Belief embodiment through eye movements facilitates memory-guided navigation

Abstract: Natural behavior is flexible and supported by abstracted away beliefs. Over the course of evolution, the brain evolved complex recurrent networks to interpret and act upon a dynamic and uncertain world, but its computational powers and mechanisms generating natural behavior remain largely a mystery. Most of our insights into neural computation are based on binary tasks with highly constrained actions that are artificially segregated from perception. Tightly controlling laboratory behavior by preventing natural, continuous movements has simplified interpretability but also hindered our ability to gain insights from natural behavioral strategies. Artificially keeping the eyes fixed, for example, has been standard in monkey studies of working memory and decision-making

To understand dynamic neural processing underlying natural behaviour, we use continuous-time foraging tasks in virtual reality. Although task rules do not require any particular eye movement, we find that where subjects look is an important component of the behavior. For example, during a simple task in which humans use a joystick to steer and catch flashing fireflies in a virtual visual environment lacking position cues, subjects physically track the latent task variable with their gaze. Restraining eye movements worsened task performance suggesting that embodiment plays a computational role. We show this strategy to be true also during an inertial version of the task in the absence of optic flow and demonstrate that these task-relevant eye movements reflect an embodiment of the subjects' dynamically evolving internal beliefs about the goal. A neural network model with tuned recurrent connectivity between oculomotor and evidence-integrating parietal circuits accounted for this behavioral strategy. Critically, this model better explained neural data from monkeys' posterior parietal cortex compared to task-optimized models unconstrained by such an oculomotor-based cognitive strategy. These results highlight the importance of unconstrained movement in working memory computations and establish a functional significance of oculomotor signals for evidence-integration and navigation computations via embodied cognition.