Video Article

Vertical T-maze Choice Assay for Arthropod Response to Odorants

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Abstract

Given the economic importance of insects and arachnids as pests of agricultural crops, urban environments or as vectors of plant and human diseases, various technologies are being developed as control tools. A subset of these tools focuses on modifying the behavior of arthropods by attraction or repulsion. Therefore, arthropods are often the focus of behavioral investigations. Various tools have been developed to measure arthropod behavior, including wind tunnels, flight mills, servospheres, and various types of olfactometers. The purpose of these tools is to measure insect or arachnid response to visual or more often olfactory cues. The vertical T-maze olfactometer described here measures choices performed by insects in response to attractants or repellents. It is a high throughput assay device that takes advantage of the positive phototaxis (attraction to light) and negative geotaxis (tendency to walk or fly upward) exhibited by many arthropods. The olfactometer consists of a 30 cm glass tube that is divided in half with a Teflon strip forming a T-maze. Each half serves as an arm of the olfactometer enabling the test subjects to make a choice between two potential odor fields in assays involving attractants. In assays involving repellents, lack of normal response to known attractants can also be measured as a third variable.

Introduction

Arthropods (including insects and arachnids) are often defined as pests, because they either compete with human consumption in agricultural or urban settings or transmit causal pathogens of disease. A large amount of investment is made into development of control tools for such pests. These tools can vary widely and significant progress has been made in developing biorational tools that either modify or exploit the natural behavior of pests with the use of behavioral attractants or repellents.

Arthropod pests often rely on olfactory signals or cues for mate and/or host location. Therefore discovery of effective attractants or repellents for pests can often lead to development of control tools. This process of discovery involves several steps. First, the natural behavior of the test subject must be understood. For example, one must ascertain whether one sex of a given species attracts the opposite sex for mate location. If so, one must determine whether this attraction is mediated by a chemical and where that chemical is produced. Further steps include determining when the chemical is produced and its eventual identification. Throughout this procedure, the test subject's (insect or mite) behavioral response to odorants must be tested. Initially, the behavior of the test subject will be tested to the natural material. For example, a male moth's response may be tested to that of the extract of its female conspecific's pheromone gland. Alternatively, an herbivore's response to the natural odors of its host plant may be tested. While these investigations often have a practical focus on development of management tools, they can also be applied to research that addresses more fundamental questions, such as speciation. Subsequent steps involve testing the arthropod's response to synthetic versions of identified natural products.

Understanding how arthropods respond to chemicals requires the development of appropriate tools to measure their behavior. The data generated by such tools will depend on how well the investigator is able to measure natural behaviors in a controlled setting. Over six decades ago, sustained flight olfactometers and tunnels were developed to measure insect response to odorants. Olfactometers vary significantly in design and are often tailored to the specific insect or problem being investigated. The goal of this article is to describe the design and use of a vertically oriented, T-maze olfactometer for measuring insect response to odorants (Figure 1). The olfactometer's vertical orientation takes advantage of the negative geotaxis (tendency to move up) exhibited by many insects. A light source positioned directly above the olfactometer takes advantage of the positive phototaxis (tendency to move toward source of light) exhibited by many insects. The olfactometer is particularly useful for hemipteran insects that tend not to exhibit movement readily in horizontally-oriented olfactometers and that are heavily influenced by light intensity with respect to orientation. However, this device can be used for a wide range of flying and crawling insects, as well as arachnids. The olfactometer can be employed to evaluate both attractants and repellents. In the case of attractants, the bifurcated odor field is established with the putative attractant released on one side versus clean air released on the opposite side. A choice is recorded when the insect released at the base of the olfactometer chooses one of the two odor fields. In the case of repellents, a third behavior is possible. In addition to
upward movement into either of the two odor fields, lack of upward movement may be recorded indicating a non-responsive stimulus or repelling stimulus from either odor fields.

Protocol

1. Assembly of a custom-designed, two-port divided T-olfactometer previously described in Mann et al.\(^9\) is shown in Figure 1. The olfactometer consists of a 30 cm glass tube that is bifurcated into two separate ports with a Teflon strip forming a T-maze. Each half is analogous to an arm of a 2-choice style olfactometer enabling the test subject to choose between two potential odor fields.

2. Prior to all tests, expose test subjects to clean air versus clean air or solvent versus clean air in the T-maze olfactometer to verify the stimulus from either odor fields.

3. For optimal light diffusion, the assembly should be mounted within a 1.0 x 0.6 x 0.6 m opaque container to maximize uniform light diffusion.

4. Connect the olfactometer arms to odor sources that will be housed in solid-phase micro-extraction holding/odor source chamber (SPMEC) (ARS, Inc., Gainesville, FL) through Teflon;glass tube connectors. Each SPMEC is comprised of a straight glass tube (17.5 cm long x 3.5 cm wide) supported with an inlet and outlet valve for incoming and outgoing air streams (Figure 1).

5. Deliver purified and humidified air through the SPMEC (or guillotine volatile chamber) via two pumps connected to an air delivery system containing treatments in place of the SPMEC (Figure 1).

6. Record if subject enters the treatment arm, control arm or remains in the release port or below the T-maze division.

7. Connect the olfactometer arms to odor sources that will be housed in solid-phase micro-extraction holding/odor source chamber (SPMEC) (ARS, Inc., Gainesville, FL) through Teflon;glass tube connectors. Each SPMEC is comprised of a straight glass tube (17.5 cm long x 3.5 cm wide) supported with an inlet and outlet valve for incoming and outgoing air streams (Figure 1).

8. Deliver purified and humidified air through the SPMEC (or guillotine volatile chamber) via two pumps connected to an air delivery system containing treatments in place of the SPMEC (Figure 1).

Representative Results

Attraction of Asian citrus psyllid (Diaphorina citri) adults to the odors of their natal host plant volatiles (citrus) is depicted in Figure 2A. Significantly (\(\alpha < 0.05\)) more adults chose the arm of the T-maze olfactometer receiving odors from living citrus plants as compared with a blank (clean air) control.

An example of repulsion is shown in Figure 2B. In this case, the insects were exposed to one arm of the T-maze receiving citrus volatiles, while the second arm received volatiles from a citrus plant that was treated with the known repellent, dimethyl disulfide\(^11\). In this case, three types of behaviors were observed. The number of psyllids arrested at the release arm and not responding did not differ statistically from the number entering the arm receiving the odors from citrus plants alone (Figure 2B). However, no psyllids entered the arm containing the host plant volatile when co-presented with the repellent (Figure 2B).
Figure 1. Schematic diagram of vertically oriented T-maze olfactometer joined to air delivery system and odor treatment release devices. The diagram is an adaptation of Figure 1 in Mann et al. A test subject is placed individually into the release chamber of the 2-port divided T-olfactometer. It moves towards the odors through a gate valve which allows controlled upward movement into the olfactometer and prevents the insect from crawling back into the release point area. The tube bifurcates 10 cm after the gate value. A positive response to an odor is recorded once the insect moves 0.5 cm into a specific side of the division. The guillotine volatile collection chamber may be used in place of a solid-phase micro-extraction holding/odor source chamber (SPMEC) as an odor source.
Discussion

Herein, an assay device and protocol are described for measuring the response of small arthropods (Insecta: Hemiptera: Psyllidae) to odorants. The method involves a choice test, allowing the insect to make a choice between two odorant fields in the case of assays evaluating a putative attractant. Furthermore, the test subject may display three types of behaviors by leaving the release arm and entering either one of two potential odor fields, or remaining in the release arm, in the case of repellency assays. The olfactometer allows for high throughput data collection because it takes advantage of the negative geotactic (tendency to move upward) and positive phototactic (tendency to move toward light) natural behavioral response of many arthropods. Although the present demonstration uses a psyllid insect test example, the assay can be readily adapted to arthropods broadly, both those that use flight or walking as predominant modes of transportation.

Olfactometers designed for measuring the response of insects were initially developed decades ago and have played a major role in elucidating insect attractants and repellents\(^\text{12}\). The specific designs of such olfactometers vary widely; however, variations on the general theme of the two-choice assay described here, as well as, similar Y-tube assays have been often used to measure arthropod response to chemicals. Larger flight tunnels that may cause sustained flight of insects\(^\text{9}\) have also resulted in collection of groundbreaking data elucidating the fundamental mechanisms of insect flight and orientation to semiochemicals, as well as, data informing practical use of pest control tools.

It is often necessary to tailor design an olfactometer and associated instrumentation for the biology of the specific arthropod test subject. Those olfactometers that can be used among a general group of insects are more useful than ones specific to a small group; however, sometimes the economic significance of a small group of insects dictates the need for development of a very specific olfactometer and assay technique. The currently described design builds on previously familiar arthropod techniques. It allows for a more standard two-choice assay than Y-tube bioassays in which the experimental arena or choice test takes the form of a Y-shaped glass device\(^\text{7}\). Typically, one arm of such a Y-tube will receive a treatment odorant, while the other will be left blank\(^\text{13}\). Variations on such olfactometers may include addition of multiple radiating arms\(^\text{14}\) and even addition of a soil medium for assaying the behavior of organisms moving through soil\(^\text{15}\). In developing such olfactometers and associated assays, it is important to consider how closely natural conditions are replicated and thus the true relevance of the assessed
behavioral responses in terms of the test subjects' biology. To a large degree, the data collected will only be as useful as the relevance of the behavioral bioassay with respect to the organism's behavioral ecology\textsuperscript{16}.

The currently described olfactometer and behavioral bioassay is specifically designed for a hemipteran insect that tends to initiate flight as short "jumps"\textsuperscript{16}. The vertical orientation of the olfactometer and the light source arrangement facilitate initiation of insect movement and thus subsequent chemically-mediated orientation behavior can be assayed efficiently and with high throughput. This behavioral assay arrangement can likely be used for a broad array of flying or walking arthropod taxa or could be also easily modified to fit the need of non-arthropod organisms.

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