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The Impact of Indoor Environment on Engineering Students' Inhibition Control Ability

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ABSTRACT

Inhibition control is one of the executive functions identified as the process by which goals influence prepotent response tendency. Most of the engineering courses include problem solving activities, and it has been proven that cognitive inhibition abilities improve students' performance. So, understanding the factors that can enhance interference control skills is highly valuable in education.

The Stroop task was designed to investigate interference control by evaluating how incongruent conditions can increase response time (RT), called the Stroop effect. In this study, we investigate the impact of indoor temperature (20° C, 24.40° C, and 26° C) on interference control ability using Event-Related Potential (ERP) studies. Ten engineering students from the University of Oklahoma performed Stroop/reverse Stroop tasks using Neurobs' Presentation (Neurobehavioral Systems, Inc., Albany, CA). The ERP components related to the Stroop effect and the anatomical location of the topographic scalp maps were evaluated.

The prefrontal network is active during the process, with one exception. N100-N200 components with higher amplitudes are related to the selective attention observed in this study in all three thermal conditions. The statistical analysis showed a significant impact of the thermal condition on response time in the incongruent condition presented by the Stroop test and general incongruent condition.

Keywords: Cognitive Inhibition, Engineering Education, ERP, Experimental design, Indoor environment, Stroop, Thermal condition

1. INTRODUCTION

Executive function is a collection of higher cognitive processes essential to coordinate and optimize different cognitive functions and behavior. Executive functions come into play when the ongoing mental processes need to be changed, resisted, or are unclear [1,2]. While there is an extensive list of executive functions and their subcomponents, three primary functions have been identified: working memory, inhibition control, and cognition flexibility. These functions were proposed primarily by Akira Miyake et al.in 2000 [3]. They discuss three basic diverse but the same time-related executive functions: updating, inhibition, and shifting. Updating is related to the Working memory function, which is the ability to maintain and update the related information. The inhibition controls behavior, thoughts, and emotion against external distractions and internal predispositions. Lastly, shifting is closely connected to cognitive flexibility and refers to the ability to shift back and forth between multiple tasks or mental sets and analyze the problem from different perspectives.

The concept of inhibition control is widely used in the psychology field as well. Response inhibition or self-control are psychological aspects of inhibition control and can be further divided into automatic and active inhibition. In neuroscience, however, interference control is generally used for the mental process of selective attention (concentration) and cognitive inhibition [4]. Various experimental paradigms have been employed to study inhibition control, with the Stroop paradigm being one of the most used [5]. The Stroop task was developed in 1935 by John Ridley Stroop and measures attention processing and controlled inhibition ability [6]. The Stroop effect involves the purposive inhibition process of an automatic learned response to environmental stimuli [7]. It is characterized by the longer reaction time (RT) when naming the ink color of an incongruent color–word pair (e.g., the word blue printed in green ink) compared to a matched color-word combination. The increased reaction time (RT) is the cognitive inhibition measurement criteria utilizing the Stroop task [5].

There are different versions of the Stroop task besides the classical one, including the reverse Stroop test, picture-word conflicts, counting Stroop test, and virtual reality Stroop task (VRST). In reversed Stroop task (word condition), participants should respond to the meaning of the word ignoring the congruent or incongruent physical color [8]. The Virtual Reality Stroop Task (VRST) is a high-dimensional cognitive assessment in which participants ride in a simulated vehicle along a desert road as cognitive Stroop stimuli are presented. VRST was developed and validated for the assessment of both cognitive [9,10] and affective [11] processing.

Previous Brain imaging studies have revealed the neural regions linked to the Stroop task with the prefrontal cortex and anterior cingulate cortex identified as the main activity areas [12,13,14]. The dorsolateral prefrontal cortex [15] and dorsal aspects of the anterior cingulate cortex [16] have been associated with cognitive inhibition during Stroop task performance [17,18]. In brain imaging studies using the Event-related potentials (ERP) technique, researchers are trying to identify the ERP components related to the Stroop effect and investigate factors that can impact the cognition inhibition process in the brain. ERPs (Event Related Potentials) are time-locked electroencephalogram (EEG) activities related to specific stimuli. EEG is one of the noninvasive neuroimaging techniques, recording changes in neurons' electrical activity through electrodes placed on the scalp. EEG signals are analyzed based on the amplitude, frequency, and electrode position. Mainly, they are classified into five separate groups based on their frequency, which includes:
δ (0.1–4 Hz), θ (4–7 Hz), α (8–13 Hz), β (13–30 Hz), and γ (30–45+ Hz). Each of them is associated with some specific physiological functions, for instance while delta band occurs in deep sleep, beta band is related to arousal state. ERPs, which are voltage fluctuations associated with specific events, are labeled based on their polarities (positive or negative), timing, and scalp distributions. For example, the N400 component has a negative potential (N) and peaks between 300-500 ms [7].

One of the earliest ERP studies investigating cognitive inhibition was conducted by Duncan-Johnson, and Kopell in 1981 [19]. They tried to differentiate whether the delayed response time is related to the stimulus comprehension or response-production stage. Their findings showed no differences in the latencies of the P300 traces in both congruent and incongruent conditions, but the RT to the incongruent stimulus was slower than the congruent ones. They argue that color and word evaluation happen apace with each other while the latency invariance due to the Stroop effect occurred after stimulus processing. Atkinson et al. [20] reported N100 and P100 components are related to the Stroop effect. N200 component relation to cognitive control effect is investigated by different studies and is thought to reflect specifically conflict monitoring [21,22], besides the Stroop effect. Negativity around 200ms has been reported with other inhibition control paradigms like Go/no go, Flanker, and Simon tasks [7].

Szücs and Soltesz [23] reported a negative peak between the 360 and 420 ms time interval due to incongruent conditions compared to congruent or neutral ones. Hanslmayr et al. [24] showed increased negativity around 400 ms, which is known to semantic procession, indicating the interference suppression in the Stroop task as the amplitude is higher in incongruent combinations than congruent or neutral ones. In contrast, some studies reported a late slow potential related to incongruent conditions [24,25]. Some studies also found an additional Centro-parietal positive deflection in the incongruent compared to the congruent condition and argued that it reflects the conflict resolution process or the following semantic reactivation of the meaning of the word [26,27].

Identifying the ERP components representing the Stroop effect, the ERP study is one of the most valuable functional studies helping to understand the cognitive inhibition process of the brain and the factors that can impact this ability. Understanding the factors affecting each level of cognitive skills is essential in the educational field, as the education goal is to create and elaborate these skills. Attention and response inhibition skills, for instance, have been shown to improve performance in courses involving problem-solving activities. In the engineering field, most courses, such as Thermodynamics, Engineering Computing, and almost all of the courses contain designing projects require problem solving abilities. Therefore, gaining a deeper understanding of the inhibition control process and the factors that affect it would be valuable.

Pedagogical studies do not primarily focus on constant factors such as age or developmental brain disorder. However, understanding the traits that have the potential to be controlled or regulated can significantly impact the learning process and human productivity. These factors can be divided into personal and environmental factors, which are somehow interrelated. The learning environment refers to the physical properties of the place where learning occurs, and the characteristics of the methods and materials used during the educational activity. These environmental attributes are listed but not limited to temperature, color, humidity, room light, noise, room volume, and presence of other people. Different studies have observed various environmental factors on different cognitive skill levels. In their paper, Lan et al. (2011) observed that attention, concentration, and motivation to perform the task are reduced due to a warm environment (30° C) compared to cooler temperatures (around 22℃) [28].

In their study, Doohan, Meg A., et al. (2022) reported that core body temperature did not affect congruent or incongruent inverse efficiency scores in the Stroop task [29]. Conversely, Mazloumi et al. [30] and Marathe et al. [31] provide evidence that heat stress impacts the incongruent combination in the Stroop task but not the neutral or congruent condition. They concluded that heat stress affects cognitive inhibition differently depending on the complexity level of the cognitive task. In complex tasks requiring more attention, heat stress affects cognitive performance more than less complex ones.

This study is designed to address the contradictory findings in the existing literature on the effects of the thermal condition of the learning environment on cognitive inhibition control. By investigating the role of the temperature on cognitive inhibition using the Stroop task, we aim to contribute to a further understanding of how environmental factors can impact cognitive skills.

2. MATERIALS AND METHODS

Ten participants (n=10) with normal or corrected to normal vision aged between 22-32 years old participated in this study. The participants were engineering students at mechanical engineering department of the University of Oklahoma. The EEG system used in this study was a 24-channel system from mBrainTrain. M1/2 is the reference electrode of the EEG system. The placement of the 24 electrodes followed the 10/20 international placement system (Figure 1). Neurobs Presentation (Neurobehavioral Systems, Inc., Albany, CA) synchronized the EEG acquisition with the stimulus presentation.

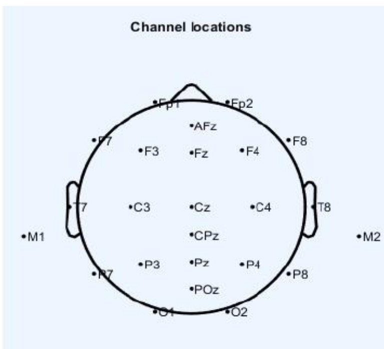

FIGURE 1: 10/20 INTERNATIONAL PLACEMENT SYSTEM

The experiment was performed in the psychrometric chamber. The chamber's dimensions were 457.2 cm × 406.4 cm × 330.2 cm (W × L × H) at the University of Oklahoma (OU) Aerospace and Mechanical Engineering (AME) facilities. The chamber is equipped with an air-conditioning system, air ventilation system, CO_2 sensor, humidity measurement sensor, and equipment to control them. While the CO2 level was kept between 400-1000mmp, based on the ANSI/ASHRAE, three different temperatures were selected and studied: 24.4° C/75.92° F (PMV=0, neutral thermal sensation), 20° C/68° F (PMV=-2, cool), 26° C/78.8° F (PMV=+1, slightly warm).

EEGlab, a Matlab plugin, was used to pre-process the EEG data collected from the participants. A broad filter (finite impulse response (FIR) filter) from 0.5 Hz to 100 Hz was applied. Subsequently, a notch filter from 58 Hz to 62 Hz was applied to remove electrical noise. An independent component analysis was performed to remove artifacts unrelated to brain data. During ERP analysis, A 30 Hz low-pass filter, with a slope of 24 dB/Oct, was applied to each segment of ERP, and amplitudes exceedingly approximately $+/-100\,\mu$V were removed.

ERP latencies were analyzed by one-way ANOVA test for between-group temperature factor. The normality distribution of each data was analyzed by the Shapiro-Wilk test.

3. RESULTS AND DISCUSSION

The ERP waveform analysis revealed that the N200 component was constantly observed across all three different thermal conditions. In addition, N400 and late positivity were observed in a few cases. However, the specific relation between N400 and late positivity components to the congruency condition of the test will be investigated in future studies (Figure 2)

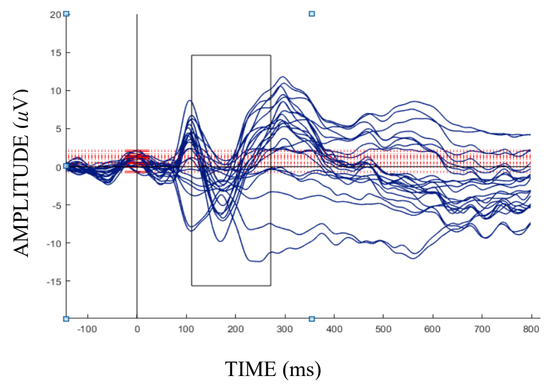

FIGURE 2: EVIDENT NEGATIVITY IN 100-300 ms TIME INTERVAL(N200)

Furthermore, the topographical map illustrated that the Prefrontal regions were the general main active brain cortex during the test (Figure 3), with an exception. Two participants had only occipital cortex activity in 20°C condition. However, in 24°C and 26°C conditions, the frontal and left temporal-central cortex were more active regions in the same participants. The evident N200 component was missing in both cases in almost all electrodes at 20°C condition. A possible reason for this finding could be related to personal preference. Thermal comfort is an individual factor that is identified based on the performance related to the desired temperature. Occipital neural network activity without frontal and parietal cortex activity in this specific temperature can indicate that the non-comfortable temperature results in response to visual stimulation without attention processing.

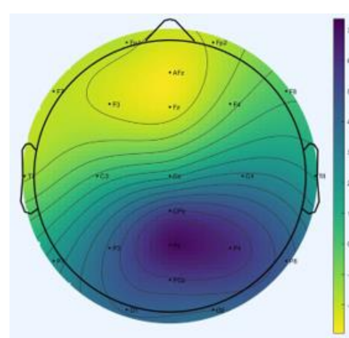

FIGURE 3: AVCTIVE PARIETO FRONTAL NUERAL NETWORK

The mean amplitude of prefrontal electrodes was generated to evaluate the possible temperature effect on the Negativity of N200. The Fp1, Fp2, F3, F4, Fz, C3, C4, Cz electrodes were selected. The average for 20°C was the highest (Ave= -0.6026), followed by 24°C (Ave=-0.6018), then 26°C (Ave=-0.6010.4). These results point towards the interrelation between temperature and the amplitude of the N200. The higher temperature is related to the lower amplitude of N200. Further investigation of the effect of temperature on the mid-latency Negativity and late positivity component is also necessary to thoroughly understand the ERP components related to the indoor thermal impact on the Stroop effect.

In all three thermal conditions, incongruent conditions caused a longer response time (RT) than congruent ones, demonstrating the Stroop effect.

Comparing the Stroop and reverse Stroop tests, it is observed that the response time is longer in the Stroop test in both congruent and incongruent conditions (Figure 4). This finding is aligned with the selective attention theory, which suggests that identifying the color of the words takes more attention than reading the text [33,34]. There are other theories that can explain this observation. For example, based on automatic word recognition theory [35], reading words is an automatic cognitive process and is faster than recognizing colors. Or, based on the speed of processing theory [36], reading is faster than the color recognition process.

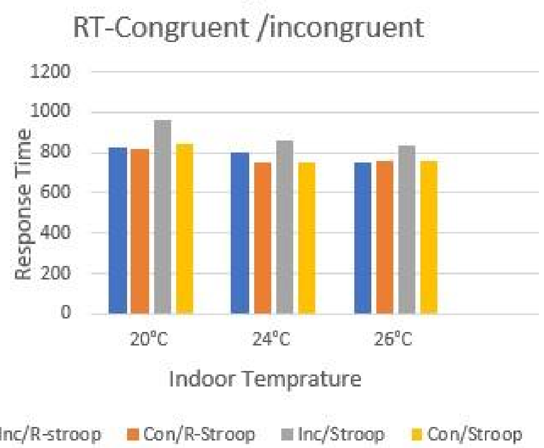

FIGURE 4: RESPONSE TIME IN CONGRUENT AND INCONGRUENT CONDITIONS

Figure 5 illustrates the impact of the temperature on response time (RT). Comparing average response time indicates that as the temperature increases, the RT becomes shorter. In the 20°C condition, RT is longer in all congruent and incongruent conditions represented by both tests.

At the 26°C indoor temperature, the RT is shorter in incongruent conditions presented by either the Stroop or Reverse Stroop test. However, the most remarkable difference happened in incongruent conditions presented by the Stroop test. Generally, temperature change leads to greater time differences in RT for incongruent conditions than congruent ones. Another noteworthy point in this figure is related to the congruent condition represented by both tests; RT differences due to temperature change exhibits an irregular pattern and differ from the incongruent condition.

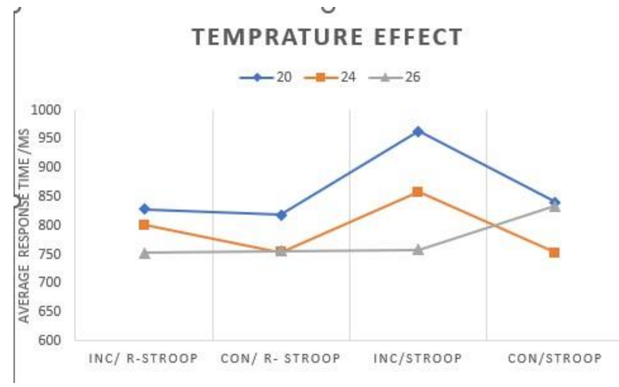

FIGURE 5: TEMPERATURE EFFECT ON INHIBITION CONTROL

The one-way ANOVA test analyzed ERP latencies. The p-value for the temperature effect on incongruent conditions evaluated by the Stroop test (p-value =0.053) and overall incongruent condition (incongruent conditions in both tests) (p-value =0.085) was significant with 90% confidence. However, the temperature effect on incongruent conditions evaluated by the Reverse Stroop test was insignificant (p-value = 0.65). The temperature impact on congruent conditions evaluated by the Stroop test (p-value=0.64), reverse Stroop test (p-value =0.19), and overall congruent condition (congruent conditions in both tests) (p-value = 0.26) was insignificant.

The results obtained from this study highlight the significant impact of temperature on inhibition control. This effect is particularly notable in incongruent conditions. It can also be inferred that the Stroop test is more effective than the reverse Stroop test in analyzing inhibition control ability. This finding potentially be attributed to the nature of these tests and the concept of congruency. The cognitive processes involved in the Stroop test are more complicated than the reverse Stroop task. According to different theories, word recognition tends to be faster than color recognition. Additionally, incongruent conditions present more complicated tasks than congruent conditions. Based on this observation, it can be concluded that indoor environment thermal condition becomes more critical when the task is detailed and involves a more intricate cognition process. These findings agree with the results reported by Mazloumi et al. [30] and Marathe et al. [31].

The presented study had a few limitations which can be addressed in future research. First, despite the acceptable amount of data, the number of participants was limited. If we consider the personal differences, this limitation can affect the results of this study. Also, other than preliminary screening, we did not include any psycho-behavioral survey to categorize the data based on personality and affection.

4. CONCLUSION

The primary objective of this study was to investigate the potential influence of indoor environment quality on cognition control ability. Stroop/Reverse Stroop test was employed to evaluate the hypothesis under consideration. ERP analysis was performed to identify the possible related components and understand the anatomy involved in the cognition control process. The study observed a prominent pattern of higher Negativity between 100-300ms (N200) as a main finding. The alteration of the mean amplitude of the selected electrodes for N200 in response to the temperature change provided evidence of the possible impact of thermal conditions on the Stroop effect. The higher temperature was associated with lower N200 amplitudes during the Stroop/ R-Stroop test. The prefrontal neural network was identified the most active brain region during this Negativity.

Furthermore, the study observed a significant difference in response times related to the temperature, particularly in the incongruent condition evaluated by the Stroop test and overall incongruent condition. However, the effect of thermal condition on inhibition control ability assessed by the reverse Stroop test was insignificant.

Based on these results, it can be concluded that the indoor environment temperature remarkably impacts the inhibition control process, particularly when stimulated by complicated tasks.

Future studies would include an investigation of the mid-latency Negativity and late positivity ERP components, as well as the mean amplitude differences of the related components between congruent and incongruent conditions.

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