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AN EEG PROTOCOL FOR INVESTIGATING EMOTION RELATED CORTICAL ACTIVITY IN IMMERSIVE VIRTUAL REALITY

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ABSTRACT
Emotion processing depends on distributed cortical networks and is frequently disrupted across neurological and psychiatric disorders yet it is rarely assessed in clinical settings using electrophysiology. This paper is a pre-registered report that represents a specified protocol to characterise the neural correlates of emotions using (electroencephalogram) EEG in an immersive virtual reality(VR) registered with CTRI(India). Three confirmatory hypotheses are proposed, (H1)Theta and Alpha power will show condition dependent modulation, (H2) Frontal Alpha Asymmetry will show valence related hemispheric lateralisation (H3) functional connectivity and graph theoretical networks differ across different emotion conditions. A total of 120 participants will be exposed to positive, negative and neutral emotions in VR while EEG signals are recorded using international standard 10-20 systems. EEG preprocessing and statistical analysis are predefined with repeated measures using ANOVA used for confirmatory testing. A secondary exploratory Support vector machine (SVM) analysis will evaluate whether emotional states can be differentiated across different conditions in EEG features. This protocol is designed for the implementation of standard clinical EEG systems providing a translational framework for future studies in the clinical populations.
KEYWORDS: EEG, Emotions, Virtual Reality, Healthcare, connectivity

INTRODUCTION

Disturbances in emotional processing are clinically significant features in many neurological conditions including epilepsy, stroke, Traumatic brain injury and neurodegenerative disorders(Pessoa, 2008). These impairments contribute substantially to the functional disability in affective behaviour, decision making, social interactions and quality of life. Emotional functions are assessed by a subjective self report questionnaire yet objective electrophysiological measure remains limited in clinical practice. Electroencephalogram(EEG) provides a non-invasive, temporally precise method used to measure brain activity. The established markers of oscillatory patterns, Frontal Alpha Asymmetry, Functional connectivity reflecting different processing of emotional conditions under large scale networks(Buzsáki, 2006; Klimesch, 2012; Bassett & Sporns, 2017). Current EEG paradigms rely on static or two dimensional stimuli which do not fully capture the complexity of real world emotional experience(Pan & Hamilton, 2018).

To address these limitations, it is important to consider how emotional processing is organised at brain networks. Emotional processing involves the coordinated activity across cortical and subcortical systems including prefrontal, limbic, amygdala and associated regions which operates through dynamic network interactions rather than isolated structures(Pessoa, 2008; Rolls, 2023). Capturing these interactions requires a precise method that reflects both temporal dynamics and large scale network organisation. EEG provides a practical approach for this by measuring the oscillations and inter region synchronization.

Functional connectivity and graph theoretical approach provides a framework for quantifying interactions between distributed brain regions and characterizing the network organization during emotional processing(Bassett & Sporns,

2017). There remains a lack of structured protocols that integrate these network measures with experimentally controlled paradigms of different conditions while maintaining compatibility with standardized clinical EEG systems. Experimental paradigms that allow controlled induction of emotional states while maintaining ecological relevance are important for advancing the neurophysiological investigation.

Virtual Reality(VR) has increasingly been adopted in neuroscience for stimulating complex environments and modulating behavioral responses under controlled conditions (Freeman et al., 2017). These paradigms enable presentation of multimodal and dynamic stimuli engaging neural systems more consistently. The combination of VR and EEG offers an emotional processing across multiple levels including regional activation and network levels (Bohil et al., 2011). Although, the pre-defined experimental protocol that integrates immersive stimulation with clinical EEG systems remains limited. The present study addresses this by integrating the VR and EEG system to examine emotional related brain activity by measuring the oscillatory, asymmetry, and connectivity based approaches within structured analytical frameworks.

Objectives

The primary objective of this study is to investigate emotion related brain activity during immersive virtual reality. The aim of this study is to examine the condition dependent differences in spectral powers, frontal alpha asymmetry and functional connectivity across the positive,
neutral and negative emotional conditions. A secondary objective is to assess the differentiation of the emotional states in EEG features

METHODOLOGY

Participants will be recruited through posters shared via online in medical college, A total of 120 individuals aged 18-65 years of both male and female will be recruited for the participation. Inclusion criteria includes individuals with no history of psychiatric or neurological conditions and no history of any diagnosis, major medical condition, and ability to tolerate the immersive virtual reality, exclusions includes individuals with epilepsy, severe motion sickness, and on current medication for illness. MOCA,Becks Depression scale, Hamilton anxiety are used for pre screening for selection of participants. The study including the human subjects conducted in accordance with the Declaration of Helsinki, was approved by the Institutional ethics Board of Sri Ramachandra institute of Higher education and Research with approval number : IEC-NI/25/JAN/100/01. The procedure will be clearly explained and written consent was obtained for all subjects.

Experiment

Emotional states will be elicited using publicly available standardized VR stimuli developed by Stanford University, including environments from Stanford Virtual Human Interaction Lab database, in combination with additional curated 360° VR videos. stimuli will be categorized into positive , negative and neutral conditions. Each video will be presented for 60-90 seconds with a total of 9 videos. Meta Quest 3s device will be used for VR stimuli and continuous EEG was recorded following the international standard 10-20 system electrode placement with sampling rate of 70Hz for estimation of Delta (0.5-3.5Hz), theta (4-7.5Hz), alpha (8-12.5Hz) and beta (13-30Hz) of frequency bands.

Statistics

Statistical analysis will be performed using repeated measures analysis of variance (ANOVA) with emotional conditions. Dependent variables will include spectral powers across frequency bands, frontal asymmetry and functional connectivity measures. Statistical significance will be set at $p<0.05$, secondary exploratory analysis will be done using SVM and leave one subject out(LOSO) cross validation.

DISCUSSIONS

The present protocol frameworks the clinically oriented approach for examining the neural basis of emotional processing in the VR using EEG. The use of controlled experimental conditions allows systematic comparison of emotional states across the brain regions. This is particularly relevant in conditions where affective disturbances are subtle and heterogeneous and it provides a framework for identifying the consistent EEG patterns. The structured experimental design supports reproducibility across different settings with framing the importance of relatable biomarkers. The present framework also supports translational research for future studies with implementation of extending to clinical populations with disorder specific emotional disturbances in the neural activity and plan the structure of therapeutic interventions. This is particularly relevant in psychiatric and neurological conditions where emotional and behavioral disturbances significantly affect the patient's clinical outcomes. Variability in individual emotional responses may influence the clinical EEG patterns, the current study aimed to prioritize clinical feasibility in high resolution of signal acquisition. The protocol offers a clinically relevant and reproducible approach for neural activity of emotional processing with potential implications in research and clinical settings in measuring neurophysiology.

Outcome Measures

The primary outcome of this study is condition dependent features of EEG patterns across different emotional conditions. These will include the patterns in theta and Alpha band of spectral powers. Frontal Alpha Asymmetry calculated from the homologous frontal electrodes interpreting the difference in positive and negative states. Functional connectivity reflecting the regions connected towards the emotions with neural synchronization with graph theoretical metrics will be used to quantify network level organisations. The classification metrics of emotional states will be assessed using SVM with accuracy evaluated using LOSO cross validation.

Data availability

Data generated in this study will be available upon reasonable request, subject to institutional ethical guidelines.

Ethical consideration

The study including the human subjects conducted in accordance with the Declaration of Helsinki, was approved by the Institutional ethics Board of Sri Ramachandra institute of Higher education and Research with approval number : IEC-NI/25/JAN/100/01. The study was conducted according to the institutional requirements and following local legislation. The study was also registered in Clinical Trial Registry of India CTRI: CTRI/2025/07/091939 All the participants were given the consent signed before participating in the research and informed of the rights to withdraw. The data will be solely used only for the research purposes.

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Conflict of interest

The authors declare that they have no known financial or personal relationships that could have appeared to influence the work reported in this paper.

Generative AI

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