The Contribution of Morphological Characteristics to the Bouncing Gait of Sea Stars: A Cross-Species Comparison

Rowan Etzel '19

A novel discovery in the Johnson lab is that of a previously undescribed underwater bouncing gait in sea stars, a type of locomotion that differs from the formerly described crawling gait. The bouncing gait is characterized by the coordinated movement of a sea star's podia, or tube feet, and is associated with an increase in speed from the crawling gait (Ellers *et al.*, 2014; Johnson *et al.*, 2017, Ellers *et al.*, 2018). In the lab, the bouncing gait can be induced by inverting the sea stars to agitate them. We are interested in how well the mechanics of the bouncing gait fit an accepted terrestrial model of locomotion called the inverted pendulum model, whether or how the locomotion-relevant geometric scaling of individuals changes with size, and how various morphological differences (such as sea star arm length, ambulacral area, density, height, and podial area) can inform differences in bouncing behavior between sea star species.

To study this, sea stars were filmed in recirculating seawater flow tanks using two cameras, placed below and to the side, to capture the gaits. The goals of filming were to film crawling and bouncing gaits, the transition between gaits and the fastest speed of each sea star. Tracker software was used to gather raw position and time data, which were processed using a *Mathematica* program to determine parameters such as maximum speed across three bounces and bouncing frequency.

This summer my work was centered on analysis and preparation of our comprehensive *Asterias forbesi* data set for publication (including the data I collected last summer to fill in gaps in the data obtained in 2015 for individuals of *Asterias forbesi* and to expand the size range on both ends to include microscopic juveniles (~1 mm in diameter) and very large sea stars (~20 cm in diameter)). This summer I also compared the bouncing gaits among three species: *Asterias forbesi*, *Protoreaster nodosus* (the original species in which bouncing was observed in 2013), and *Luidia clathrata* (a species found in Florida). I filmed five *Luidia clathrata* using the same methods as for *Asterias forbesi* and analyzed the *Protoreaster nodosus* data using the updated protocols to compare them both to our *Asterias forbesi* results.

I observed differences in frequency, amplitude, maximum and minimum speed, and average speed across species, and examined the relationships of these parameters with morphological variation between species as a potential explanation. I found that shape in *Asterias forbesi* and *Protoreaster nodosus* does not scale isometrically, meaning that they change shape as they grow. In contrast, *Luidia clathrata* does scale isometrically, so a large sea star should have the same proportions as a smaller one. *Àsterias forbesi* and *Protoreaster nodosus* both demonstrated a positive correlation between maximum velocity and size, while *Luidia clathrata's* velocity actually decreased with size. Data from *Protoreaster nodosus* and *Luidia clathrata* both fit the proposed inverted pendulum model, while that of *Asterias forbesi* did not.

Future work will involve finalizing our publication quality *Asterias forbesi* data set for incorporation into the forthcoming paper. We could obtain more *Luidia clathrata* and *Protoreaster nodosus* for greater sample sizes of those species to allow better comparisons of the bouncing gaits between these species. We could also consider testing more species for the bouncing gait to further characterize differences between more species.

Faculty Mentors: Amy Johnson and Olaf Ellers
Research Partner: Jordan Khoriarty
Funded by the Henry L. and Grace Doherty Charitable Foundation Coastal Studies Research Fellowship

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