The Quality of Phosphene Perception is Determined by the Amplitude-Modulated Frequency and Oscillation Patterns within Transcranial Electric Stimulation

Che-Yi Hsu
Institute of Cognitive Neuroscience, National Central University

Abstract

Brain oscillations not only correlate with visual awareness but also play an active role in its underlying mechanisms. While most studies emphasize linear oscillatory properties, the role of nonlinear oscillations, especially amplitude modulation (AM), in visual perception remains unclear. This study investigates the role of AM oscillations in phosphene perception through two experiments using transcranial electric stimulation methods.

In Experiment 1, transcranial alternating current stimulation (tACS) was employed to elicit phosphenes illusory flashes perceived without retinal photon stimulation in 12 healthy participants (4 females, aged 20–44 years). Results demonstrated that AM tACS induced phosphene perception with a higher threshold intensity than sinusoidal stimulation. Participants were more sensitive to frequencies around the beta band, and AM stimulation overrode carrier frequency effects, leading to slower perceived flashing rates regardless of carrier frequency. This suggests that the perceived flashing frequency of AM-tACS induced phosphenes is primarily dictated by the AM frequency, potentially overriding the influence of the carrier frequency.

In Experiment 2, we utilized oscillatory transcranial direct current stimulation (otDCS) with a fixed polarity compared to tACS. This is based on previous research that shows transcranial alternating current stimulation (tACS) is capable of eliciting phosphenes. However, the specific mechanisms underlying the effects of rhythmic electric field fluctuations and the alternation of polarity remain unclear. To address this issue, Twenty-five participants (12 females, aged 20–45 years) received otDCS and tACS over the occipital lobe under anodal, cathodal, and polarity-switching conditions. The AM effect was robust across all polarity conditions, indicating that relative changes, rather than absolute electric field magnitudes, drive phosphene perception. Additionally, otDCS conditions revealed polarity-dependent differences, with anodal stimulation producing brighter phosphenes compared to both cathodal otDCS and tACS. Moreover, tACS elicited faster response times than both cathodal and anodal otDCS. AM frequencies induced higher thresholds and slower response times than sinusoidal frequencies, suggesting the critical role of amplitude modulation in temporal information processing.

These findings highlight that AM plays a crucial role in visual perception, likely through neural phase-locking mechanisms to its envelope. The study demonstrates that AM frequency, polarity, and oscillation are substantial factors influencing visual awareness. These insights also suggest potential therapeutic applications in visual disorders.