INTEGRATING VIRTUAL REALITY, ELECTROENCEPHALOGRAPHY, AND TRANSCRANIAL MAGNETIC STIMULATION TO STUDY THE NEURAL CORRELATES OF AWE EXPERIENCES: THE SUBRAIN PROTOCOL

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Background: Awe is a complex emotion with a positive yet mixed nature that resembles the Romantic concept of the sublime. Over the last twenty years, it has increasingly become the subject of scientific investigation. However, the underlying brain mechanisms remain unclear. In order to fully capture its nature in a laboratory setting, researchers have increasingly relied on virtual reality (VR) as a method of eliciting emotions, even complex ones, in controlled settings.

Aims: The SUBRAIN study proposed an innovative experimental protocol that integrated virtual reality (VR), electroencephalography (EEG) and transcranial magnetic stimulation (TMS) to investigate the brain mechanisms underlying the complex emotion of awe.

Methods: Data was obtained from 42 healthy young adults, including 6 for the pilot study. While participants navigated three awe-inspiring VR scenarios and a neutral one, the brain's electrical activity was recorded using EEG. Cortical excitability and connectivity were then investigated by performing a TMS-EEG session immediately after each VR navigation. Alongside brain signals, self-report questionnaires were used to evaluate changes in the subjects' emotional state induced by VR. This data was then analyzed to investigate the neural mechanisms of awe.

Results: EEG findings suggest that awe introduces complexities in brain activity that could be better captured by nonlinear metrics, such as wavelet entropy, which revealed scenario- and frequency-specific brain mechanisms. Subjectively perceived awe intensity was found to correlate with brain activity in frontal (theta, alpha, beta and gamma bands) and right temporal (theta, alpha and gamma bands) lobes. Combining EEG microstates with explainable AI enabled us to classify awe-inducing vs. awe-neutral VR with 75% accuracy, with transitions between default mode network and other brain networks playing a key discriminating role. TMS-EEG data also showed differences between scenarios and awe intensity, demonstrating the ability of electrophysiological measures to capture the different neural mechanisms underlying different instances of awe.

Conclusions: SUBRAIN is the first study to investigate the brain activity and connectivity underlying awe experiences in VR. Pairing awe-inducing VR experiences with questionnaires investigating participants' emotions and feelings, and using non-invasive neural techniques, provided extensive and novel knowledge on this complex phenomenon.

Keywords: Awe, Virtual reality, EEG, Neuromodulation

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