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Analysis of the Linkage Between Wing Structure and Chemical Plume Tracking Performance of an Insect Based on Odor Visualization

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Abstract: In this study, focusing on the silkmoth's odor source behavior, we developed a system for simultaneous odor dynamics and behavior measurement to investigate the effect of silkmoth wing flapping and wing structure on odor reception. We used a chemical mixture of smoke and pheromone (Bombykol) to visualize the odor. In the simultaneous measurement experiment of odor dynamics and behavior, two wind conditions and four silkmoth wing conditions were used, where the wings were excised to modify the physical characteristics. Our findings revealed that the silkmoth with only the forewing can localize the odor source with high probability, suggesting that the forewing has the effect of odor intake. Additionally, our results suggested that wing flapping creates intermittency and direction in odor reception.

Keywords: Odor visualized, Insect, Wing flapping

1. INTRODUCTION

In this study, we developed an experimental system to simultaneously measure insect odor source localization behavior and visualize odor diffusion. We analyzed the relationship between wing structure and odor intake.

Odor source localization refers to detecting airborne odor and localizing its source. Autonomous robots have been studied for locating disaster victims and hazardous materials by using olfaction [1][2]. However, odor distribution is complex due to external disturbances like wind, making it difficult to reach the source by simply following the odor gradient [3]. In contrast, insects use odorants for communication and decision-making [4]. Inspired by this, researchers have attempted to replicate insect odor adaptability in a robot [5]. While adaptability is often discussed in terms of behavior, acquiring reliable information in uncertain environments is equally crucial.

This study focuses on how an insect processes odor inputs. We investigate the odor localization behavior of an adult male silkmoth (*Bombyx mori*). When detecting female sex pheromones, the male flaps its wings while walking. Previous studies suggest this flapping helps direct odor toward the body [6], but how wing flapping contributes to odor intake and alters odor distribution remains unclear. Additionally, how forewing and hindwing contribute to odor intake is unknown.

In this study, we developed an experimental system to analyze odor dynamics and behavior simultaneously. By observing odor reception during localization, we clarified the effect of wing flapping. Furthermore, we tested how the silkmoth's wing structure influences odor intake efficiency during odor source localization under four conditions that altered its wing structure.

† Ryoko Sekiwa is the presenter of this paper.

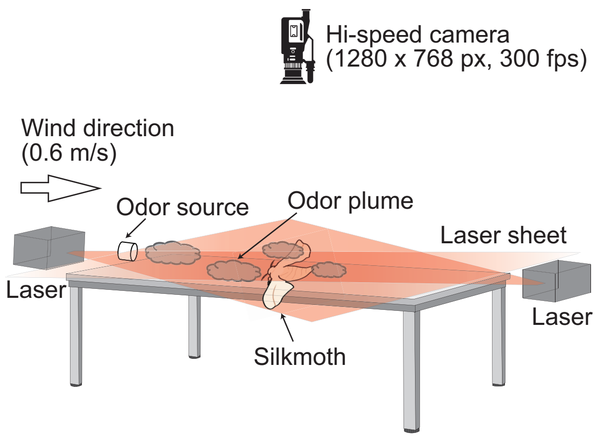

Fig. 1 Overview of experimental setup.

2. EXPERIMENTAL SYSTEM

The experimental setup for simultaneous odor dynamics and behavior measurement is shown in Fig. 1. To visualize odor dynamics and silkmoth reception, we used a glass tube with a piece of filter paper soaked in sex pheromone (Bombykol, 1000 ng) as the odor source, emitting smoke at 1 Hz. Laser light from both sides illuminated the odor (Fig. 1). A silkmoth began searching from 150 mm away in the visualized odor field and was tracked with a high-speed camera (k8-USB) until reaching the source. A search was determined successful when the silkmoth came within 30 mm of the source.

3. THE EFFECT OF WING FLAPPING

3.1. Experimental conditions

In the odor dynamics-behavior experiment, wind conditions were constant (Fix) or periodically changed (Swing). Silkmoths were altered by wing excision, with conditions including winged (Wing), wingless (Wingless), forewings only (Front), and hindwings only (Back).

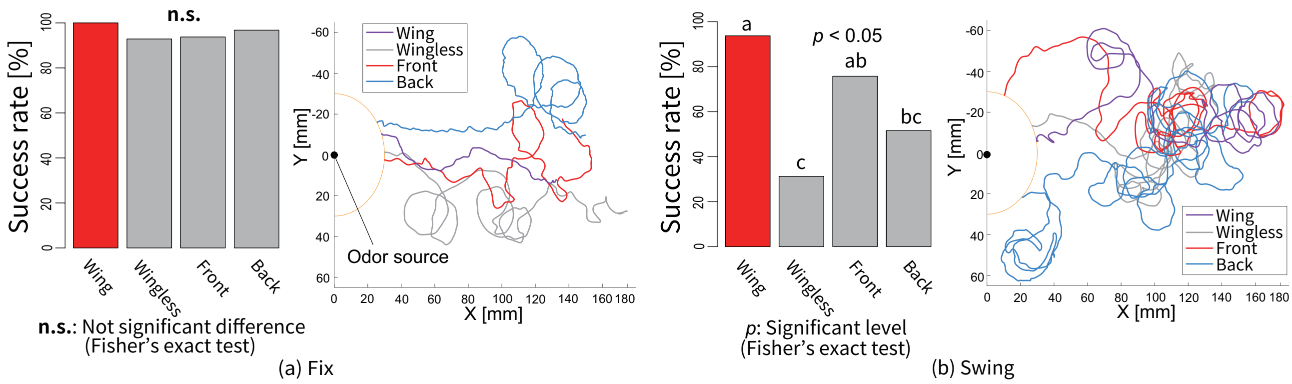

Fig. 2 Success rate and trajectory results.

3.2. Functional analysis of wing structure in odor source localization

The experimental results of the simultaneous measurement experiment of odor dynamics and behavior are shown in Fig. 2. As shown in Fig. 2(b), the rotational behavior occurred more frequently under the Swing condition, suggesting that odor diffusion is complex and causes the silkmoth to become confused.

We next focused on success rates. In Fig. 2(a), under the Fix condition, there were no significant differences between the silkmoth conditions. However, in the Swing condition (Fig. 2(b)), significant differences were observed between Wing and Wingless, Wing and Back, and Wingless and Front. These results suggest that the forewings may significantly contribute to odor intake.

Since the silkmoth uses its antennae for odor detection, we also focused on the area around the antennae of the silkmoth with wings. Frequency analyses of the time series luminance (amount of odor intake) variations around the antennae under the Swing condition are shown in Fig. 3(a). The horizontal axis represents time, with 0 indicating 1 second before the silkmoth localized the odor source. The analysis covers the period from 4 seconds before localization. The left vertical axis represents the number of silkmoths, and the right vertical axis represents frequency. Yellow regions indicate strong frequency components, suggesting that the silkmoth receives the odor. The intermittent yellow components in Fig. 3(a) suggest that wing flapping generates intermittency of odor intake.

The relationship between luminance values around the silkmoth's antennae and its posture under the Fix condition is shown in Fig. 3(b). The horizontal axis represents the silkmoth's posture, with 0 deg indicating when the silkmoth was facing the odor source and positive values indicating leftward turns. The vertical axis represents the normalized luminance mean (0 to 1). Fig. 3(b) shows higher luminance when the silkmoth faces the odor source, suggesting directional odor intake. The absence of luminance in the backward direction suggests that hindwing flapping may obstruct odor flow from behind.

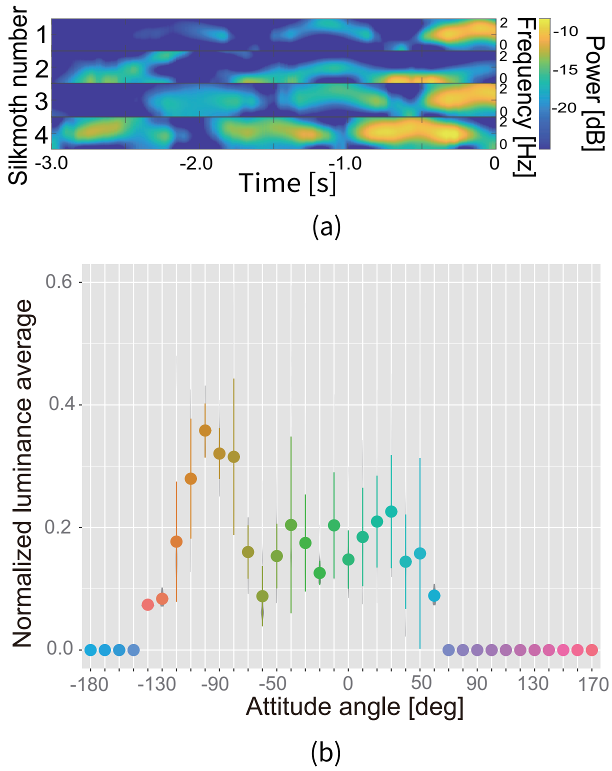

Fig. 3 (a) Luminance frequency analysis (under the Swing condition) and (b) relationship between luminance and attitude (under the Fix condition).

4. CONCLUTION

In this study, we developed an experimental system to simultaneously measure insect odor source localization behavior and visualize odor diffusion. Using this system, we conducted the simultaneous measurement experiment of odor dynamics and behavior. The results showed that silkmoth wing flapping creates odor intermittency and directionality. They also suggest forewings may help odor intake, while hindwings may obstruct odor flow from behind.

To further clarify wing roles, we will measure odor velocity around the wings under identical conditions.

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