thermal sensation on emotional responses as measured through brain waves. *Build Environ*. 2017;**118**:32–9. https://doi.org/10.1016/j.buildenv.2017.03.023.
19. Salehi B, Ghanbaran AH, Maerefat M. Intelligent models to predict the indoor thermal sensation and thermal demand in steady state based on occupants' skin temperature. *Build Environ*. 2020;**169**:106579. https://doi.org/10.1016/j.buildenv.2019.106579.
20. Kirchner WK. Age differences in short-term retention of rapidly changing information. *J Exp Psychol*. 1958;**55**(4):352–8. [PubMed ID: 13539317]. https://doi.org/10.1037/h0043688.
21. Abbasi AM, Motamedzade M, Aliabadi M, Golmohammadi R, Tapak L. The impact of indoor air temperature on the executive functions of human brain and the physiological responses of body. *Health Promot Perspect*. 2019;**9**(1):55–64. [PubMed ID: 30788268]. [PubMed Central ID: PMC6377698]. https://doi.org/10.15171/hpp.2019.07.
22. Chen YN, Mitra S, Schlaghecken F. Sub-processes of working memory in the N-back task: an investigation using ERPs. *Clin Neurophysiol*. 2008;**119**(7):1546–59. [PubMed ID: 18448388]. https://doi.org/10.1016/j.clinph.2008.03.003.
23. Jaeggi SM, Buschkuehl M, Perrig WJ, Meier B. The concurrent validity of the N-back task as a working memory measure. *Memory*. 2010;**18**(4):394–412. [PubMed ID: 20408039]. https://doi.org/10.1080/09658211003702171.
24. Khodadadi M, Amini H. *[N-back software]*. Tehran: Institute for Behavioral and Cognitive Science; 2014, [cited 2022]. Persian. Available from: https://www.sinapsycho.com/.
25. Ugursal A, Culp C. Gender differences of thermal comfort perception under transient environmental and metabolic conditions. *ASHRAE Trans*. 2013;**119**(2).
26. Pasut W, Zhang H, Arens E, Kaam S, Zhai Y. Effect of a heated and cooled office chair on thermal comfort. *HVAC&R Res*. 2013;**19**(5):574–83. https://doi.org/10.1080/10789669.2013.781371.
27. Zhai Y, Zhang H, Zhang Y, Pasut W, Arens E, Meng Q. Comfort under personally controlled air movement in warm and humid environments. *Build Environ*. 2013;**65**:109–17. https://doi.org/10.1016/j.buildenv.2013.03.022.
28. Pasut W, Arens E, Zhang H, Zhai Y. Enabling energy-efficient approaches to thermal comfort using room air motion. *Build Environ*. 2014;**79**:13–9. https://doi.org/10.1016/j.buildenv.2014.04.024.
29. Veselý M, Zeiler W. Personalized conditioning and its impact on thermal comfort and energy performance – A review. *Renew Sustain Energy Rev*. 2014;**34**:401–8. https://doi.org/10.1016/j.rser.2014.03.024.