Closed-Loop BCI with Haptic Feedback and ML for Attention Support in ADHD

Leveraging EEG Signal Analysis for Enhanced Education

Milton O. Candela Leal, Luis A. Marrufo Franco, Baudel H. Ruiz de la Fuente, César F. Cruz Gómez, Mauricio A. Ramírez Moreno

ABSTRACT

While ADHD challenges academic performance, current tools like the Continuous Performance Test (CPT-II) assess attention without offering immediate intervention. This project aims to develop a Brain-Computer Interface (BCI) system with haptic feedback to improve sustained and selective attention in students with ADHD. Using EEG signals from Enophone headphones and an Arduino-based haptic module, the system provides real-time feedback via vibrations to help maintain focus during learning tasks. It integrates a machine learning model to analyze EEG data and optimize focus through a closed-loop feedback; thus, advancing attention monitoring technology, benefiting education and health per UN SDG 3 & 4, while improving assistive tools for individuals with attention disorders.

INTRODUCTION

ADHD is one of **the most common neurological disorders**, affecting **7.1% of children and 5% of adults,** with a higher prevalence in **men (3:1 to 16:1)** [1][2] and **40.7%** of students with ADHD **have difficulty concentrating** for **more than 20 minutes** in virtual classes [3][4]. Advances in **EEG and neurofeedback technology** have demonstrated their **effectiveness in improving cognitive performance**. Likewise, haptic feedback offers a promising tool to address attention deficits in clinical and educational contexts. This project builds a Brain Computer Interface (BCI) system with Enophones and an Arduino Bluetooth for real-time haptic feedback.

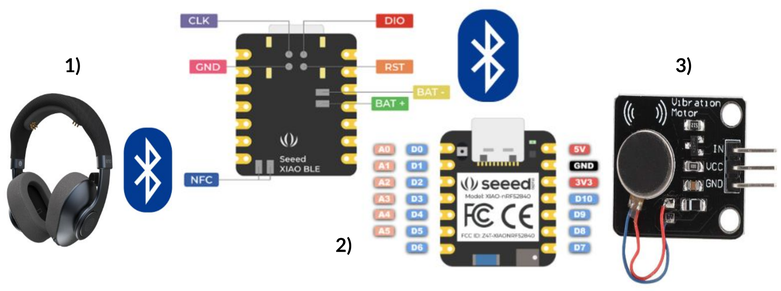

Fig. 1: 1) Enophones; **2)** Front and Back pinout configuration of the Seeed Studio XIAO nRF52840; **3)** Mini vibration disc sensor used for the vibration system.

Methodology

Divided in phases (Fig. 2)

- **Phase 1** literature review in on attention, and doing the CPT-II to train a model that predicts attention.
- **Phase 2** focused on designing and assembling a neurofeedback system with EEG-synchronized haptic feedback (Fig. 3).
- **Phase 3** validated the prototype through controlled tests comparing no feedback, MLR-based feedback, and the Engagement Index (Fig. 4).

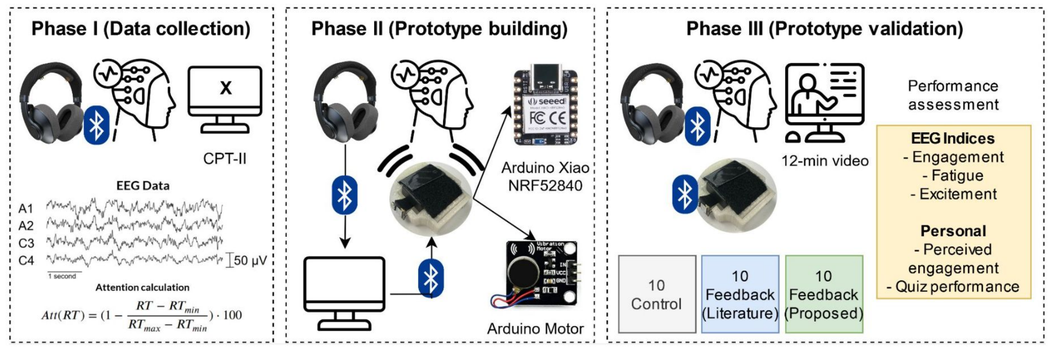

Fig. 2: Methodological overview, divided into III phases: Data collection, prototype building, and prototype validation.

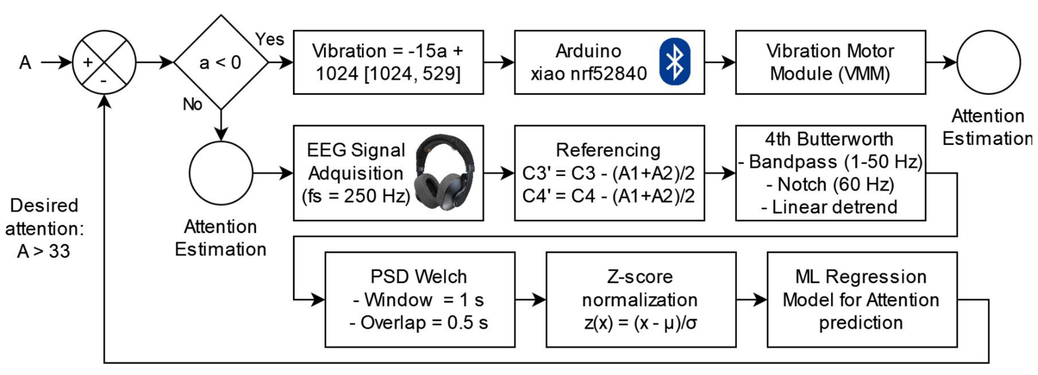

Fig. 3: Closed-loop algorithm employed in order to pre-process and process EEG signals, in addition to estimating the level of attention and sending a corresponding analog signal to the arduino controller. This in a loop fashion to have a constant monitoring of attention level and its corresponding haptic feedback response.

Results

The MLR model outperformed the engagement index (R^2=0.7253, MSE=1283.21 vs R^2=0.0930, MSE=18040.05). The neurofeedback groups had greater engagement index among the test (Fig. 5), this is exhibited across subjects, with greater engagement index, but with greater fatigue and excitement index, reflecting areas of opportunity (Fig. 6).

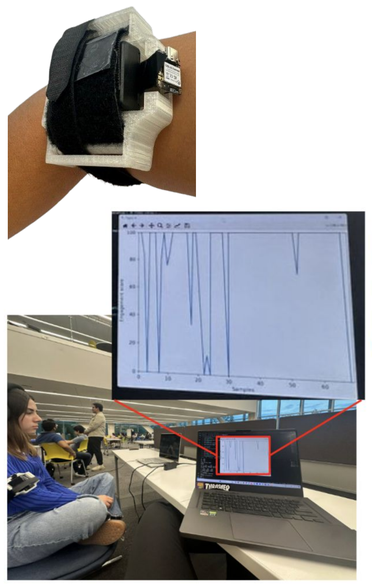

Fig. 4: Demonstration of the functional prototype and the real-time graph.

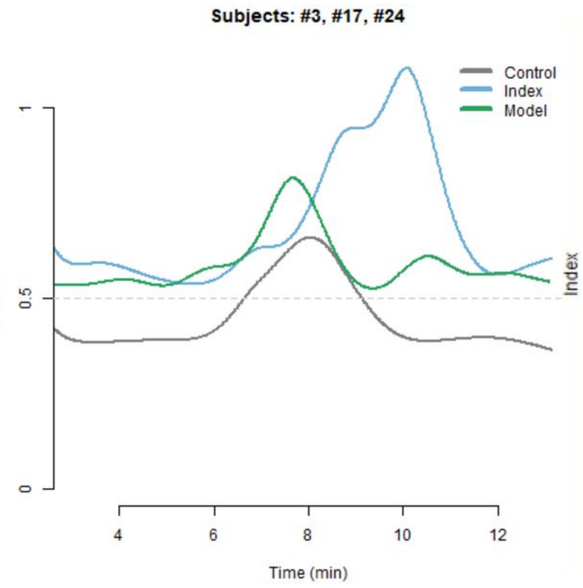

Fig. 5: Line plot of engagement index across the lecture from three random subjects that belong to each different group.

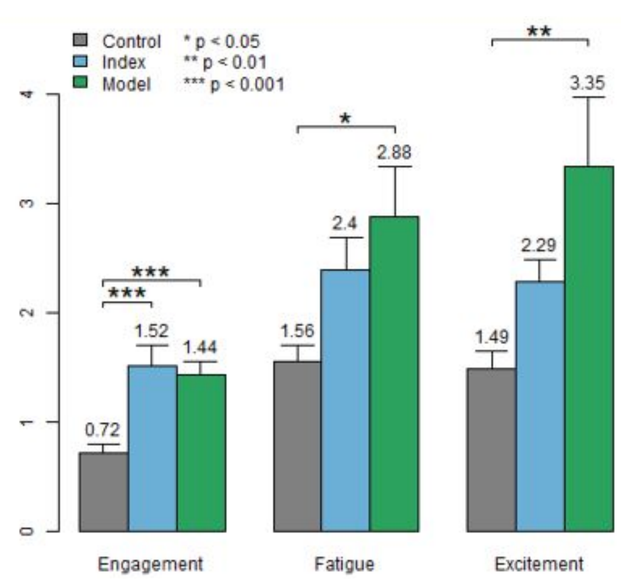

Fig. 6: Barplot of EEG-derived indices across groups, depending on whether neurofeedback was received and which model was used to do so.

CONCLUSION

The developed prototype improved sustained attention in students using haptic neurofeedback and an MLR algorithm that outperformed the traditional engagement index (R^2=0.7253, MSE=1283.21). While attention levels increased, student's performance remained the same, in addition to having increased levels of mental fatigue. This project integrated bioinstrumentation and neuroengineering, laying the groundwork for future improvements like measuring quiz performance or refining the system and optimizing the rhythm to avoid fatigue and habituation in longer sessions.

References

[1] Williams, O. et al. (2023). *Annals of Medicine & Surgery*
[2] Etchepareborda, M. (2004). *Revista de Neurología*
[3] J. Gagliardi. (2021). *Journal of Attention Disorders*
[4] V. Tessarollo, et al. (2022). *Journal of Attention Disorders*, vol. 26, no. 6, pp. 902–914

Acknowledgement

Tecnológico de Monterrey

CONSCIOUS TECHNOLOGIES
CAMPUS CITY & BRAIN TEC

Building Reliable Advances and BRAIN Innovations in Neurotechnology

Tecnológico de Monterrey
Escuela de Ingeniería y Ciencias