EEG Signal Analysis of Attention Levels in VR and AR Learning Tasks

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***Abstract*— The rapid advancement of Virtual Reality(VR) and Augmented Reality (AR) technologies tied with the fact that immersive technologies have become increasingly useful for productivity has opened the gate for a new type of learning. While both technologies have demonstrated potential in education, their impact on cognitive processes, especially concentration, requires further investigation. This research investigates the concentration difference during learning with VR and AR. We quantified the focus on learning, using electroencephalogram (EEG) signals gathered from participants while completing several cognitive tasks to determine how these technologies can influence their attention levels. This study aims to clarify which educational setup (VR or AR) increases their cognitive attention by measuring their concentration index for preadolescents and adolescents.**

I. Background

Concentration is a fundamental aspect of cognitive function that determines how learners interact with and memorize educational content. Variations in attentional focus can significantly influence learning effectiveness, with sustained attention being associated with better retention and understanding of information. Despite the promise of VR and AR in education, the question of how these 2 methods affect attention during learning tasks remains largely unexplored. This study seeks to fill this gap by leveraging EEG-based signals to measure and compare attention levels in VR and AR environments.

II. Methods

The experimental design involved a comparative study of attention levels in VR and AR learning environments using the Meta Quest 3[1] headset and BrainAccess MIDI [2] EEG headset which has 16 channels and a 250 Hz sampling frequency. The VR environment immerses the user in a fully digital world, while the AR environment uses the passthrough mode to combine the VR experience with the real world. The study acquired data from 10 middle and high school students aged 12 to 17, a demographic chosen for its relevance to educational research. Participants were immersed in the same environmental setup to minimize external distractions and ensure the reliability of EEG data.

Participants engaged in a series of cognitive tasks designed to assess various attentional functions, including mental, visual-spatial, auditory, linguistic, and attentional control. These tasks were performed using a mouse and keyboard connected to a laptop, with the content displayed on a virtual screen within the VR and AR environment. This setup is consistent in the environments having no difference in the way of interaction. The tasks included:

- Card Memory Match: Participants were shown cards on a virtual display and asked to find matching pairs.
- Spot the Difference: Participants compared two images displayed on the virtual screen to find differences.
- Chess: A virtual chess board was used, with participants making moves using the mouse.
- Wordle and Reaction Time Exercises: These tasks were conducted within a browser on the virtual display, with participants using the keyboard and mouse.

The cognitive focus was quantified with the help of the concentration index [3] in Eq. (1). The SMR band (12-15 Hz) was used instead of the beta band thanks to the fact that this range is associated with more active cognitive processing, alertness, and sometimes anxiety or stress when overactive.

$$\text{Index} = \text{power of } [\{\beta + \text{SMR}\} \ / \ \theta] \qquad (1)$$

Using a broader 12-20 Hz range would blur these distinctions and could potentially obscure the specific effects associated with SMR activity. After the quantification, we checked the percentile increase from the baseline, where each subject kept their eyes open, while not being in the proximity of any stimuli, compared to each cognitive task in part (FIG. 1).

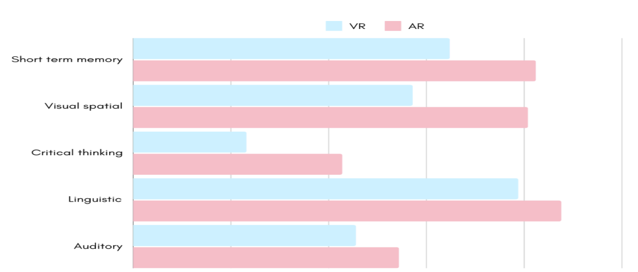

FIGURE 1

The EEG data underwent a preprocessing phase, including filtering to remove noise and Independent Component Analysis (ICA) [4] to isolate relevant brainwave signals from artifacts such as eye movements, blinks, and muscle activity. Following preprocessing, the data was fed into several classifiers such as Random Forest, Multilayer Perceptron, and Gradient Boosting Classifier in which we conducted two primary classification experiments to assess how well a machine learning model could differentiate between learning environments: real-world, VR and AR.

The first experiment involved a straightforward two-class classification task where the model was trained using EEG data from participants in both real-world and VR environments. This model performed exceptionally well, accurately distinguishing between real-world and VR tasks with an accuracy of 83% obtained using Random Forest Classifier. The success of this model indicates that the brain's response to fully immersive VR environments is distinct from its response to real-world tasks, making it relatively easy for the classifier to differentiate between these two conditions.

The second experiment extended the classification task to include data from AR environments, creating a three-class classification problem. Here, the model continued to perform well in distinguishing between real-world and VR environments. However, it struggled significantly when trying to classify AR data, achieving a maximum accuracy of only 37% when using deep neural networks. This poor performance suggests that the EEG signals generated during AR tasks do not fit neatly into a distinct category like VR or real-world tasks.

We hypothesize that this difficulty arises from a phenomenon we observed, which we refer to as the Augmented Reality Phenomenon (ARP). This phenomenon suggests that the human brain does not consistently perceive AR tasks as entirely distinct from either real-world or VR tasks. Instead, depending on the individual, the brain may interpret AR-based visual cognitive tasks as being similar to either real-world tasks or VR tasks. This variability in perception could explain why the model struggles to classify AR data accurately, as the EEG signals in AR may overlap significantly with those from the other two environments.

III. Data Acquisition

To ensure the accuracy of the results, the study implemented a meticulous data acquisition protocol. The room was equipped with air conditioning, natural light, and minimal external noise to create a conducive atmosphere for focused engagement.

The tasks were conducted on a laptop connected to the VR headset, allowing participants to experience the same content using both VR and AR. Each session lasted approximately 15 minutes, providing sufficient time to observe sustained attention while avoiding cognitive fatigue. During these sessions, we closely monitored EEG data for signs of attentional shifts, focusing on key brainwave frequencies (theta, alpha, SMR, beta, gamma) and visual cortex activity, which are known indicators of attentional focus.

Artifacts, which can significantly distort EEG readings, were carefully monitored and mitigated. These artifacts include involuntary movements, such as blinking or muscle twitches, as well as external electrical interference.

All of the subjects that we have acquired data from are taken with their parent's consent for participating in our tests. The data has been anonymized and will not be shared with anyone.

IV. Results

The analysis of EEG data revealed a pronounced difference in attentional levels between VR and AR environments. Our measurements showed that participants in AR environments exhibited a 57% higher level of attention compared to those in VR settings. This significant disparity suggests that AR's integration of digital content with the physical world allows for a more seamless and cognitively engaging learning experience. The ability to remain connected to the physical environment while interacting with digital overlays appears to enhance cognitive focus, enabling learners to maintain attention more effectively than in a fully immersive VR environment. Furthermore, this study proves that the brain can categorize the AR environment as being a real-world or a VR environment.

The implications of these findings are substantial for the future design of educational technologies. AR's ability to sustain attention more effectively than VR could lead to more widespread adoption in educational contexts where maintaining cognitive engagement is crucial.

V. Conclusion

This study shows a new phenomenon of how the brain can understand AR and the importance of understanding the cognitive impacts of emerging educational technologies. By comparing attention levels in VR and AR environments, we have identified significant differences that could inform the design and application of these technologies in educational settings. AR's superior performance in sustaining attention suggests that it may be better suited for tasks requiring prolonged cognitive engagement, offering a more effective tool for educators seeking to enhance student learning outcomes. Future research should continue to explore the cognitive implications of immersive technologies, with a particular focus on how these tools can be optimized to support diverse learning needs.

References

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