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# Cool Me Down: Effects of Thermal Feedback on Cognitive Stress in Virtual Reality

Vincent Philippe<sup>1\*</sup>,

Jeanne Hecquard<sup>1\*</sup>, Emilie Hummel<sup>3\*</sup>, Ferran Argelaguet<sup>1</sup>, Marc Macé<sup>2</sup>, Valérie Gouranton<sup>3</sup>, Claudio Pacchierotti<sup>2</sup>, Anatole Lécuyer<sup>1</sup>, and Justine Saint-Aubert<sup>2</sup>

<sup>1</sup> Inria, Univ Rennes, IRISA, Rennes France

<sup>2</sup> CNRS, Univ Rennes, Inria, IRISA, Rennes France

<sup>3</sup> Univ Rennes, INSA Rennes, Inria, IRISA, Rennes France

**Abstract.** We investigate the influence of thermal haptic feedback on stress during a cognitive task in virtual reality. We hypothesized that cool feedback would help reduce stress in such task where users are actively engaged. We designed a haptic system using Peltier cells to deliver thermal feedback to the left and right trapezius muscles. A user study was conducted on 36 participants to investigate the influence of different temperatures (cool, warm, neutral) on users' stress during mental arithmetic tasks. Results show that the impact of the thermal feedback depends on the participant's temperature preference. Interestingly, a subset of participants (36%) felt less stressed with cool feedback than with neutral feedback but had similar performance levels, and expressed a preference for the cool condition. Emotional arousal also tended to be lower with cool feedback for these participants. This suggests that cool thermal feedback has the potential to induce relaxation in cognitive tasks. Taken together, our results pave the way for further experimentation on the influence of thermal feedback.

**Keywords:** Thermal feedback, Stress, Affective haptics, Virtual reality

## 1 Introduction

Stress can be harmful to health, potentially leading to issues like hypertension, accelerated aging, and cognitive impairment [12]. Virtual reality (VR) can help stress management via inoculation therapy (progressive exposure to a stressor) [16] or relaxing simulations [14]. Adding thermal feedback to the simulations could be an engaging way to help manage stress, as temperatures can affect emotions through valence (pleasantness) and arousal (activation, intensity) levels [17]. Stress has been studied during social interactions and seems to be reduced by warmth as it promotes social proximity [8] and encourages reliance on emotional decision-making [13]. When feeling lonely or excluded, people seek warmth to socially thermoregulate [6,7]. Cool temperatures would then work against any goals of relaxation [18].

However, when removing the social component of the equation, such as in cognitive tasks, one could theorize that cool temperatures would be welcomed as a

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\* These authors contributed equally to this work

calming agent. The temperature of some body parts increases when users are actively engaged in a stressing task [9]. Cool thermal feedback could help balance the thermal comfort, defined as the mind’s condition expressing satisfaction with the thermal environment [2], alleviating stress in VR experiences. Individuals exposed to cool environments are more likely to rely on cognitive decision-making processes [13]. Greater thermal comfort could also help to increase performance [4].

In this regard, this paper investigates the effects of thermal haptic feedback on stress and emotions while exposed to a cognitive stressor. A user study was conducted, where participants completed a stressful task in immersive VR while receiving warm, cool, or neutral feedback applied to the left and right trapezius with Peltier cells. The tasks consisted in rapid mental arithmetic calculations aiming to stimulate participants intellectually. Our primary hypothesis is that, in this task of cognitive stimulation, “cool” stimulus helps stress management.

## 2 User study

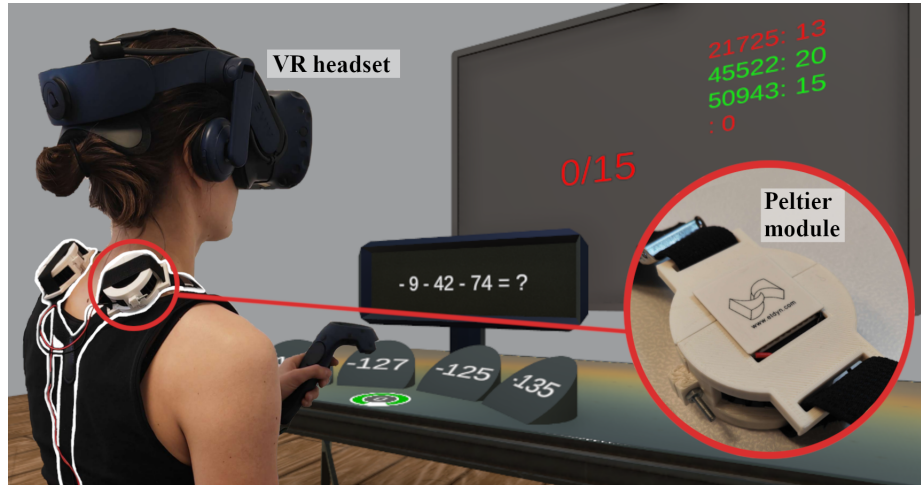
The user study aimed to assess the influence of thermal feedback on user stress level during a cognitive task in VR. Participants performed time-constrained mental arithmetic operations in VR for 5 minutes (Fig. 1). This stressor task was inspired by the Trier Social Stress Test [10], without the social component. Thermal feedback was applied on the skin covering the participant’s trapezius muscles, one of the spots where temperature increases most with stress [9]. Participants experienced the stressor under 3 conditions: warm, cool, and neutral (i.e. close to skin temperature) thermal feedback. Following the past research on thermal feedback, we made several hypotheses :

- (H1) Cool feedback contributes to reduce stress;
- (H2) Cool feedback influences emotions, lowering arousal and heightening valence;
- (H3) Cool feedback increases thermal comfort;
- (H4) Cool feedback leads to better performance.

The procedure was approved by the Inria’s ethical committee. A total of 36 volunteers (28 men, 6 women, 2 others) completed the experiment, with an average age of 24.6 years ( $\pm$  4.9 years).

### 2.1 Apparatus

**Virtual Environment** Participants were immersed in the virtual environment using an HTC VIVE Pro head-mounted display. Participants could interact with the virtual scene with the HTC Vive controllers. The environment was rendered using the Unity3D engine. It consisted of a virtual room, with a black board showing a timer of the remaining time before the end of the task and a scoreboard of fake previous participants to increase competitiveness. The participants were seated in front of a table used to display the arithmetic operations. The calculations consisted of either adding or subtracting 3 random numbers ranging from 1 to 99. A total of 4 answers were displayed in front of the participant who chose and validated them by touching them with the controller. The time to answer was limited to 16 seconds to heighten the difficulty.



**Fig. 1.** Participants were immersed in a virtual room where they answered arithmetic questions for 5 minutes. During this period, the two Peltier modules strapped to their backs either warmed up, cooled down, or stayed neutral.

**Thermal feedback** Thermal feedback was applied on the trapezius with a wearable device made of (Fig. 1). On the straps of the suspenders were sewn two pieces of 3D-printed pieces to hold a thermoelectric Peltier (*European Thermodynamics*, 5.3 V, 1.1 A, 2.9 W, 30 mm x 30 mm) cell and a heat sink that could slide along the straps. The Peltier cells were connected to an Arduino UNO board through DC motor drivers (DRV8838). Two external power supplies (5 V, 2.2 A max) powered the Peltier cells. Participants wore tank tops so the cells would directly touch the skin.

Since the temperature sensibility varies among people, the temperatures for the warm, cool, and neutral feedback were calibrated for each participant to match the “warm”, “cool”, and “neutral” on the ASHRAE-7 scale [3]. The calibration began with the participant finding their neutral reference, then adjusting the temperature upward to the point of light discomfort referred to as “hot”. The participants then slightly lowered the temperature until they reached the “warm” reference. This calibration allowed participants to distinguish clearly between the two sensations: warm is comfortable, and hot is not. After a 30-second pause to eliminate heat bias, participants repeated this calibration process for the cool condition, starting from “cold” and raising the temperature to “cool”. Participants used a slider to change the temperature. The room used for the experiment averaged a temperature of  $24.6 \pm 1.1$  °C. Participants chose  $38.5 \pm 1.9$  °C for the warm,  $30.5 \pm 1.5$  °C for the neutral, and  $24.9 \pm 3.4$  °C for the cool stimulus.

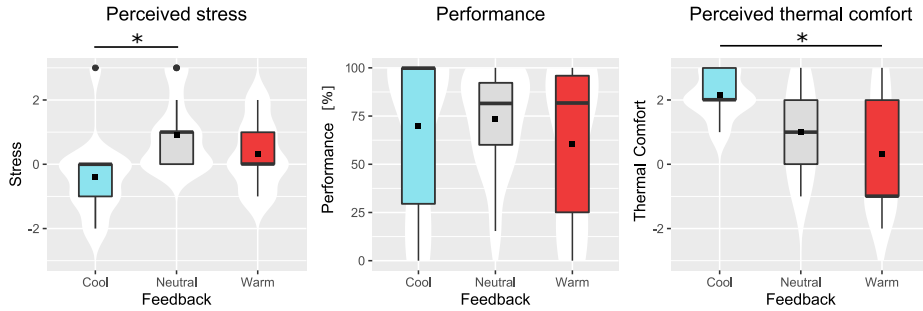
## 2.2 Protocol and Measures

Participants received an explanation of the procedure and were immersed in the virtual environment. They were asked to calibrate the temperature and experienced a training session without thermal feedback. They then performed the three exper-

imental conditions (“warm”, “cool”, and “neutral”) in a Latin square order. For each condition, participants were instructed to achieve the highest possible score for a 5-minute session of mental arithmetic. After each condition, the participants had a 10-minute break without VR to relax and return to their neutral stress level. In order to enhance the relaxation effect, participants were offered a coloring picture. The whole experiment had a duration of 1 hour and 30 minutes.

Before and after each condition, stress levels were assessed with the Acute Stress Appraisal questionnaire [11]. The difference between both measures revealed, for each participant, the relative stress of exposition to the stressor. The thermal comfort was also measured before and after each condition with the ASHRAE-7 scale [3]. Emotions were separated into arousal and valence with the Self Assessment Manikin [1]. As for performance, the number of participants’ correct answers was used. The final score was normalized to represent a percentage of the best participant’s score across all conditions since scores varied exceedingly between participants.

### 3 Results



**Fig. 2.** Results for the stress, performance and thermal comfort for participants preferring cool feedback.

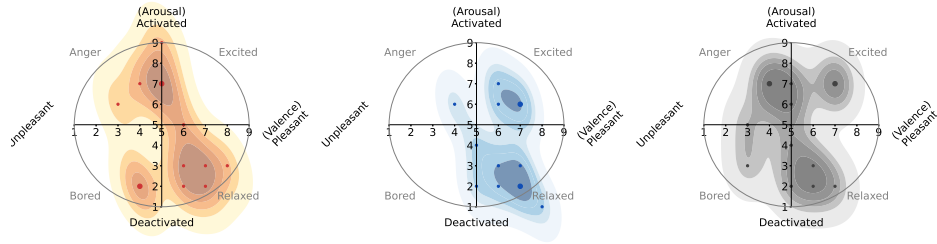
Normality assumptions were not met so non-parametric analyses were performed using the Friedman test followed by the Nemenyi procedure with corrections for pairwise comparisons. Only significant results are detailed, other statistics and graphs can be found in the annex.

Overall, thermal feedback did not significantly influence the participants’ stress, emotions, or performance. However, further examination revealed trends for clusters in the population depending on their preferred temperature. In total, 14 participants are in the “neutral”, 13 in the “cool” and 9 in the “warm” cluster. No order effect was observed, and so significance tests were conducted.

For the cool cluster (Fig. 2), Friedman test revealed a significant effect of the thermal condition on stress ( $p = 0.015$ ,  $\chi^2 = 8.45$ ). Stress with neutral feedback was significantly higher than with cool feedback ( $p = 0.031$ ,  $d = 0.97$ ). Significant effects of thermal conditions on thermal comfort was also found ( $p = 0.003$ ,  $\chi^2 = 11.73$ ).

Thermal comfort with cold feedback was significantly higher than with hot feedback ( $p = 0.013$ ,  $d = 0.58$ ). Spearman test also revealed a small correlation between the level of stress and the thermal comfort ( $p = 0.015$ ,  $r = -0.34$ ).

A significant difference was also found for arousal in the cool cluster ( $p = 0.018$ ,  $\chi^2 = 8$ ) (Fig. 3), with a trend for lower arousal with cool feedback than with neutral feedback ( $p = 0.081$ ,  $d = 0.43$ ). Results for others clusters did not show any significant difference.



**Fig. 3.** Models of emotions (valence and arousal) for the participants for warm (left), cool (middle) and neutral (right) feedback, for participants preferring cool feedback. Bigger dots mean more participants.

## 4 Discussion

This study aimed to investigate the impact of thermal feedback on stress, emotions and performance during a cognitive task. The results did not support a global effect on the population but revealed the presence of clusters based on thermal feedback preferences which were differently affected by temperature.

**(H1)** stated that cool feedback would have an effect on reducing stress. This hypothesis is partially supported, as participants who preferred cool showed reduced stress with cool feedback compared to neutral feedback. No significant effects were found for participants who preferred warm or neutral feedback. Previous research supports warmth as an effective relaxation agent [5] but our study suggests that cool feedback could be effective for cognitively-induced stress.

**(H2)** suggested that thermal feedback would influence emotions. This hypothesis also received partial support through the clustering of preferred temperatures. The participants who preferred the cool condition reported a trend for lower arousal levels when exposed to cool feedback compared to neutral feedback. Participants in this cluster seem more relaxed with cool feedback, echoing the findings of **(H1)**. The visualization of participant emotions during warm feedback (cf. Fig. 3) is coherent with the literature, wherein warmth can lower arousal and heighten valence, but hotness heightens arousal and lowers valence [17]. These prior studies offer that thermal feedback tends to heighten the arousal of emotions. Conversely, our results suggest

that emotions can also be regulated in stressful situations. It would be interesting to conduct further research on this aspect to confirm the trend for a decrease in emotional arousal in stressful situations.

It has been observed that thermal feedback had a notable influence on participants' thermal comfort for the cool cluster, partially supporting **(H3)**. This observation aligns with the idea that when individuals actively engage in a cognitive task, their perceived thermal sensation might increase, resulting in reduced thermal comfort. In the experiment, the thermal comfort with cool feedback was higher than with warm feedback for the cool cluster, suggesting again that cooling down may be a better option than warm feedback. However, this theory needs further support: this could be attributed to the room temperature that averaged 25 °C, which falls on the higher end of the ideal temperature range for thermal comfort (22-26 °C).

Finally, **(H4)** is not supported by the results. Previous studies observed that individuals tend to perform better at neutral temperatures (e.g. [15]). In our case, stress might have increased the participants' body temperature, which in turn might have negatively impacted the performance in all conditions.

Overall, these results suggest that cool thermal feedback has the potential to reduce stress in cognitively demanding tasks (e.g. cognitive behavioral therapy, rehabilitation programs, etc). They pave the way for further experimentation on the influence of thermal feedback. For instance, our results suggest that individuals are not affected in the same way by the thermal feedback, so it would be interesting to categorize them. In this way, personalized feedback could be displayed. Many people also suffer from chronic stress, and it would be worth testing if thermal feedback can help stress management on the long-term to help this population.

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