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User Test and EEG Insights of Bimodal, Visual and Vibrotactile, Stimulation

Gabriela Herrera Altamira¹, Stéphanie Fleck², Anatole Lécuyer³, Laurent Bougrain¹

¹ NeuroRhythms Team, Université de Lorraine, CNRS, LORIA, F-54000, Nancy, France

² PErSEUs Team, Université de Lorraine F-57073, Metz, France

³ Hybrid Team, Inria, University of Rennes, Irisa, UMR CNRS 6074, Rennes, France

Contact: gabriela.herrera-altamira@loria.fr

INTRODUCTION

- Kinesthetic motor imagery (KMI) is a mental task often used in Brain-Computer Interfaces (BCI).
- KMI is a hard task lacking kinesthetic feedback. Vibrotactile (VT) feedback may help the user and support MI [1], but the required intensity and activation sequence choices remain vague.
- VT stimulation elicits electroencephalography (EEG) modulations [2], yet, it is unclear whether the EEG activity depends on the vibration intensity and activation pattern.
- We assessed the **effects on EEG signals of coupling VT and visual stimuli and its associated perceptual coherence.**

METHODS

Experimental Procedure

18 neurotypical participants compared 4 different VT configurations to **select the one that best matched a virtual grasping movement.** (COERLE, approval number: 2022-17).

Vibration was applied on the left arm and the virtual hand shown was the left one.

VT configurations:

- Number of motors
- Activation patterns

Four stimulation levels:

- Intensity
- Duration

One VT configuration per run

16 trials per run (4x each level)

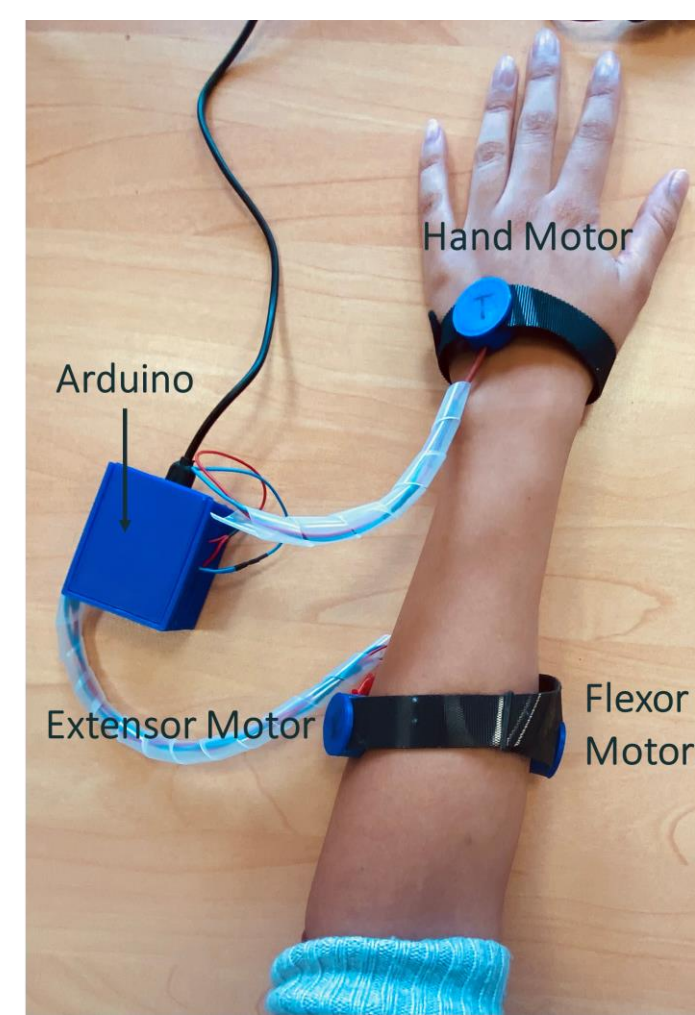


Fig 1. Vibrotactile device

Information recorded: EEG (64 channels), users evaluations for each configuration.

RESULTS

User evaluation

Users preferred the 3-motor device configuration and the sequential activation pattern.

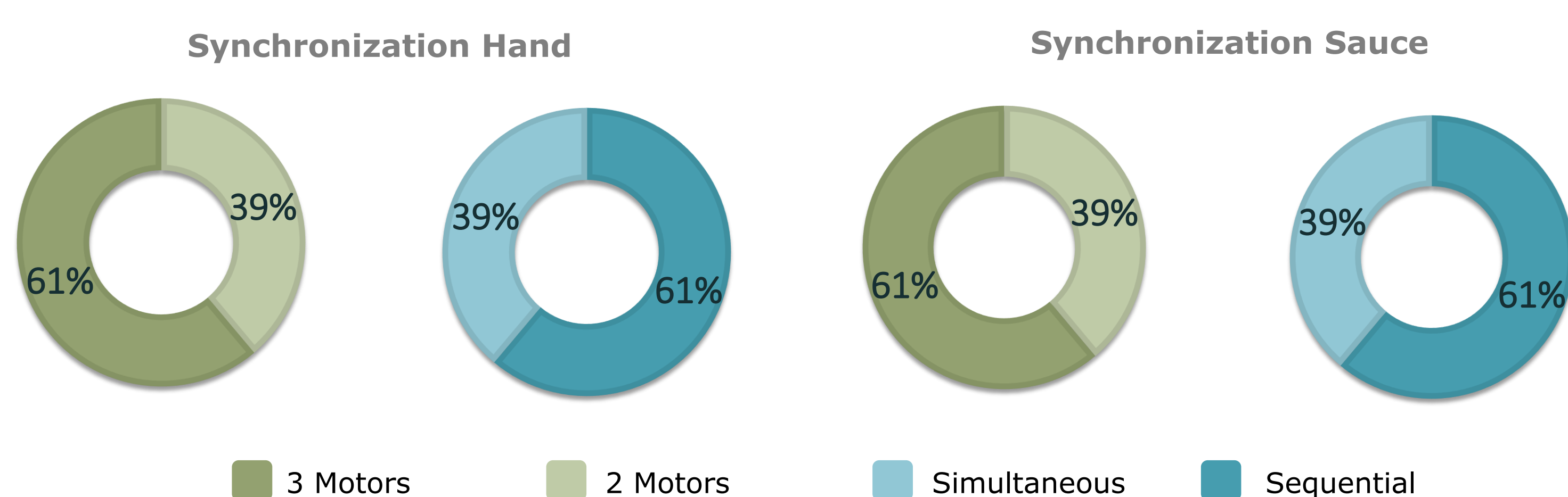


Fig 5. User evaluation of the bimodal stimulation

Activity in alpha and beta

- Bilateral ERDs are elicited by visual and VT stimulation in alpha and beta.
- Contralateral ERDs in alpha+low beta are present in the 4 levels while the ipsilateral ERD was present only in *Medium* and *High* conditions.
- Contralateral occipital ERDs are present mainly in alpha+low beta.

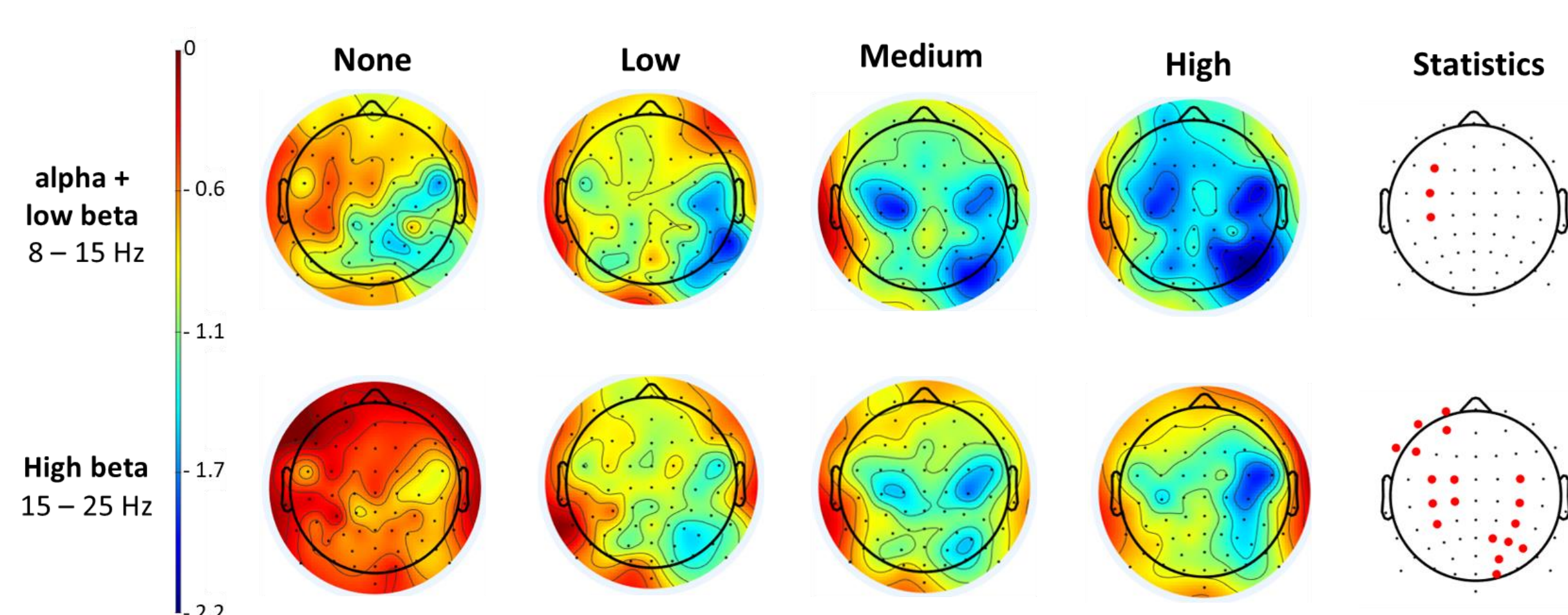


Fig 6. ERSPS topographies of the brain activity in alpha and beta frequency bands averaged over two seconds ($t=0-2000$ ms). Statistic threshold $p < 0.01$.

OBJECTIVES

1. Understand the brain activity due to visual and VT stimuli before using it as feedback for KMI-based BCI.
2. Define the VT configuration that better corresponds to the virtual environment and offers the best user experience.
 - Number of motors
 - Activation pattern
3. Ensure the vibrotactile stimulation is coherent and synchronized with the visual stimulation.
4. Study the effects of the vibration on the EEG signals.

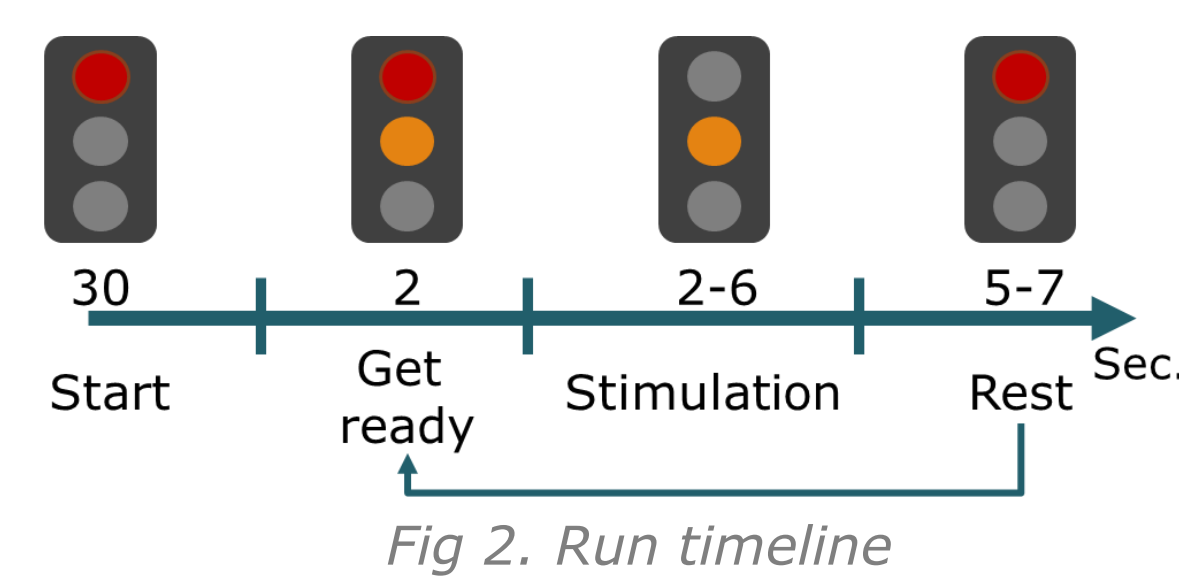


Fig 2. Run timeline

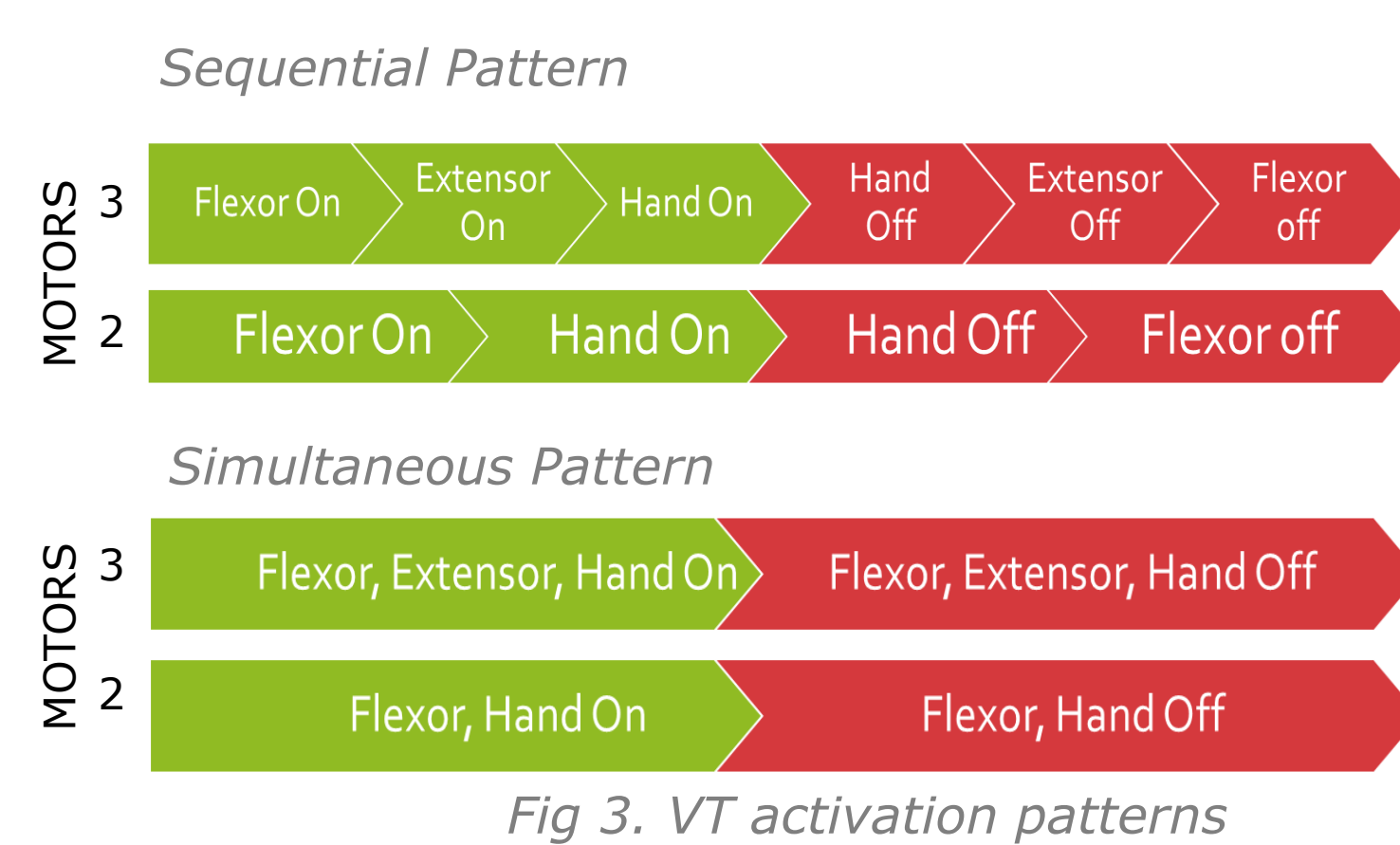


Fig 3. VT activation patterns

	None	Low	Medium	High
Vibration Intensity				
Visual Animation				
Duration [s]	2	2	4	6

Table 1: Levels of the bimodal stimulation

Offline Analysis

We used EEGLab v2022.1 to process EEG signals. We used its statistics study tool to perform statistics with FDR correction and $p < 0.01$ for the Event-Related Spectral Perturbations (ERSPs) topographical analyses. We removed one participant due to bad acquisition.

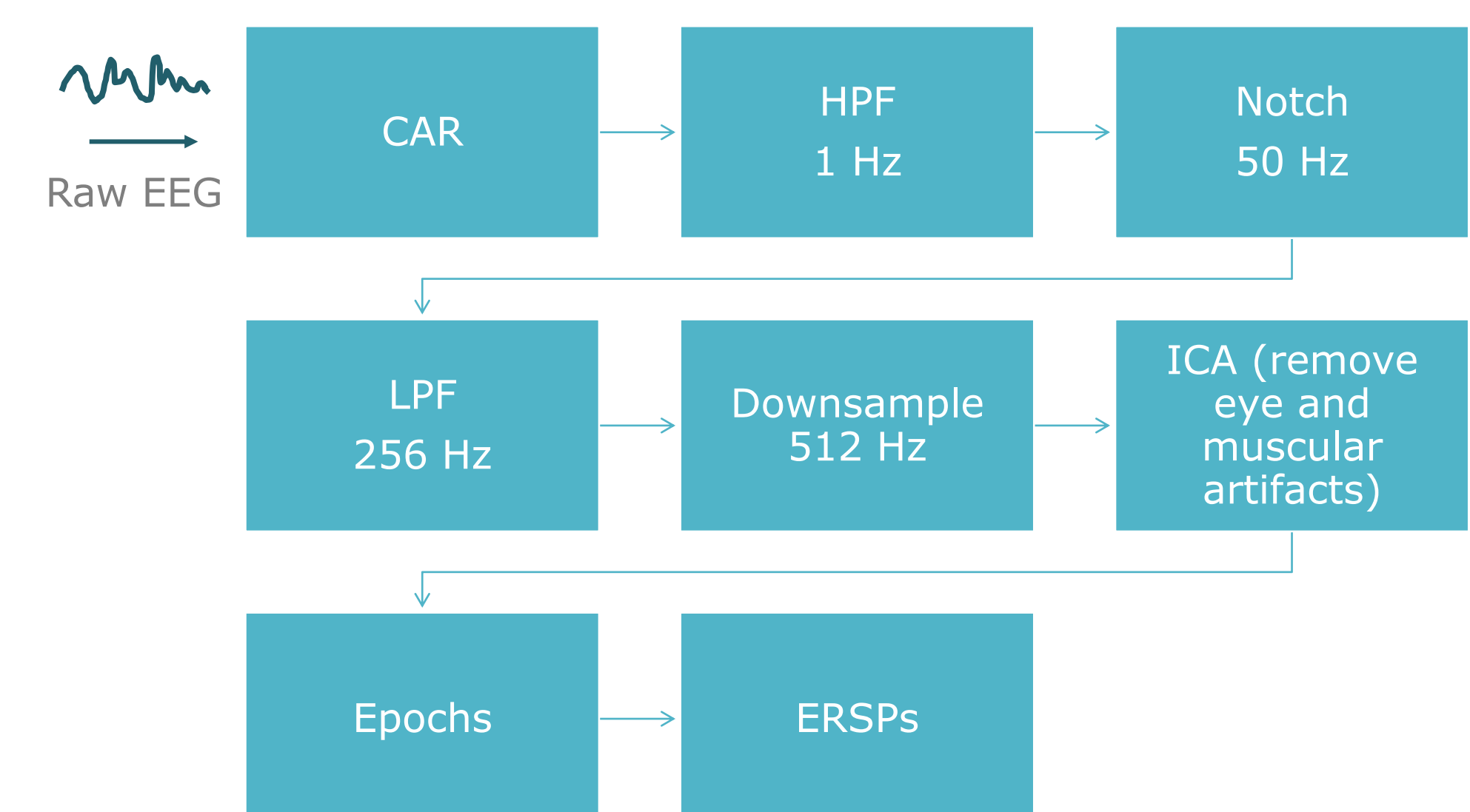


Fig 4. EEG offline processing pipeline

Activity in delta

A transient ERS was present in delta (1-4 Hz) activity during the *Medium* and *High* stimuli in central areas only at the beginning of the stimulation.

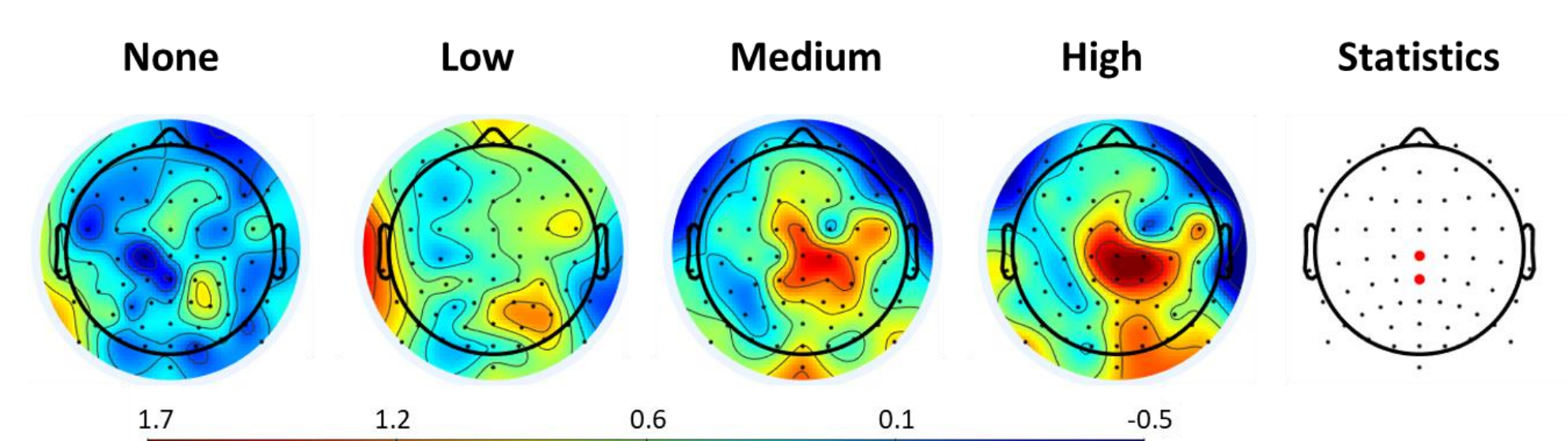


Fig 7. ERSPs topographies of the brain activity averaged over the first second of the stimulation ($t=0-1000$ ms) in the 1-4 Hz delta band. Statistic threshold $p < 0.01$.

DISCUSSION

- We did not observe significant differences in the EEG activity among the VT configurations, thus we may choose the configuration preferred by the users: the **3-motor sequential**.
- Contralateral occipital ERDs in alpha may be due to action observation of the left virtual arm.
- Delta activity may be an indicator of attention increase due to the vibration [2]. As we only saw it in *Medium* and *High* conditions, attention may depend on the vibration intensity.
- These results may favor giving **delayed feedback** after KMI so that the BCI may differentiate the KMI-related brain activity from the stimuli-related one.
- The **next step** is to evaluate visual, VT, and bimodal feedback after the KMI, its effects on the EEG, accuracy, and user experience.

REFERENCES

- [1] W. Zhang, A. Song, H. Zeng, B. Xu, and M. Miao, "Closed-Loop Phase-Dependent Vibration Stimulation Improves Motor Imagery-Based Brain-Computer Interface Performance," *Front Neurosci*, vol. 15, no. January, pp. 1–13, 2021, doi: 10.3389/fnins.2021.638638.
- [2] W. Li, Q. Xu, Y. Li, C. Li, F. Wu, and L. Ji, "EEG characteristics in "eyes-open" versus "eyes-closed" condition during vibrotactile stimulation," *Biomedical Signal Processing and Control*, vol. 68, p. 102759, 7 2021.