The Potential of Artificial Intelligence in Detecting Cognitive Load

Abstract:

Recognizing and effectively managing cognitive load plays a pivotal role in optimizing learning and working environments and may enable real-time workload allocation tailored to individual capabilities and has implications for managing mental health. This study investigates the potential of detecting the onset of cognitively loading events by analyzing individuals' pupil and eye movement responses to a variety of laboratory-based tasks. A total of 58 participants completed four distinct tasks: Dot Probe Task (DPT), Mental Arithmetic (MA), Psychomotor Vigilance Task (PVT), and Visual Working Memory (VWM). During the tasks, their pupil size and gaze positions were recorded with a computer-mounted eye tracker. Among the task sets, the DPT had 160 onset times, the MA task had 40 onset times, the PVT had 80 onset times, and the VWM task had 144 onset times. The problem was framed as a binary classification task, wherein 1 second windows were labeled as 1 if they occurred immediately after a trial onset and 0 if not. A Convolutional Neural Network (CNN) architecture was employed as the model for training the tasks, and the model's performance was evaluated using the F1 score metric. Among the individual tasks, the DPT task demonstrated the highest F1 score of 0.91, followed by the MA task with a score of 0.82, and the PVT task with a score of 0.80. The VWM task exhibited the lowest performance, yielding an F1 score of 0.39, slightly better than random guessing but falling short of reliable predictive capability. When training all four tasks together, the model achieved an F1 score of 0.70, indicating limited generalization ability. Although the general model underperformed compared to the individual DPT, MA, and PVT tasks, it displayed promising results beyond random guessing.

The model utilized both pupil size and gaze position for prediction, with pupil size predominantly driving the outcomes. By solely considering pupil size, the average F1 score across the five experiments reached 0.67. However, incorporating gaze position improved the average F1 score to 0.72. The Machine Learning model successfully predicted the onset time using pupil size due to the observed pattern. Its behavior aligned with Hoffing's research, except for the PVT task. Generally, the data exhibited an initial contraction in pupil size after the onset, followed by rapid dilation, resulting in a peak pupil size larger than the size at the onset time. The PVT task displayed solely dilation in pupil size without an initial contraction. The smallest pupil size, marking the end of the contraction phase, typically occurred between 0.6 and 0.8 seconds after the onset time. Regarding the magnitude of the drop in pupil size, the DPT task demonstrated the most substantial decrease of approximately 0.4 mm, while the other tasks exhibited a decrease of approximately 0.1 mm. Following the contraction phase, the pupil continued to dilate, with the peak size varying depending on the task duration. For short tasks like PVT, the peak occurred around 0.5 to 1 second after the onset, while medium tasks like VWM and DPT displayed peaks around 1.5 to 2.5 seconds. In contrast, longer tasks like MA typically exhibited peaks after approximately 3.5 seconds. These results demonstrate the potential of AI in accurately predicting cognitive load based on pupil and eye movement responses, paving the way for future advancements in personalized learning and optimizing cognitive workload allocation.