EyeEEG: Deep learning modelling of pupillary dynamics based on intracranial EEG

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Abstract

Introduction: Pupillary dynamics reflect cognitive processes through four main neural circuits that integrate sensory and cognitive information to modulate pupil size: the parasympathetic and sympathetic pathways, a locus coeruleus-centred circuit, and a superior colliculus-centred circuit. We aim to model the relationship between brain activity, pupil-size dynamics, and cognitive performance across two tasks: (1) an attentional shifting task (Set-Shift), and (2) a cluttered scene visual search task (Curious George).

Methods: We employed time-resolved hierarchical mixed-effects modelling to correlate pupil dynamics with performance. To model brain-pupil coupling, we leveraged convolutional neural networks and vision transformer architectures to predict pupil time courses from intracranial electroencephalography (iEEG) signals.

Results: In Set-Shift (n=13), smaller peri-stimulus pupil diameter was associated with faster response ($p<0.05$ after permutation cluster correction). Similarly in Curious George (n=9), smaller pupil diameter preceding target identification was associated with more focused search strategy ($p<0.05$ after correction), demonstrating a link between pupillometry and performance. We then developed a deep learning model to predict pupil size from iEEG signals. Due to varying electrode placements, subject-specific models successfully predicted pupil diameter in 5 of 12 subjects ($p<0.001$; mean R=0.47 (95% CI of 0.32-0.63)). We tested generalizability of this model in one subject with data from both tasks. Using the weights trained from Set-Shift, the model yielded mean r=0.4, p=1×10-5 in Curious George, suggesting that the predictive neural patterns are generalizable across tasks.

Conclusion: Our findings demonstrate that pupil size serves as a valuable index of neural activity and cognitive performance across distinct task paradigms. This study advances understanding of brain-pupil coupling by revealing patterns in brain activity and pupillary dynamics.