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Influence of flow velocity on motor behavior of sea cucumber *Apostichopus japonicus*

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HIGHLIGHTS

- Cameras and software were used in behavior research with accurate analysis.
- Distance moved, time spent, and speed of movements of sea cucumbers were measured.
- Speed of movements is associated with body size of sea cucumbers.
- Weak flow can promote the motor behavior, comparing with fast flow and still water.

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ABSTRACT

The influence of flow velocity on the motor behavior of the sea cucumber, *Apostichopus japonicus* was investigated in the laboratory. Cameras were used to record sea cucumber movements and behavior analysis software was used to measure the distance traveled, time spent, upstream or downstream of the start position and the speed of movements. In general, the mean velocity of *A. japonicus* was below 0.7 mm s^{-1}. The maximum velocity recorded for all the sea cucumbers tested was for a large individual (89.25 ± 17.11 g), at a flow rate of 4.6 ± 0.5 cm s^{-1}. Medium sized (19.68 ± 5.53 g) and large individuals moved significantly faster than small individuals (2.65 ± 1.24 g) at the same flow rate. *A. japonicus* moved significantly faster when there was a moderate current (4.6 ± 0.5 cm s^{-1} and 14.7 ± 0.3 cm s^{-1}), compared with the fast flow rate (29.3 ± 3.7 cm s^{-1}) and when there was no flow (0 cm s^{-1}). Sea cucumbers did not show positive rheotaxis in general, but did move in a downstream direction at faster current speeds. Large, medium and small sized individuals moved downstream at the fastest current speed tested, 29.3 ± 3.7 cm s^{-1}. When there was no water flow, sea cucumbers tended to move in an irregular pattern. The movement patterns show that the sea cucumber, *A. japonicus* can move across the direction of flow, and can move both upstream and downstream along the direction of flow.

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1. Introduction

The sea cucumber *Apostichopus japonicus* (Echinodermata: Holothuroidea) is mainly distributed in shallow temperate and temperate-cold waters along the coasts of northeastern Asia, including the northern coast of China, Japan, two Koreas, Russia, and Alaska (USA) [16]. The sea cucumber *A. japonicus* preferentially inhabits reefs or rocky substrates, with free flowing, clear water and no freshwater influx [5]. In China, *A. japonicus* has a long history of consumption, owing mainly to its health benefits and medicinal properties [43]. As one of benthic nutrient recyclers in marine ecological system, *A. japonicus* plays an important role in marine ecological system. Their activities such as feeding, moving and reproduction can have an impact on the energy cycle of marine ecological system [46]. Sea cucumbers move very slowly, their migrations and aggregations are influenced by environmental drivers, such as temperature [21], salinity [22] and illumination [25].

Also, water flow is one of the most important environmental drivers. It is closely linked with physiology and behavior of aquatic animals, such as reproduction [4], feeding behavior [20], and distributions [37]. Flow velocity can affect the feeding of bivalves such as the sea scallop, *Placopecten magellanicus* [33]. Moreover, water flow can restrict the distribution of attached organisms by dislodging them [39]. Water flow also affects the swimming behavior of fish, and pioneering studies have provided fundamental insights into the kinematics, physiology and hydrodynamics of fish locomotion [3,15].

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For echinoderms, to adapt to the water flow in marine ecosystem, they can adjust their activities with various strategies. At shallow depths, wave action limits sea urchin grazing [8,17–19,26,27,42]. The sea lily, *Metacrinus rotundus* exhibited an active behavioral response to the presence of organic particles in a current [24]. The sea star, *Asterias vulgaris* moves upstream when approaching prey in the field [29], while *Asterias forbesi* does not show rheotactic behavior [7]. However, the quantifying motor behavior of echinoderms affected by water flow, has not been investigated. Like many other aquatic animals, sea cucumbers have distinct reactions on water flow. Holtz and MacDonald [20] investigated the effects of flow speed on the feeding behavior of the sea cucumber, *Cucumaria frondosa* in the laboratory and the field. Qiu et al. [34] found that *A. japonicus* was easily washed away when inhabiting mud substrates in a current. At a current speed of 0.05 m s^{-1}, the juveniles could no longer attach to the substrate. As the current speed increased, more sea cucumbers were affected, until at a speed of >0.145 m s^{-1}, all the sea cucumbers were washed away. However, there are few studies on the behavioral reactions of *A. japonicus* to water flow.

In this study, we used video technology and behavior analysis software to investigate the motor behavior of individual *A. japonicas*. Quantitative indices were applied to analyze the experiment data. The objective was to evaluate the influence of water flow on the motor behavior of this species under laboratory conditions. We monitored the behavior of *A. japonicus* at different flow rates in order to: (a) evaluate the motor behavior of individuals with quantitative indices, (b) investigate behavioral responses and tropism and (c) describe patterns of movement. Such information may be helpful for understanding of migration and aggregation patterns of *A. japonicus* in the wild. We hope our study can provide a reference for other behavior research of echinoderms.

2. Materials and methods

2.1. Source of animals

The experiment was conducted from March 2014 to May 2014. *A. japonicus* was collected from Laizhou Bay in Yantai, China. More than 400 *A. japonicus* were collected and held in seawater at a temperature of 14.8 ± 1.2 °C. During the acclimation and experimental periods, the animals were fed a diet of artificial feed at 10:00 each day. Seawater parameters were kept at constant levels. Dissolved oxygen was maintained above 6.0 mg L^{-1}, the level of ammonia was less than 0.3 mg L^{-1}, pH ranged from 7.8 to 8.2 and salinity ranged from 29‰ to 31‰.

2.2. Experimental facilities

The experiments were conducted in an annulus tank (4 m × 2 m) with a 0.45 m wide region for water flow (Fig. 1). A water pump was used to circulate water through the tank and a frequency converter connected to the water pump was used to adjust water velocity. The flow rate ranged from 0 cm s^{-1} to 30 cm s^{-1} (Fig. 1). Water velocity was measured using a flow meter (INFINITY-EM AEM-USB, JFE-Holdings Inc., Japan).

2.3. Experimental design

The locomotion of small, medium and large *A. japonicus* was investigated at four flow rates, 0 cm s^{-1}, 4.6 ± 0.5 cm s^{-1}, 14.7 ± 0.3 cm s^{-1} and 29.3 ± 3.7 cm s^{-1}. Sea cucumbers were separated into three size classes, small (2.65 ± 1.24 g, $n = 120$), medium (19.68 ± 5.53 g, $n = 120$) and large (89.25 ± 17.11 g, $n = 120$) for the experiment. Thirty replicate trials were run for each of the twelve treatments in the experiment, and each trial was conducted using a new sea cucumber. In each experiment, one sea cucumber was placed in the center of a rectangular arena (45 cm × 80 cm) in the straight section of the tank. The arena was divided into two zones, the area upstream from the center was referred to as the minus zone and the area downstream from the center was referred to as the plus zone (Fig. 2). In each trial the *A. japonicus* individuals were oriented across the direction of water flow. Each trial was run until the sea cucumber moved out of the arena or the time for the trial reached 1 h.

2.4. Behavior recording and track acquisition

Time lapse cameras (Brinno TLC-200) were used to record the activities of *A. japonicus* at 1 minute intervals. Video images were analyzed using Ethovision (version 9.0) software, to record the tracks of *A. japonicus* at four flow rates.

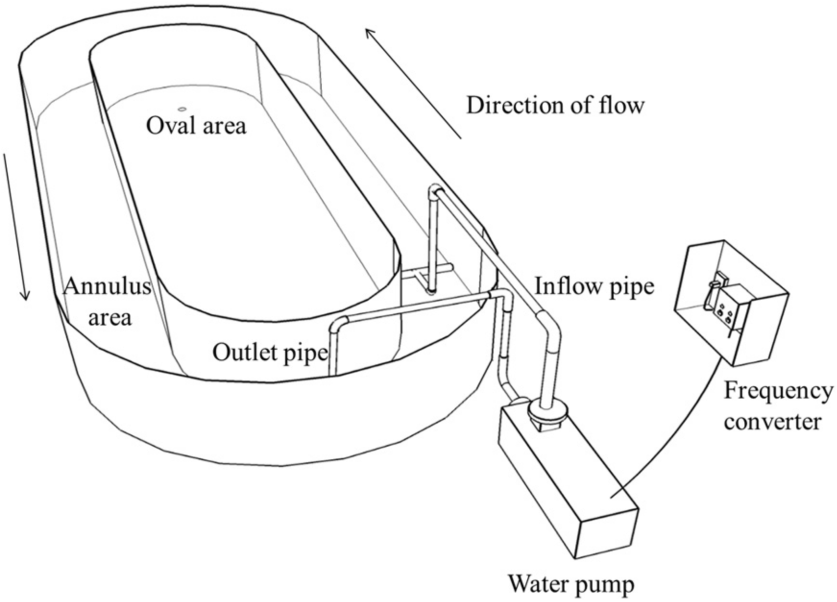

Fig. 1. The tank used in the experiment.

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