III-59. Integrative properties of motor cortex pyramidal cells during quiet wakefulness and movement

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The primary motor cortex (M1) plays a prominent role in the initiation and control of voluntary movements. Due to its direct link with behaviour, M1 is an ideal platform to study how brain state and behaviour are related to single neuron dynamics. We perform patch-clamp recordings and somatic current injections in the M1 of awake mice to characterise the intracellular activity and integrative properties of excitatory neurons in supercial (L2/3) and deep (L5B) layers during quiet wakefulness and movement. We find that during quiet wakefulness, L2/3 neurons display sparse spiking activity (0.5+0.7 Hz) while L5B cells display sustained firing (5.6+3.5 Hz) and that the membrane potential (Vm) in both cortical layers is characterized by slow fluctuations in the delta-band range (2-4 Hz). We identified two subpopulations of pyramidal cells in L5B -the main output layer of M1- that either suppressed (L5Bsupp) or enhanced (L5Benh) their firing rates during movement. In L5Bsupp neurons, movement decreased slow Vm oscillations and variance with no change in mean Vm, resulting in divisive gain modulation and reduced spike rates. In L5Benh neurons, movement also reduced slow Vm oscillations but this effect was counterbalanced by a net depolarization and increased Vm fluctuations in the high frequency band (12-50 Hz), resulting in increased firing rates. Based on integrate-and-fire simulations, we estimate that during movement L5Benh neurons preferentially receive an increase in excitatory inputs (%) with more substantial correlations on a fine time-scale. Together, these changes have a linear multiplicative effect on the input-output gain of L5Benh neurons. Our data demonstrate a remarkable diversity among cortical layers, a strong modulation of integrative properties depending on brain state and suggest that the cortex exploits behavior-dependent modes of operation.

III-60. Neural dynamics following optogenetic disruption of motor preparation

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The structure of neural activity in primate primary motor (M1) and dorsal premotor (PMd) cortex suggests that movement preparation drives cortical activity to a beneficial state for initiating movement, leading to quicker reaction times (RTs). Subthreshold electrical microstimulation in PMd largely erases this RT benefit (Churchland 2007), hypothesized to result from a time-consuming 'replanning' process. However, recent evidence demonstrates that movement may proceed without passing through this preparatory state (Ames 2012). Here, we asked whether disrupting preparatory activity instead slows RTs because post-stimulation neural activity follows a distinct peri-movement trajectory relative to non-stimulated trials. We employed optogenetic perturbation to probe the neural dynamics which underlie this behavioral disruption. We targeted the excitatory opsin C1V1TT to putative excitatory neurons in the arm region of PMd of two rhesus macaques trained on an instructed-delay reaching task. Optical stimulation (200ms continuous-pulse) in PMd delivered during the delay period within 100ms of the movement cue (late-stimulation) slowed RTs relative to non-stimulated trials, demonstrating that optical stimulation can disrupt movement preparation. To our knowledge, this represents the first optogenetically-mediated

behavioral effect in the primate arm-motor system. Stimulation delivered $>$200ms before the movement cue (early-stimulation) did not affect RTs, suggesting that PMd can recover from optogenetic disruption on a rapid timescale. We computed the difference in PMd/M1 population firing rates on stimulated versus non-stimulated trials. Both early- and late-stimulation pushed neural state significantly away from non-stimulated trajectories. By movement onset, neural differences largely (though not completely) decayed for early stimulation trials, whereas these differences persisted into the movement time for late-stimulation trials. Therefore, targeted optogenetic perturbation of premotor cortical activity can disrupt motor preparation by diverting neural activity onto a distinct, presumably less-beneficial peri-movement trajectory.

III-61. Characterization of dynamical activity in motor cortex

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There has been increasing interest recently in understanding the role that internal dynamics play in the response of neural populations, in both sensory [1] and motor systems [2]. In particular, [2] has recently shown evidence of consistent, internally-driven dynamical activity in populations of motor cortical neurons by focusing on rotations in the neural state space. However, that work stopped short of exploring other dynamical features or characterizing their dominance. Here we characterize the structure of neural population dynamics by studying canonical features including: i) expansive vs. rotational structure (the two building blocks of simple linear systems); ii) time invariance vs. variance (to examine the temporal complexity of data); and iii) normality vs. nonnormality (a feature of theoretical importance due to its connection to Hebbian vs. balanced amplification [3]). Here we present algorithms that enable analysis of all these dynamical features. While time invariance vs. variance can be studied with simple least squares, the other features require novel contributions. Expansive systems are fit using new extensions to the method in [2], and fitting normal systems requires extensions to and combinations of classic results from differential geometry and linear algebra, which we derive below. We use these novel methods to analyze data from motor cortex. Despite the simplicity of the linear time invariant model, we show that activity across many different experimental conditions has consistently strong dynamics fitting this model (48.5% of the data variance is explained), and furthermore that the linear time invariant component is highly normal and rotational (93.2% and 91.3% of the time invariant system, respectively). In contrast, the time invariant system has trivial expansive component (8.7%). In all, this work deepens the characterization of dynamics in motor cortex and introduces analyses that can be used similarly across other cortical areas.

III-62. Decoding arm movements from hybrid spike-field potentials in human motor cortex

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Action potentials recorded in motor cortex offer an information-rich input to motor prosthetic applications, yet recording stable spiking activity from the same neuronal population across months to years is an unresolved