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Resolving inconsistent effects of tDCS on learning using a homeostatic structural plasticity model

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Transcranial direct current stimulation (tDCS) is increasingly used to modulate motor learning and rehabilitation, yet its effects vary depending on polarity, intensity, electrode montage, and timing. Traditional models based on Hebbian or homeostatic plasticity only partially explain these inconsistencies. We propose that homeostatic structural plasticity (HSP) can offer a more comprehensive explanation. Using a spiking neural network model governed by HSP, we simulated motor learning alongside different tDCS protocols.

Our results show that the timing and spatial targeting of tDCS critically determine its impact on motor learning. tDCS applied before learning had minimal effects, slightly reducing connectivity when applied uniformly. During learning, targeted anodal stimulation enhanced engram connectivity, while cathodal or uniform stimulation weakened it. When applied after learning, only targeted cathodal tDCS increased engram strength. Non-specific or strong stimulation tended to distort engram structure.

These findings suggest that both facilitatory and inhibitory effects of tDCS observed in human studies can be explained through changes in engram connectivity under HSP. Our model provides a mechanistic framework for understanding how tDCS modulates memory formation depending on application parameters, potentially guiding more effective and individualized stimulation protocols.

References

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