Models of rodent facial musculature for the study of active tactile sensing

SPECIFIC AIMS

The rodent vibrissal (whisker) system is one of the most widely-used models in neuroscience for the study of thalamocortical processing, sensorimotor integration, and active sensing[1-3]. During many tactile exploratory behaviors, rats and mice sweep their whiskers back and forth in a rapid, rhythmic motion called "whisking"[4-7]. Our understanding of how the nervous system processes sensory signals from the whiskers has progressed rapidly over the past decade[8-22]. Impressive progress has also been made in understanding the motor control of whisking, and it is now known to be driven by a brainstem central pattern generator[24]. At the same time, behavioral studies have revealed highly complex, task-specific whisking motions, including unilateral variability in whisker spacing, amplitude, frequency, and velocity, as well as extensive bilateral asymmetries in these parameters[26-35].

Whisking is thus a fundamentally rhythmic sensing behavior, but also incorporates a wide variety of task-specific movements to support diverse behavioral requirements. Researchers working in the vibrissal system are ***nearly*** poised to begin a wealth of systems-level investigations of closed-loop motor control and sensory acquisition.

One critical gap prevents the field from performing many of these important closed-loop studies: we do not yet have a three dimensional (3D) model of rodent facial musculature. Without such a model, we cannot identify the patterns of muscle activation that underlie changes in whisking parameters. We cannot know the degree to which different features of whisking are under biomechanical constraint versus which are neurally controlled. We cannot fully understand descending neural control of whisking motions. We cannot understand the mechanisms by which the rat changes whisking motions to acquire particular types of sensory information.

The central goal of this proposal is to develop 3D models of rodent facial musculature that close this gap. The models will expose the mechanical degrees of freedom available during whisking; will identify the biomechanical constraints on whisking behavior; and will be combined with dynamic simulations of vibrissal sensing to expose the neuromechanical basis for whisking variability during exploratory behaviors.

My laboratory is uniquely qualified to undertake the proposed work, as we have spent more than a decade developing mechanical models of vibrissal-based sensory touch[36-44]. We now turn our attention to the motor plant, aided by several toolsets we have developed over the years. The proposed work exploits our models of the morphology of the rat and mouse vibrissal arrays[45-49], our advances in quantifying 3D head and whisker motions[50-53], and our suite of vibrissal mechanical models[36-44], including a recently-developed dynamical model of the complete rat vibrissal array[54, 55].

Aim 1: Quantify key elements of the 3D anatomy of the mystacial pad musculature and follicles. Previous studies have provided excellent descriptions and schematics of muscle anatomy[25, 56-66], but we lack critical quantitative data needed to construct a 3D muscle model. We will use a novel combination of tactile profilometry, histology, MRI, and micro-CT to *meet the need* for accurate anatomical models.

Aim 2: Construct a 3D model of the mystacial pad musculature and follicles to simulate motion of the vibrissal array. We do not aim for an exact model, but rather one that can tell us about relative functional relationships between muscles. The model will be closely based on papers by Haidarliu et al.,[25, 56, 57, 63, 64] and gradually incorporate the new anatomy of Aim 1. We will use high-speed 3D kinematic analysis to constrain the model and *test eleven specific predictions of previous studies.*

Aim 3: Integrate 3D models of mystacial pad musculature with 3D models of vibrissal dynamics to perform experiments that close the vibrissal active-sensing loop. We combine the model developed in Aims 1 and 2 with our established models of vibrissal mechanics[36-44, 54, 55] to disentangle the relative roles of neural motor control and biomechanical constraint during different types of exploratory behavior. By integrating tactile feedback from the whiskers, we take a step towards closing the loop between motor action and the sensory data acquired. *Three specific hypotheses will be tested in the sub-aims.*

The proposed work will inform all levels of study of the vibrissal-trigeminal system, from primary sensory neurons to sensory and motor cortical areas, to brainstem regions involved in controlling whisker motions. More generally, whisking represents a unique window into how volitional control can modulate or override centrally-patterned movement. The transition between varieties of rhythmic and non-rhythmic movement has important implications for the coordination of sniffing, breathing, olfaction, chewing, swallowing, and suckling, and the proposed work thus could shed light on the neuromechanical basis for some pediatric and geriatric dysphagias.