Optimal time interval reproduction in a neural circuit model

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Humans and other animals combine current sensory information and expectations based on prior knowledge to drive behaviors. Such interaction between immediate and prior experience is likely used to minimize errors and is therefore often described with Bayesian models. The neural implementation, however, remains open.

Here we investigate a neural circuit model that has been proposed recently to explain various timing behaviors, including the reproduction of time intervals (Egger et al. 2020). Time reproduction is one of the behavioral methods to investigate error minimization and related optimal behavioral strategies. In such experiments, behavioral responses are characterized by specific biases such as the central tendency or regression effect, i.e. the overestimation of small time intervals and the underestimation of large ones.

The model comprises two mutually inhibitory units that receive a shared, tonic input. A third unit functions as a readout unit. The input to the circuit controls at which speed the readout unit increases its activity and therefore scales its responses such that a threshold is reached at different times. Scaling of neural activity has been described experimentally in connection with timing behavior (Wang et al. 2018, Egger et al. 2019, Meirhaeghe et al. 2021). During the presentation of the stimulus interval, the circuit predicts the to-be-reproduced duration. From the mismatch between this prediction and the actual stimulus duration, an error signal is derived, according to which the input and consequently the speed is adjusted for the subsequent reproduction.

We used the circuit to simulate interval reproduction experiments and explored the conditions for robust time estimates that are consistent with characteristic behavioral effects, e.g., more pronounced central tendency for stimulus ranges with longer durations (range effect). A crucial parameter is the weight with which the input to the circuit is adjusted to balance the mismatch between the predicted interval and the stimulus duration. Adjusting this weight in accordance with error minimization, leads to putting more weight on the prior experience for longer stimuli, which naturally entail more uncertainty, and is thus biological plausible.

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