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Title: Stochastic optimal control as a theory of brain-machine interface operation

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Abstract

The closed-loop operation of brain-machine interfaces (BMI) provides a framework to study the mechanisms behind neural control through a restricted output channel, with emerging clinical applications to stroke, degenerative disease, and trauma. Despite significant empirically-driven improvements in closed-loop BMI systems, a fundamental, experimentally-validated theory of closed-loop BMI operation is lacking. Here we propose a compact model based on stochastic optimal control to describe the brain in skillfully operating canonical decoding algorithms. The model produces goal-directed BMI movements with sensory feedback and intrinsically noisy neural output signals. Various experimentally-validated phenomena emerge naturally from this model, including performance deterioration with bin width, compensation of biased decoders, and shifts in tuning curves between arm control and BMI control.

Analysis of the model provides insight into possible mechanisms underlying these behaviors, with testable predictions. Spike binning may erode performance in part from intrinsic control-dependent constraints, regardless of decoding accuracy. In compensating decoder bias, the brain may incur an energetic cost associated with action potential production. Tuning curve shifts, seen after the mastery of a BMI-based skill, may reflect the brain's implementation of a new closed-loop control policy. The direction and magnitude of tuning curve shifts may be altered by decoder structure, ensemble size, and the costs of closed-loop control. Looking forward, the model provides a framework for the design and simulated testing of an emerging class of BMI algorithms that seek to directly exploit the presence of a human in the loop.

Keywords

stochastic optimal control, closed-loop behavior, brain-machine interface, neuroprosthetic device, paralysis

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