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Evaluation of Visual-Induced Motion Sickness from Head-Mounted Display Using Heartbeat Evoked Potential: A Cognitive Load-Focused Approach

Joseph Thomas[1], Roji Thomas[2], Shahana M.S[3], Anu Joseph[4],Aneesha Antony[5]
[1,3,4,5]PG- Master of Computer Application, kristu Jyoti College of Management and Technology, Changanacherry, kerala
[2]Assistant professor- kristu Jyoti College of Management and Technology, Changanacherry, kerala

ABSTRACT
According to the sensory conflict theory, motion sickness is closely tied to the brain's ability to process information and its resources for adjusting to the variety of sensory inputs present in VR content. The goal of this study was to create a mechanism for analyzing motion sickness using the heart-evoked potential (HEP) phenomena and to suggest new metrics for doing so. In this study, participants watched VR content on 2D and head-mounted displays (HMD) for 15 minutes. Using paired t-tests and ANCOVA, the responses of HEP measures such as alpha power, latency, and amplitude of the first and second HEP components were compared.
This study established that motion sickness impairs cognitive functioning, as indicated by an increase in HEP's alpha power. Additionally, during the sensation of motion sickness, the suggested indicators, such as latency and amplitude of the HEP waveform, demonstrated substantial variations and displayed strong relationships with alpha power measurements. According to the multitrait-multimethod matrix, latencies of the first HEP component in particular are suggested as superior quantitative evaluators of motion sickness to other measures. The proposed motion sickness model was put into practise using a support vector machine and validated using data from 20 additional subjects. The findings of the motion-sickness categorization included accuracy, F1 score, precision, recall, and area under the curve (AUC) of 0.875, 0.865, 0.941, 0.8, and 0.962, respectively.
Keywords:VR,Virtual Reality,Heads-up Displays,Heartbeat Evoked Potential.

1. Introduction

Virtual reality (VR), which has only recently gained popularity, has made a significant contribution to technological development and boosted economic activity in this field. Additionally, it has changed the direction of global industry.The last 20 years have seen the usage of VR in a variety of industries, including architecture, education and training, mobile technology, medical visualisation, user interfaces, entertainment,and manufacturing.Because the technology enhances the sensation of immersion, realism, interactivity, and coexistence, VR appears to have a good impact on people. The technique is known to create motion sickness when seen visually (VIMS).To enhance the viewing experience of VR content, earlier research have examined motion sickness using self-reporting, behaviour, and physiological reactions.Studies using self-reporting data showed that subjective rating results from a simulator sickness questionnaire were accurate. Heartbeat Evoked Potential (HEP) is a shift in alpha brain waves that allows the brain to be informed of changes in key organs like the heart, including blood pressure, heart rhythm, and variability.When the heart and brain are in sync, the electroencephalogram (EEG) of the brain shows a similar negative peak at the same time as the R-peak of the ECG signal.When the heart and the brain work together, the electroencephalography (EEG) of the brain shows a matching negative peak at the same time as the R-peak of the ECG signal, indicating motion sickness.

2. Experimental Methods or Methodology

Prior to the main activity, a pre-task was completed to gauge the participants' susceptibility to motion sickness. The participants had to see the VR content through a HUD for 10 minutes before reporting

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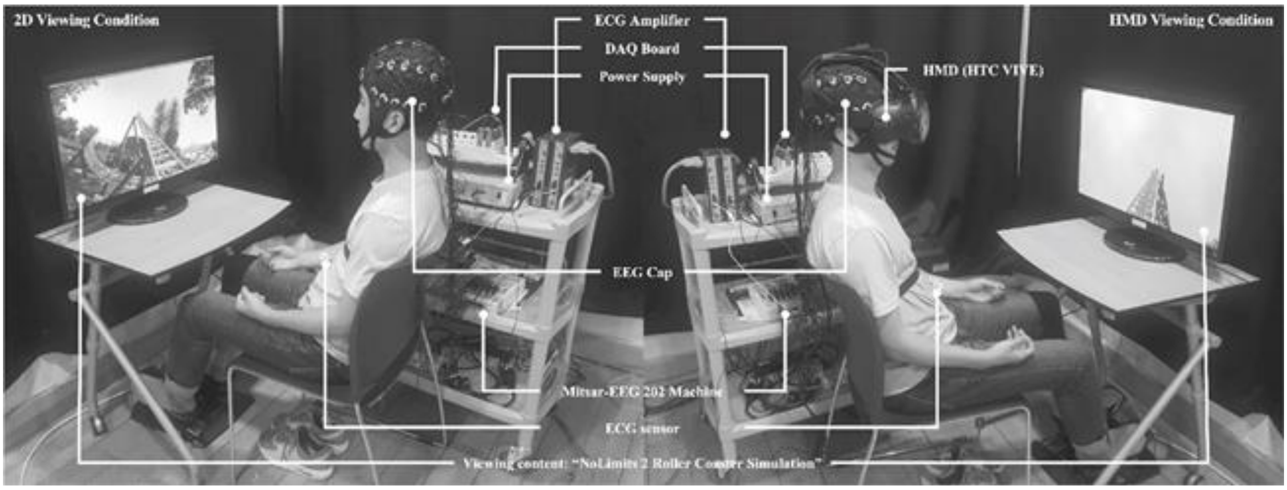
their motion sickness through an interview and subjective rating. The subjective rating, often known as the SSQ, consisted of three factors: nausea (7 items), oculomotor symptoms (7 items), and disorientation (7 items). Before and after seeing the VR content, the participants were additionally asked to self-report subjective motion sickness for 16 items on a four-point scale (0–3) with the following requirements: There are three categories of symptoms that can cause disorientation: (1) nausea (general discomfort, increased salivation, sweating, nausea, difficulty concentrating, stomach awareness, and burping); (2) oculomotor symptoms (general discomfort, fatigue, headache, eyestrain, difficulty focusing, difficulty concentrating, and blurred vision); and (3) disorientation (difficulty focusing, nausea, fullness of head, blurred vision, dizzy (eyes open), dizzy (eyes close), and vertigo The primary experiment did not include participants who did not experience motion sickness or did not experience it to a severe enough degree to end the experiment. On the first day, they viewed the 2D version of the VR content, and on the second, the HMD version, or the other way around. The order of activities (i.e., 2D and HMD) was randomly selected based on a counterbalanced repeated measures design to reduce sequence/order effects because this study was intended "within subject design". Before and after the VR content, there was a reference part that lasted for five minutes. We measured ECG and EEG signals before and after each VR content viewing session.



2.1 Statistical Analysis

This study's "within subject design" objective was to evaluate and contrast viewers' experiences of motion sickness while viewing both 2D and HMD content. In light of the normality test, a paired t-test was run on the sample data. Additionally, this study was submitted to an analysis of covariance because the independent t-test was unable to validate the viewer's status prior to seeing the VR content (ANCOVA). The baseline pre-VR content was used as a covariate in the ANCOVA to compare dependent variables between groups following the VR content. The Bonferroni adjustment was employed to manage statistical significance in order to handle the issue of multiple comparisons based on the number of each individual hypothesis (i.e., 0.05/n). The HEP indicator threshold for this experiment was set at 0.0033 (HEP indicators: alpha power, amplitude, and latency, =0.05/15). To corroborate both the statistical significance and the effect size, the effect size based on Cohen's d and the partial eta-squared value (2 p) were calculated. Cohen's d standard values of 0.10, 0.25, and 0.40 were typically regarded as modest, medium, and big, respectively, in terms of effect size.

3. Results and Discussion

The development of the VR market in general and the HMD device in particular is significantly hampered by VIMS. In order to address this issue, numerous earlier studies have attempted to evaluate motion sickness. But no conventional technique has yet been presented, and the earlier suggested systems had flaws. The purpose of this study was to investigate heart-brain synchronisation (HEPs)

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in order to develop a sophisticated method for evaluating motion sickness based on cognitive performance. This study compared the alpha power of HEP from an earlier study based on the MTMM matrix with novel indicators such as latency and amplitude of HEP to determine motion sickness. This study established whether motion sickness is caused by 2D and HMD viewing situations based on the SSQ. Participants felt motion sickness after the HMD viewing task, but not after the 2D viewing task, according to the subjective assessment from the SSQ.

Overall, the study produces three important results. First of all, motion sickness drastically reduced the alpha powers of the first HEP components in the FP1, FPz, and FP2 areas. Previous research has revealed that afferent and efferent pathways, which are connected to cognitive processes, might affect how the brain processes sensory information. The first HEP component's alpha power increased during cognitive loading, and that finding is consistent with this research. This rise is connected to the time it takes for "rate of change" information to go from the heart to the brain via afferent pathways in the vagus nerve. The first HEP component's alpha power increases when information about heart rhythm is sent quickly to the brain because the brain needs information from sensory input to start cognitive processing. As a result, this study's findings that cognitive stress is the root cause of motion sickness can be inferred from the first HEP component's growing alpha power.

CONCLUSION

The purpose of this work was to develop a technique for measuring motion sickness when viewing VR content on an HMD utilising the HEP phenomena and to suggest a new motion sickness indicator (cognitive function).

This study confirmed that multisensory input from motion sickness causes a decline in cognitive processing in the brain, as seen by decreases in the first HEP component's alpha power in areas FP1, FPz, and FP2. Additionally, in this study's individuals who experienced motion sickness, the suggested indications of latency (initial component in FP1, FPz, and FP2) and amplitude (FP2) of the HEP waveform were considerably different and had stronger correlations with alpha power measurements (cognitive load). When test-retest reliability, discriminant validity, and convergent validity were verified using the MTMM matrix, latencies in the first HEP component were specifically advised as superior quantitative evaluators of motion sickness (cognitive load) than alpha power and other measures. The proposed method is more adaptable than offline approaches like the ERP method since the HEP measures were retrieved from the heartbeat's HEP waveforms, unlike offline approaches. Additionally, our suggested method, implemented in RBF-SVM, performed better than earlier research in classifying the motion-sickness state than cutting-edge motion sickness detection algorithms.

The suggested HEP measurement approach can be used to quantify motion sickness and establish the ideal viewing conditions for VR material, taking into account aspects such as the viewer's characteristics, the viewing environment, the content, and the device. These findings will boost VR's acceptance and stimulate the creation of new VR with fewer harmful side effects.

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