SCORPION NAVIGATION
aka, "Self-Driving Arachnids"

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Do scorpions use air currents in echolocation?

Eddie Anguiano, Emily Friend, Wyatt Gill, Joey Romano

Instructor: D. Gaffin

ABSTRACT: Although the use of ricocheted sound waves for orientation (echolocation) is a rare ability, several animal species use this process. Scorpions detect seismic vibrations using organs on their feet, and a previous experiment tested if scorpions can use these organs to detect the seismic return of their own footsteps bouncing off nearby objects. In that study, scorpions moved preferentially towards a solid wall vs. an opening in the wall regardless of whether the wall was in contact with sand. This result argued against seismic echolocation. We hypothesized that scorpions might instead be using an air-based form of echolocation by using minute hairs called trichobothria on their pedipalps (claws). Trichobothria are known to be sensitive to air currents; perhaps these hairs detect a self-produced envelope of air that ricochets off objects and back to them. To test this idea, we built two circular testing arenas: one with a mesh wall to let air pass and one with a solid wall; both arenas had one quarter of their wall removed. We released scorpions in the center of the arenas and predicted that animals with their eyes covered would show a preference towards the solid wall in the solid arena and no preference in the mesh arena. The type of arena did not significantly affect movement patterns, suggesting that scorpion vision may be more important for orientation than previously thought.

Editor's note: This experiment was inspired by the work of the late Sarah Rose Million, a former student in Dr. Gaffin's lab. Her work, which was a followup of a study by a different student (Vail Stephens) was never completed, but included the idea to test for echolocation based on air currents. This team of students chose to honor her by following up on her work.

Keywords: scorpion, orientation, trichobothria, sensory

Introduction

Echolocation is used by relatively few organisms. Echolocating animals emit sound waves that travel through a medium (air or water), hit an object and create echoes. The echoes return waves to the organism, allowing it to determine the direction and distance to the object [10, 7]. It is known that bats, dolphins, and some whales and birds use echolocation; even blinded rats can detect obstacles by self-produced audio cues [3].

Sound waves travel through solids at much faster speeds than through air or water, making localization difficult. Nevertheless, it seems possible that scorpions might be using some form of echolocation through a solid medium. Scorpions can detect and respond to vibrational waves traveling in sand up to 50 cm away [5]. Two organs on the legs are responsible for this: the basitarsal compound slit sensilla and tarsal hairs [6]. In his Honors thesis, Vail Stephens postulated that scorpions might detect self-produced vibrations from their own footsteps that echo off objects and back to their slit sensilla for orientation. However, the experiment was not conclusive since the animals showed biased movements towards the object both when it was in contact with the sand and when it was suspended just above the sand [13]. This result suggested that another mechanism might account for this behavioral bias.

Scorpions have minute hairs on their pedipalps (claws) called trichobothria, which can detect subtle air currents [9, 1, 12]. Other arachnids have trichobothria too, and a study determined that wandering spiders detect and respond to air particle movement from flying prey [2]. Perhaps scorpions use their trichobothria to orient towards their own air currents that reflect from objects. This could explain how the scorpions detected the suspended objects in the experiment by Stephens. The idea is that as the scorpion moves, it displaces an envelope of air that ricochets off surrounding objects and back to the trichobothria for detection and orientation.

We were curious if scorpions use self-generated air currents to orient towards objects. In this study, we blindfolded our animals to eliminate the role of vision, which was not done in the previous study by Stephens. We observed the choice of direction our animals made inside small circular arenas composed of either a solid wall or a mesh wall. Both of the arenas had one fourth of their wall removed to create an opening. We hypothesized that if scorpions detect air waves from their own movement, then they will walk preferentially towards the wall of the solid area arena, but show no preference in the mesh arena. We found that the animals showed no bias in either of the test conditions, suggesting that vision might be more important in scorpion orientation than previously thought.

Materials and Methods

Animals

We used 20 *P. utahensis*: 10 male and 10 female. The animals were collected in October 2021 from sandy areas near Monahans, Texas. We kept the scorpions in individual plastic containers (12 cm long, 7.5 cm wide, and 7 cm deep) with 50 ml of sand on the bottom. The scorpions were fed one cricket from Fluker's Cricket Farm Inc. every two weeks, and their plastic containers were misted with water once a week. Scorpions were stored inside a laboratory cart in a laboratory room maintained at roughly 20°C. The cart was covered by a dark sheet and a timer-controlled drop lamp (EcoSmart 60-watt light bulb) was mounted to illuminate the cart interior. The timer was adjusted so that the lamp turned off at 1200 and turned on at 2200. We changed the light cycles because scorpions are most active at night and we wanted their active period to correspond with our class time. Scorpions were removed from the cart to perform a trial and returned once the trial was completed. Each scorpion was given at least 48 hours of rest between trials.

Blindfolding

We covered each scorpion's medial eyes with a piece of double-sided tape adhered to a small piece of tin foil to reduce outside visual influences. To apply the covering, a scorpion was removed from its plastic container and placed in a larger rectangular container. A plastic lid with a small hole was gently pressed on the top of the scorpion to inhibit its movement. The hole in the plastic lid was slid over the scorpion to isolate the eyes, and the tape and tinfoil were then pressed onto the dorsal prosoma to cover the medial eyes.

Experimental apparatus

We started with a large circular (CAMCO) drain pan with a diameter of 90 cm filled to a depth of about 2.54 cm with sand. Two circular behavioral testing arenas, 30 cm in diameter, were constructed for the experiment for placement inside the larger drain pan (Fig 1). One behavioral testing arena had solid plastic sides and the other had chicken wire walls to allow air flow through the apparatus. Both arenas had a 10 cm section cut out from the side material. We placed the entire apparatus on a rotating platform to vary the direction the internal behavioral arena faced in each trial to counter any directional bias relative to external factors. The drain pan and rotating platform sat on a foam pad to reduce vibrations. An inverted 32-gallon black plastic trash can (Rubbermaid) covered the entire test area to reduce visual influences. Within the behavioral test arena, we placed a small Petri dish (about 5 cm across) over the scorpion to prevent the animal from dashing immediately after being placed in the arena. This Petri dish was attached to a string that was threaded through the top of the trash can to allow release of the scorpion without removing the trash can. An IR camera (ELP Megapixel IP Camera) was mounted to the top of the trash can to record an aerial view of the scorpion's behavior. The camera was connected to a computer where the recordings were further analyzed via a MATLAB script.

Experimental protocol

We ran a total of 40 trials using 20 different scorpions (one trial in each internal arena for each scorpion). The condition each scorpion experienced first was chosen at random by flipping a coin so that all the animals did not experience the solid wall first then the mesh wall, or vice versa. We rotated the larger drain pan at random angles before each trial, and switched the direction the scorpion faced to control for directional biases.

For each trial, a scorpion was placed into the center of an internal arena and the Petri dish was placed over them. The scorpion was given a one minute acclimation period after which the Petri dish was removed from atop the scorpion via the pulley to begin a 10-minute trial. A trial was valid if the scorpion passed the decision line projected in the MATLAB

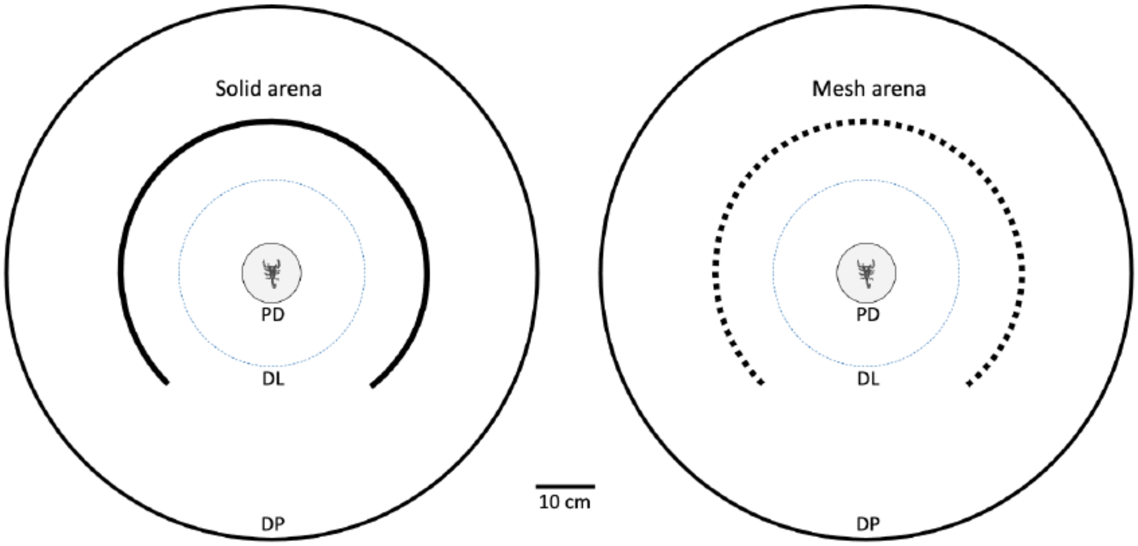

Figure 1: Behavioral testing arenas. A sand-filled drain pan (DP; 90 cm diam) held either a solid-walled (left) or mesh-walled (right) inner arena, each with a quarter of their wall removed. Inner arenas had a diameter of 30 cm. The tested scorpion was contained under a small Petri dish (PD) prior to release. The blue dashed circle is not part of the apparatus, but is a measurement standard we added in MATLAB to determine where to end a trial and record the scorpion's decision (decision line = DL).

program within the ten minutes. Trial were discarded if the scorpion failed to cross the decision line. All equipment was wiped down with 70 percent ethanol between trials.

Analysis

We reviewed the video recordings to determine the coordinates of the point that each animal in the valid trials crossed the decision line. For each recording, the coordinates of the location of the scorpion during the acclimation period and the center of the opening were also noted. These three coordinates allowed us to calculate the angle of the decision point relative to the opening. A MATLAB script fit with a Rayleigh Circular Statistics package [4] was used to statistically evaluate the distribution of the angles for each internal arena. We set our significance level at $p < 0.05$.

Results

A total of 29 valid trials were analyzed (15 in solid arena, 14 in mesh arena). While reviewing our trials we found that once an animal began to move, it would continue to move and cross the decision line and run into the wall or opening. The average time it took the scorpions in the valid trials to cross the decision line was 31.58 s $\pm$ 11.14 (SE). Many trials were discarded because the scorpions failed to move during the trial. We also excluded data from two scorpions that died during testing and from one that lost its pedipalp.

The Rayleigh statistics test for the solid and mesh arenas yielded p-values of 0.87 and 0.67 respectively (Fig 2). As such, scorpions did not show a bias in the distribution of their movements in either of the conditions.

Discussion

The scorpions in our tests showed no bias in movements in either the solid walled or mesh walled arenas. This indicates that movement was random and we accept our null hypothesis that no preference was shown between the wall or the opening in either arena condition. As such, we cannot conclude that *P. utahensis* uses its trichobothria for an air-based form of echolocation.

The results of our study contradict the findings of the Vail Stephens experiment, which found that scorpions moved preferentially away from the opening of a solid walled arena whether the arena was in contact with the sand or suspended slightly above it [13]. It is important to note that we covered the eyes of our scorpions whereas Stephens did not. It is possible that the biased movement in the earlier study came from the scorpions using vision to locate and move towards the wall. Scorpion eyes have been shown

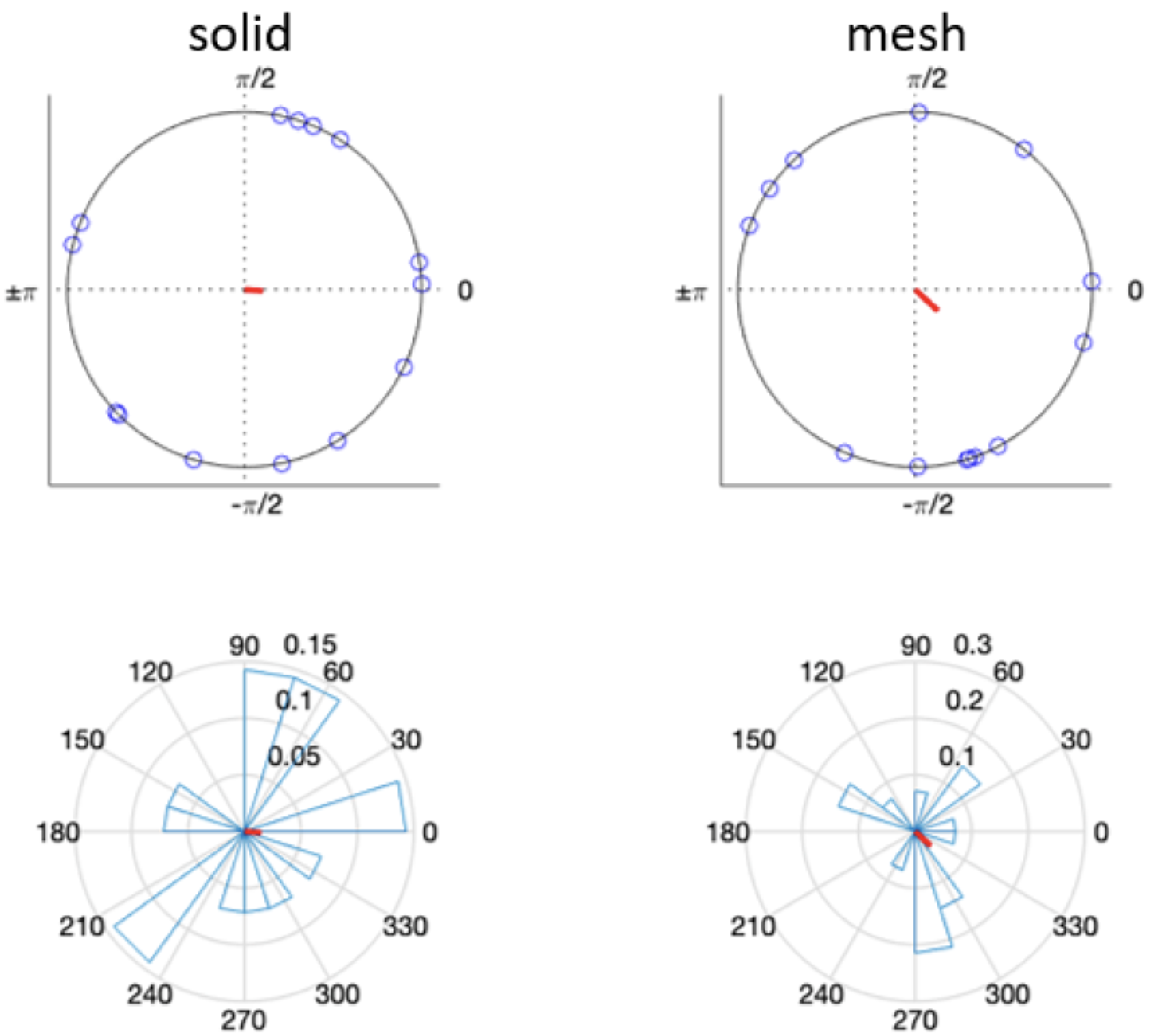

Figure 2: Scorpion movement decisions. Rayleigh tests are shown for scorpions placed in solid and mesh internal arenas. Individual coordinates are pictured in the top two graphs and radar plots of these values are shown in the bottom two graphs. The red lines show the averaged vector for each of the distributions.

to be sensitive enough to detect starlight and there is evidence that the median eyes can form images [8, 11]. Taken together, we conclude that the eyes may be important for scorpion orientation, even under very low light conditions.

Further tests are needed to learn more about the role of trichobothria (if any) in echolocation. We would like to replicate the Stephens experiment, but with the addition of blindfolds to control for visual influences. We could also remove or cover the trichobothria and repeat our study, which can help assess the role of trichobothria.

We noted a few potential sources of error during our experiments. For example, the Petri dish swung slightly when lifted, which could have pushed air around the arena and influenced the scorpion's directional decision. Another possible confounding variable were vibrations on the table caused by movement of people, the computer mouse, etc. Future tests should take added care to reduce such outside influences. Finally, our sample size was limited by available time and the number of animals. We suggest increasing the number of animals used; also precision might be increased by allowing each animal multiple attempts and calculating a mean vector for each.

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