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Title: Learning the complex mechanics of the Drosophila flight system

Abstract: The flight system of a fly needs to provide precise control of wing motion and the resulting aerodynamic forces for a wide variety of scenarios. To avoid aerial predators, the fly needs to execute an escape maneuver within a fraction of second. If a wing gets damaged, the left and right wing motion needs to be altered drastically to sustain stable flight. Under turbulent wind conditions, the fly needs to constantly trim its wing motion to stay horizontal. Thus, the actuation of wing motion needs to be fast, precise and span a large dynamic range. Surprisingly, flies achieve this level of actuation with just 12 steering muscles per wing. Each steering muscle is innervated by a single motor neuron, making the neural encoding of fly flight extremely sparse. Despite the low number of actuators, the effect of individual steering muscles on wing motion remains unknown as the mechanical complexity of the wing hinge makes it impossible to infer functionality from geometry. To study how neural activity is transformed into an aerodynamic control force, we built a high-speed camera setup that can simultaneously image the wing motion of a fly and its muscle activity using the calcium indicator GCaMP. We have collected a vast dataset of muscle activity and wing motion for hundreds of flies and subsequently trained a convolutional neural network on this dataset to learn the complex mechanics of wing actuation. The trained neural network can accurately predict the wing kinematics using unseen muscle activity traces. By computing the aerodynamic force vector produced by the predicted wing kinematics we have an accurate and complete model of how neural activity of motor neurons is transformed into aerodynamic control forces which are the basis of the fly’s versatile flight behavior.