

NEURAL AND MECHANICAL BASES OF MOTOR PRIMITIVES: TOWARD AN ANATOMICALLY CORRECT MODEL OF SENSORIMOTOR INTEGRATION

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INTRODUCTION / BACKGROUND

Motor Primitives- Building blocks of movement organization

- Motor primitives are muscle groups with individually weighted muscle activations and form a modular basis for movement
- The linear combination of motor primitives can produce observed motion
- Concept of motor primitives simplify motion control issues like the degrees-of-freedom problem.
- Motor primitives in spinal cord may form a significant substrate for therapies based on neuroengineering, brain machine interfaces and directed transplantation or neural bridging.
- Of particular concern is the role of sensory feedback on modularity

Simplicity of the β -fusimotor system:

- Mammalian motor system uncouples the γ -feedback control from the α -motor outflow unlike the β -fusimotor system which couples these
- The purely β -fusimotor neural organization in frogs simplifies this issue enabling proprioception to be fully modeled
- Significant physiological and theoretical advances may be made by 'leveraging' such simplicity.

GOALS

- To understand motor primitives better, we are building a detailed model of the frog limb and jaw control. We use these to examine how **beta spindle proprioception may be optimally integrated to control motion**, and also how it may contribute to selection and organization of motor primitives. To achieve this we aim at creating a functionally and anatomically correct neuro-musculo-skeletal model using the following tools:

Cryoplane block-face imaging:

- We use cryoplane microscopy to develop high resolution (20 μ m) 3D reconstructions of a body part.
- Select structures may be outfilled. For example, to obtain spindle distributions in the legs the lumbar dorsal roots are outfilled with Lucifer yellow.

Laser diffraction and sarcomere length:

- Sarcomeres form a nice striation pattern that resemble a diffraction grating
- We are also exploring obtaining sarcomere measures from the frozen tissue with laser interferometry.

3D biomechanical modeling:

- The data are used in a range of models. These vary from simpler Visual Nastran based and SIMM models, to a Cosserat strand utilizing muscle model being built in collaboration with colleagues at UBC in Canada.
- Cosserat strands allow better modeling of soft tissue interactions and will allow us to predict population spindle data in compound stranded muscles with realistic wrapping interactions

Major advantage: all data collected from same specimen

- More accurate reconstruction, integration and modeling

FROG HINDLIMB- MODELLING THE JUMP

Objective

- Image and reconstruct high resolution 3D musculoskeletal model of the hind limb
- Obtain spindle and GTO distribution in the leg muscles
- Obtain detailed EMG, kinetic and kinematic measurements during various jumping activities

Preliminary Result

- 20 μ m thick sections with 20 μ m resolution
- Muscle contrast improved with black-magic perfusion leads to better segmentation
- Greater detail than X-Ray or CAT scan reconstructions



FROG HEAD- MODELING THE PREY STRIKE



Objective

- Image and reconstruct high resolution 3D musculoskeletal model of the frog head
- Obtain spindle and GTO distribution in the face, jaw and neck and tongue muscles
- Obtain detailed EMG and kinematic measurements from the muscles involved in prey strike

Preliminary Result

- 20 μ m thick sections with 20 μ m resolution
- Muscle contrast improved with black-magic perfusion for better segmentation
- Greater detail than X-Ray or CAT scan reconstructions



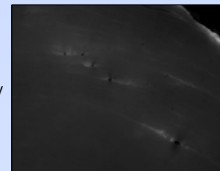
MUSCLE SPINDLE AND GTO DENSITY AND DISTRIBUTION

Objective

- To obtain densities of the muscle spindle and Golgi-tendon organs in the muscles of the frog head and hind limb
- Use differential outfill-staining to separately stain afferent and efferent nerves

Preliminary Result

- Sciatic nerve bundle stained with 2% Lucifer Yellow dye
- Image shows patches of nerves within the RA muscle
- Nerve terminations include motor end plates, spindles or GTO



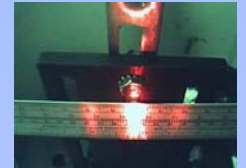
SARCOMERE LENGTH MEASUREMENT

Objective

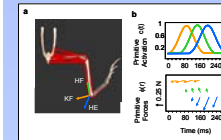
- Using laser interferometry to estimate the sarcomere lengths for different muscles from the cryoplane sections

Preliminary Result

- 50 μ m thick sections displayed best diffraction patterns
- Preliminary results estimate sarcomere length of a single muscle at 2.6 μ m in-situ



3D BIOMECHANICAL MODELLING



Objective

- To use more anatomically correct muscle model (strand) instead of the conventional 2-point actuator (Hill) model
- Create a functionally and anatomically correct neuro-musculo-skeletal model using:
 - 3D reconstruction of the skeletal and muscular system
 - Spindle and GTO density and distribution
 - Sarcomere length measurements
 - Force, EMG and neural signals
 - Kinematics data from motion capture

COLLABORATORS

CRYOTOME IMAGING-FLUORESCENT AND BRIGHT FIELD IMAGING:

- **Jonathan Nissanov:** Associate Professor, Dept. of Neurobiology and Anatomy, Drexel University, PA
 - Louise Bertrand: Research Specialist, Histologist
 - Song Liu: Technician

PREY STRIKE- HEAD AND NECK EMG:

- **Kiisa C. Nishikawa:** Regents' Professor, Dept. of Biological Sciences, Northern Arizona University, AZ
 - Jenna Monroy: Research Postdoc
 - Theodore A. Uyeno: Research Postdoc

BIOMECHANICAL MODELLING- MUSCLE STRAND MODEL:

- **Dinesh K. Pai:** Professor and Tier 1 Canada Research Chair, Department of Computer Science, University of British Columbia, Canada
 - Shinjiro Sueda: Doctoral Student

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