Locomotor control of *Polypterus senegalus* in viscous water

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1 Abstract

Animal locomotion is the result of concerted efforts of central pattern generators, sensory feedback, reflexes, the mechanical properties of bones, muscles and tendons and the physical environment. The combination of these components allows animals to adjust their locomotor output to appropriately match their environment. Amphibious animals, for example, have control systems that allow them to locomote effectively in both gravity/friction and viscosity/inertia dominated environments. Neurosensory and mechanical feedback influence motor control and can do so independent of cortical descending command. Bypassing cortical processing allows for rapid integration of environmental conditions into motor control changes and effective movement in novel environments.

Polypterus senegalus is a basal actinopterygian fish from the freshwater lakes and rivers of Africa that spends most of its time in water. However, these fish are capable of several terrestrial gaits in response to different terrestrial substrates. To what degree changes in neurosensory feedback from the different substrate types is controlling these locomotory gait changes is unknown; however, it is evident that the locomotor control system of *P. senegalus* possesses the flexibility to adjust its motor output to novel environmental conditions. The goal of our study is to use differences in environmental conditions to change the mechanical forces experienced by *P. senegalus* and understand how the associated changes in mechanical and sensory feedback are integrated into effective locomotion in an aquatic environment.

I presented fish with different viscosities of water (1 cP, 5 cP, 10 cP and 40 cP) and recorded their kinematic and muscle activity responses. Despite a 40-fold change in Reynolds number ($Re_{1\ cP} = 12000$, $Re_{40\ cP} = 300$), and an accompanying shift in flow regimen, *P. senegalus* maintain their swim speed in increased water viscosity. They achieve this by increasing the intensity of muscle activation (Figure 1) to create larger amplitude body undulation and higher wave speed and frequency (Figure 2). Since muscle activity is a direct result of motor neuron activity, these results suggest that the locomotor control system output is ramped up in high viscosity water to compensate for the increased mechanical resistance to swimming. However, these results do not allow us to determine the exact cause of this gross change.

Future work will test two hypotheses that could explain the observed change in motor control: (1) Sensory feedback to the pallium is driving the observed changes and (2) local

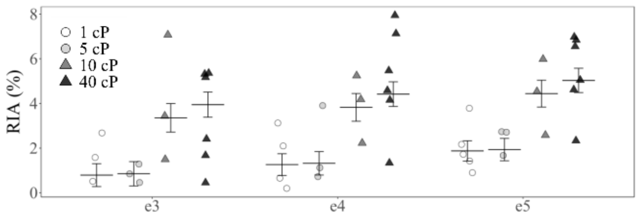

Figure 1. Muscle activation intensity increases in the posterior of *P. senegalus* in response to increased viscosity. Position along the body of the fish is along the x-axis. e3-e5, posterior three of five electrodes spaced evenly between the pectoral and anal fins. Viscosity is indicated by color and shape. RIA was calculated as a percentage of the theoretical max RIA (maximum amplitude for a burst x burst duration). RIA is significantly higher at all positions in 10 cP and 40 cP than at 1 cP.

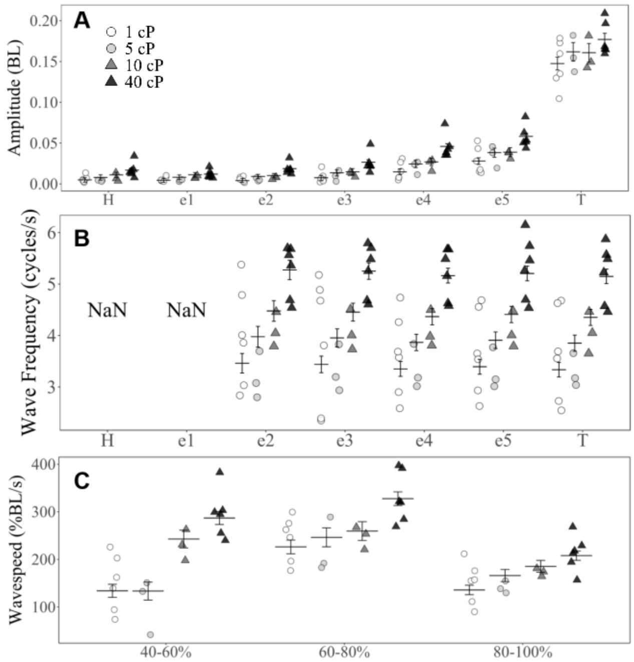

Figure 2. Amplitude of undulation (A), wave frequency (B) and wavespeed (C) increase during swimming in increased viscosity. Position along the body of the fish is along the x-axis. H, head; e1 – e5, positions of evenly spaced electrodes between the pectoral and anal fin; T, tail. Viscosity is indicated by color and shape. Wave frequency was not measured at the head and e1 since cyclical motion was not observed at 1 and 5 cP at these body positions. All variables are significantly higher at 40 cP than at 1 cP.

sensory feedback directly to the spinal cord is driving the observed changes. We discuss future experiments blocking lateral line, blocking vision and using a decerebrate, semi-intact prep (thereby removing any influence of the pallium on the observed motor control) which are the initial stages of teasing apart whether hypothesis (1) or (2) apply in this system. These tests will allow us to determine which sensory feedback systems are co-opted in this novel hydromechanical environment.