Exploring Thermal Feedback in Brain-Computer Interface User Training

François Le Jeune, Emile Savalle, Anatole Lécuyer, Marc J.-M. Macé, Pierre Maurel, Léa Pillette

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F. Le Jeune[1, *], E. Savalle[1, *], A. Lécuyer[2], M. J.-M. Macé[1], P. Maurel[3], L. Pillette[1]

[1]Univ. Rennes, Inria, CNRS, IRISA, Rennes, France
[2]Inria, Univ. Rennes, IRISA, CNRS, Rennes, France
[3]Univ. Rennes, Inria, CNRS, Inserm, Empenn ERL U1228, Rennes, France
[*]Co-first authorship. Both authors contributed equally.

E-mail: francois.le-jeune@inria.fr

Brain-computer interfaces (BCIs) rely on the acquisition of brain activity, often using electroencephalography (EEG), which is then interpreted into a command for a digital device. Motor imagery (MI) is a common task for generating recognizable brain activity for BCIs [1], albeit challenging for novice users. Neurofeedback enables to train users to modulate their brain activity to improve BCI performances [2]. Various feedback modalities have been explored, though visual modality remains dominant. Haptic feedback has potential benefits and was reportedly perceived as more natural than a visual one [3]. Furthermore, multimodal feedback combining visual and haptic stimuli seems to improve MI-BCI performance [4, 5]. Thermal feedback, an unexplored component of haptic feedback, is promising as it is affordable, ease of use, and has potential therapeutic benefits in stroke rehabilitation [6, 7]. This study aims to assess the feasibility and efficacy of thermal vs. visual feedback in EEG-based MI-BCI training (Fig. 1). For these preliminary results, we analyzed data from thirteen healthy participants experiencing three feedback modalities while performing MI: visual-only, thermal-only, and visuo-thermal. Neurophysiological activity analyses revealed significant differences in neuromodulation based on feedback modality, with visual-only and visuo-thermal feedback inducing greater desynchronization over the sensorimotor cortex compared to thermal-only feedback. Combining thermal and visual feedback did not diminish performances compared to visual feedback only. Thus, while thermal feedback elicited less pronounced brain activity modulation than visual feedback, its combination with visual feedback remains promising, particularly in rehabilitation contexts. Further research can refine thermal feedback protocols and explore its synergies with other modalities to optimize BCI performance and user engagement.

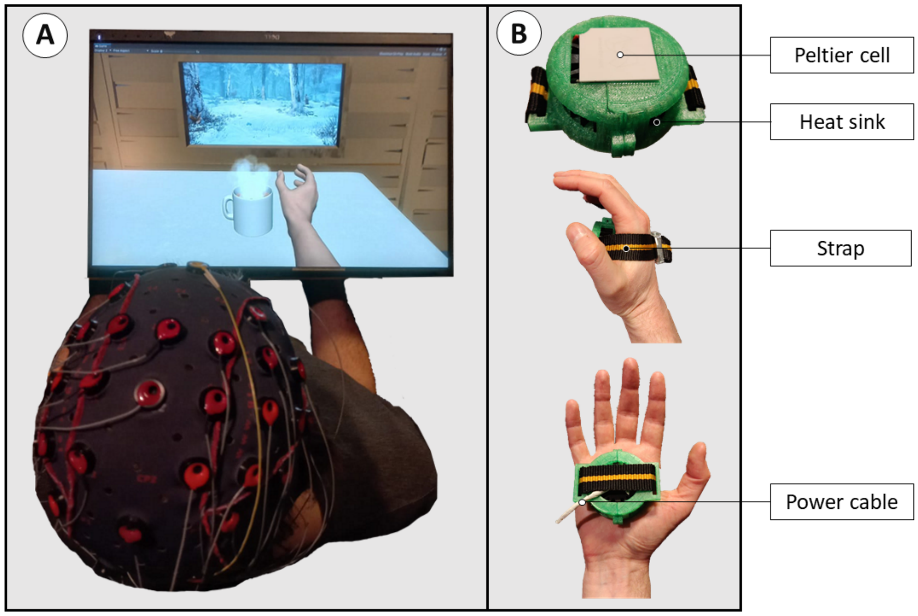

Figure 1: Experimental setup. **A-**Participant seated on a chair in front of the computer screen and wearing the EEG headset. The screen displays the visual feedback with the virtual hand superimposed above the participant's real hand. **B-**Thermal stimulation system. Top: top view of the system with 3D printed part (in green) holding a Peltier cell and a heat sink ; Middle: top view of the user's hand in position equipped with the wearable system ; Bottom: left view of the user's hand equipped with the wearable system.

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