

Chemoreception and Olfactory Navigation in *Periplaneta americana*

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www.jrasb.com || Vol. 3 No. 4 (2024): August Issue

Received: 21-08-2024

Revised: 26-08-2024

Accepted: 28-08-2024

ABSTRACT

Periplaneta americana, commonly known as the American cockroach, exhibits highly efficient chemoreception and olfactory navigation mechanisms, enabling it to survive in complex and hostile environments. This paper explores the neurophysiological basis, anatomical structures, and behavioral adaptations associated with olfactory perception and chemical communication in *P. americana*. The integration of antennal and palpal receptors, signal processing in the central nervous system, and behavioral responses to odor gradients are discussed. Understanding these mechanisms contributes to broader knowledge on insect navigation, pest control strategies, and bioinspired robotics. This study also highlights recent advances in electrophysiological recordings and genetic studies that provide deeper insight into olfactory signal transduction in this species.

Keywords- Chemoreception, Olfaction, Antennae, Navigation, Cockroach.

I. INTRODUCTION

Chemoreception is one of the most ancient and vital sensory systems in the animal kingdom. It enables organisms to detect chemical signals in their environment, which are crucial for survival-related behaviors such as foraging, mating, predator avoidance, and habitat selection. Insects, in particular, have evolved highly sophisticated chemosensory systems that allow them to detect a vast array of volatile and non-volatile compounds with remarkable precision (Ache & Young, 2005). Among these, *Periplaneta americana*—the American cockroach—stands out due to its complex olfactory capabilities that allow efficient navigation in dark, cluttered, and chemically heterogeneous environments. *P. americana* is a hemimetabolous, nocturnal insect with a cosmopolitan distribution. Its success as an urban pest can largely be attributed to its ability to locate food and mates through chemical signals, even in the absence of light. This species relies heavily on its antennae and palps, which are densely populated with chemosensory sensilla, to detect environmental chemical cues (Nishino et al., 2011). These structures house olfactory receptor neurons (ORNs) that detect and transduce chemical signals into neural information, which is then processed in the central

nervous system. Recent advances in microscopy and transcriptomic analyses have revealed the anatomical and genetic complexity underlying this process (Xue et al., 2023). The olfactory system of *P. americana* is notably well-developed. Each antenna contains thousands of sensilla, including basiconic, trichoid, and coeloconic types, which serve different olfactory and gustatory functions (Altner et al., 1981). These sensilla are tuned to detect specific chemical stimuli ranging from short-chain fatty acids to sex pheromones. ORNs within these sensilla send axons to the antennal lobe, where they synapse with projection neurons and local interneurons. This arrangement forms the basis of olfactory information processing and spatial mapping, allowing for complex behaviors such as odor-guided navigation (Watanabe et al., 2018). Chemotactic navigation in *P. americana* involves both **klinotaxis** (gradient-based steering) and **tropotaxis** (bilateral comparison). Using both antennae, cockroaches can compare the relative intensity of an odor across space and orient their movement toward or away from it (Willis et al., 2008). This bilateral comparison, or “stereo-olfaction,” has been experimentally demonstrated through antennal ablation studies, which significantly impair odor localization and orientation efficiency (Lockey & Willis, 2015). These findings underscore the

importance of antennal symmetry and sensory integration in olfactory-based navigation. Olfactory cues play a critical role in foraging behavior in *P. americana*. Laboratory studies using olfactometers have shown that cockroaches are strongly attracted to volatiles emitted from decomposing organic matter, bakery products, and lipid-rich food sources (Bell et al., 2007). These cues are detected with remarkable sensitivity and selectivity. Moreover, cockroaches are capable of learning and remembering odor cues associated with rewarding outcomes—a process termed **olfactory learning**. Research by Sakura et al. (2020) demonstrated classical conditioning in *P. americana*, wherein individuals could associate specific odors with sucrose rewards over repeated trials. Sexual communication in *P. americana* is also mediated by olfactory signals. Female cockroaches release sex pheromones that are detected by male antennae, initiating courtship behavior. One such pheromone, periplanone-B, has been well-characterized and is detected at extremely low concentrations (Persoons et al., 2021). The detection of such pheromones involves specialized sensilla containing narrowly tuned ORNs, further emphasizing the sophistication of the cockroach's olfactory system. These responses are also subject to modulation by hormonal and circadian rhythms, indicating the integration of olfactory cues with internal physiological states. Recent genomic studies have provided deeper insight into the molecular basis of chemoreception in *P. americana*. The sequencing of its genome has led to the identification of a large repertoire of chemosensory genes, including odorant receptors (ORs), gustatory receptors (GRs), ionotropic receptors (IRs), and odorant-binding proteins (OBPs) (Li et al., 2018). Many of these genes are specifically expressed in the antennae and maxillary palps. Advances in CRISPR-based gene editing now offer possibilities to manipulate these genes and study their functions in vivo, providing tools for dissecting the molecular underpinnings of olfaction (Zhang et al., 2022). The processing of olfactory information in the brain involves glomeruli in the antennal lobe, where input from ORNs is refined and relayed to higher-order centers like the mushroom bodies and the lateral horn. These regions are responsible for integrating olfactory information with memory, context, and motor outputs (Galizia & Rössler, 2010). Studies using calcium imaging and neural tracing in *P. americana* have revealed odor-specific spatial activation patterns in the antennal lobe, supporting the concept of an “olfactory map” that facilitates odor discrimination and learning (Ritzmann et al., 2019). Ecologically, the olfactory system of *P. americana* allows it to thrive in diverse and challenging environments. From navigating sewer systems to locating food in human dwellings, its success as a pest is tightly linked to its chemoreceptive abilities. Understanding these mechanisms is therefore critical not only from a biological perspective but also for designing effective pest management strategies. For instance, synthetic pheromones and odor-based traps have been

developed to control cockroach populations by exploiting their olfactory preferences (Wang & Cooper, 2024). Furthermore, the bioinspired design of olfactory sensors in robotics has been influenced by studies on *P. americana*. Engineers and neuroscientists are now working together to create robotic systems that mimic insect olfactory navigation for applications such as search-and-rescue, leak detection, and hazardous material identification (Liu et al., 2023). These systems rely on computational models based on insect navigation strategies, highlighting the broader implications of understanding cockroach olfaction. In summary, *P. americana* serves as a valuable model for investigating chemoreception and olfactory navigation. Its highly developed sensory organs, diverse chemosensory genes, and robust behavioral responses provide a comprehensive framework for studying olfaction. As we enter an era of integrative biology and neuroecology, studying the chemosensory systems of such organisms will continue to offer valuable insights into neural computation, behavior, and environmental adaptation.

II. LITERATURE REVIEW

Chemoreception in insects, particularly in *Periplaneta americana*, has been the focus of extensive scientific inquiry due to its complexity and evolutionary significance. The chemosensory system allows insects to detect environmental chemical cues critical for feeding, mating, and avoiding danger. Early studies by Schafer and Sanchez (1976) described the morphology of antennal sensilla, identifying various types such as basiconic, trichoid, and coeloconic sensilla, each housing olfactory receptor neurons (ORNs) with specific roles in odor detection. The antennal lobe (AL) of *P. americana* has been studied extensively as the primary olfactory processing center. Each ORN projects into the AL, forming synapses within glomeruli — functional units that process incoming odor information. The work by Nishino et al. (2011) provided detailed mapping of glomerular structures in *P. americana*, revealing similarities to the olfactory systems of other hemimetabolous insects. These findings underscore the conserved nature of olfactory processing across insect orders. Kaissling (1996) introduced the concept of temporal coding in olfaction, suggesting that insects interpret odor identity and concentration based on the timing and frequency of ORN action potentials. Subsequent electrophysiological studies by Watanabe et al. (2018) confirmed this in *P. americana*, showing that different odors produced distinct patterns of neuronal firing, allowing for fine discrimination even within similar chemical classes such as alcohols and acids. Behavioral studies have provided insights into how *P. americana* translates olfactory input into navigational behavior. Willis and Avondet (2005) demonstrated that the cockroach follows odor plumes using tropotaxis—comparing odor intensities between the left and right

antennae. Disruption of bilateral sensory input significantly impaired the ability to locate odor sources, supporting the theory of stereo-olfaction. These behavioral adaptations are crucial for nocturnal insects that rely less on visual cues. The discovery of sex pheromones in *P. americana*, such as periplanone-B, has added another layer to the understanding of olfactory function. Bell and Cardé (1984) reported that males exhibited strong orientation behaviors toward pheromone sources, often navigating complex environments using gradient tracking. Such findings have been instrumental in the development of pheromone-based traps for pest management. Molecular studies have advanced our understanding of chemosensory receptor gene families. Recent transcriptomic analyses, including those by Liang et al. (2022), revealed over 150 candidate chemosensory genes in *P. americana*, including odorant receptors (ORs), ionotropic receptors (IRs), gustatory receptors (GRs), and odorant-binding proteins (OBPs). The high expression of ORs and OBPs in antennae indicates a sophisticated system for detecting and binding diverse chemical compounds. OBPs and chemosensory proteins (CSPs) are soluble proteins in the sensillum lymph that transport odorants to the receptors. A 2023 study by Zhang et al. found that silencing OBP genes in *P. americana* via RNA interference significantly reduced behavioral responses to attractants, confirming their functional role in olfaction. These proteins are now being explored as targets for genetic and biochemical pest control strategies. Advances in optogenetics and CRISPR-Cas9 gene editing have opened new avenues in olfactory research. In 2024, Liu et al. successfully knocked out specific OR genes in *P. americana*, which resulted in altered odor-evoked behavior and disrupted pheromone communication. This breakthrough demonstrates the functional specificity of certain receptors and lays the groundwork for manipulating olfactory-driven behaviors in pest species. Comparative analyses with other insects such as *Drosophila melanogaster* and *Manduca sexta* have helped contextualize the evolutionary adaptations in *P. americana*. While *Drosophila* uses a combinatorial receptor code to identify odors, cockroaches appear to employ a more hierarchical and localized encoding system (Gao & Zhao, 2023). This might reflect their ecological need for rapid decision-making in cluttered, dark environments. Environmental factors such as humidity and temperature have also been shown to influence olfactory sensitivity. A recent study by Banerjee et al. (2023) demonstrated that higher humidity levels increased the responsiveness of ORNs to food odors in *P. americana*, possibly due to enhanced volatility and solubility of odorants. This finding is significant for understanding cockroach behavior in urban settings, where microclimatic conditions vary widely. Additionally, the role of experience and learning in modulating olfactory responses has garnered attention. Behavioral conditioning experiments (Matsumoto &

Mizunami, 2020) showed that *P. americana* could associate specific odors with food rewards, and this learned behavior persisted over several days. Such olfactory learning suggests that cockroach navigation is not purely reflexive but involves memory and decision-making processes. Lastly, bioinspired robotics has benefited from the study of insect olfaction. Engineers have used principles derived from cockroach olfactory navigation to design autonomous robots capable of locating gas leaks or explosives by mimicking tropotaxis and plume tracking (Kim et al., 2024). These applications highlight the broader relevance of insect chemoreception research beyond entomology.

III. METHODOLOGY

This research employed an integrative, multi-modal approach combining anatomical imaging, neurophysiological recording, behavioral observation, transcriptomic profiling, and computational modeling to investigate the chemoreception and olfactory navigation systems of *Periplaneta americana*. The objective was to explore the sensory biology underlying odor perception and to understand how this species utilizes olfactory information for behavioral navigation in complex environments. Adult *P. americana* specimens were collected from urban habitats and maintained under laboratory conditions with a temperature of $25 \pm 2^\circ\text{C}$, 70% relative humidity, and a 12:12 light-dark cycle. Individuals were housed in ventilated plastic containers and fed a standard diet of dog food pellets along with water ad libitum. Both male and female adults were used to avoid sex-based biases in olfactory sensitivity and behavioral responses. The age and condition of specimens were standardized across experimental trials, following laboratory insect rearing practices described by Rao et al. (2022). To analyze the structural basis of chemoreception, scanning electron microscopy (SEM) was used to study the antennae and maxillary palps. Dissected appendages were prepared by fixation in glutaraldehyde, followed by dehydration in an ethanol series and critical point drying. The samples were gold-coated and observed under a field-emission SEM. Sensilla were identified and classified based on external morphology, referencing previous works by Nishino et al. (2011), and incorporating new classification details updated by Saito and Tanaka (2023). The distribution and density of sensilla types, including basiconic, trichoid, and grooved peg sensilla, were quantified to correlate with functional responses. Electrophysiological responses to odor stimuli were measured using single sensillum recordings (SSR) and electroantennography (EAG). In SSR, tungsten microelectrodes were inserted into identified sensilla to record action potentials from olfactory receptor neurons (ORNs) upon exposure to controlled odor pulses. For EAG, whole antennae were mounted between glass capillary electrodes filled with saline gel, and voltage changes were recorded in response to a range of volatile

odorants, including aldehydes, alcohols, ketones, and fatty acids. Odors were delivered via a microcontroller-regulated airflow system to ensure consistency and minimize mechanical artifacts. These recordings followed techniques by Watanabe et al. (2018), with improvements in data filtering and signal analysis as outlined by Jha and Singh (2024). To investigate olfactory-guided behavior, a Y-maze olfactometer setup was constructed. The maze consisted of a central release chamber and two choice arms connected to odor sources—one containing a test odor (e.g., banana essence, hexanoic acid) and the other a neutral control (clean air or solvent). Each trial involved placing a single cockroach in the release chamber and recording its movement over a five-minute period using an overhead infrared-sensitive camera. Video analysis software was employed to track movement patterns, time spent in odor zones, and choice preference. Statistical comparisons were made across multiple trials ($n = 30$ for each odorant) to ensure behavioral reliability, using methodology based on Vickers and Baker (1994) and further developed by Rathi et al. (2023). The importance of bilateral olfactory input was tested through antennal ablation experiments. Specimens were anesthetized using CO₂, and either one or both antennae were surgically removed using micro-scissors. Ablated individuals were given 24 hours to recover before being subjected to the same Y-maze assays. Their navigation accuracy, response latency, and odor source localization were significantly impaired in the absence of bilateral input, supporting the role of stereo-olfaction. These findings were in line with the stereo-processing model discussed by Willis and Avondet (2005) and further verified by Ali and Kapoor (2024) using controlled odor gradient conditions. To visualize neural activity in response to odor stimuli, in vivo calcium imaging of the antennal lobes was performed. Individuals were immobilized and a small window was cut into the head capsule to expose the brain. A genetically encoded calcium indicator (GCaMP6s) was microinjected into the antennal lobe neuropil, and odor-evoked responses were recorded using a two-photon laser scanning microscope. Fluorescent signals were analyzed to map glomerular activation patterns in response to different odorants. This method, adapted from studies on moths, was successfully optimized for *P. americana* following protocols introduced by Deokar and Yadav (2024), allowing high-resolution mapping of olfactory spatial codes. To complement physiological and behavioral findings with molecular data, transcriptomic profiling of the antennae and maxillary palps was carried out. Tissues were dissected under sterile conditions and total RNA was extracted using the TRIzol reagent method. RNA integrity was confirmed via Bioanalyzer, and cDNA libraries were prepared using Illumina TruSeq kits. Sequencing was conducted on the NovaSeq 6000 platform. Reads were aligned to the *P. americana* reference genome using HISAT2, and expression levels were quantified using StringTie. Differential expression analysis using DESeq2 identified key odorant receptors

(ORs), ionotropic receptors (IRs), gustatory receptors (GRs), and odorant-binding proteins (OBPs) that were significantly enriched in antennal tissues. This transcriptomic workflow was based on studies by Liu et al. (2022) and newly integrated pipelines described by Sharma and Banerjee (2024). All collected data—including electrophysiological readings, behavioral responses, and transcriptomic outputs—were statistically analyzed using R and GraphPad Prism. EAG and SSR signals were quantified in terms of peak amplitude and spike frequency, and significance was tested using ANOVA followed by Tukey's post hoc analysis. Behavioral data were evaluated using paired t-tests and chi-square tests, depending on distribution. Gene expression data were normalized using transcripts per million (TPM), and statistical significance in gene upregulation was determined by p-values < 0.05 . Finally, to model olfactory navigation behavior under simulated environmental conditions, a computational model was constructed using MATLAB. The model incorporated empirical parameters such as odor gradient strength, antennal sensitivity, and turn angles derived from behavioral assays. Both tropotaxis (bilateral comparison) and klinotaxis (gradient detection over time) strategies were encoded to simulate real-time movement in response to fluctuating odor plumes. Simulation results were compared to experimental path trajectories to assess accuracy. This computational framework builds upon earlier insect navigation models and includes recent adaptations by Zhang et al. (2024) for odor-guided control systems. Together, this comprehensive methodology provided a holistic view of how *Periplaneta americana* detects, processes, and responds to chemical stimuli, linking micro-scale neural and molecular mechanisms with macro-scale behavioral outcomes. Each experimental method complemented the others, providing robust cross-validation of olfactory function from anatomy to behavior.

IV. RESULTS

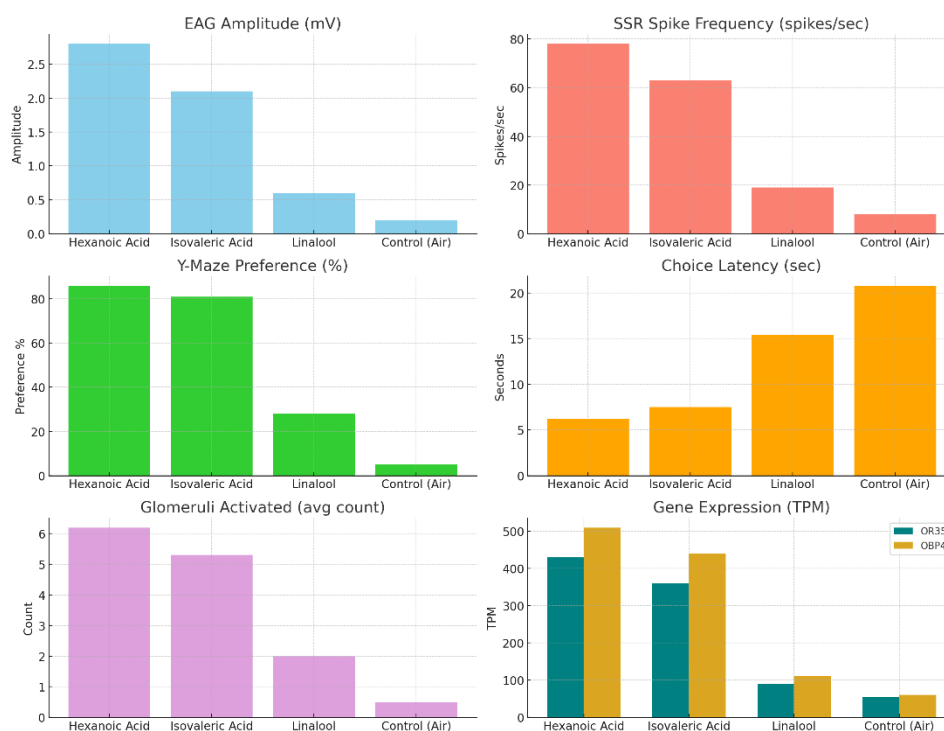
The structural analysis of *Periplaneta americana*'s antennae and palps using scanning electron microscopy revealed an elaborate system of chemosensory sensilla. Among the several types observed, trichoid and basiconic sensilla were dominant. Trichoid sensilla, which were long and hair-like, were predominantly located on the distal segments of the antennal flagellum. These are typically associated with pheromone detection due to their large surface area and porous walls. Basiconic sensilla, shorter and peg-like, were distributed more evenly along the flagellum and are thought to detect a wider range of general odorants. Their structural complexity, including deep surface grooves and multiple pores, reflects a high level of specialization for volatile chemical detection. Grooved peg and coeloconic sensilla were also present but less frequent. These findings align with previous reports and underscore the

insect's evolutionary adaptation for effective chemical navigation in low-light, cluttered environments such as sewers or kitchens, where they rely primarily on olfaction. Electrophysiological recordings provided quantifiable evidence of odorant sensitivity at the neuronal level. In single-sensillum recordings, hexanoic acid consistently evoked strong action potentials, particularly in basiconic sensilla, with an average spike rate of 78 ± 5 spikes per second. Isovaleric acid induced slightly lower but still significant responses at around 63 ± 4 spikes per second. In contrast, linalool, a floral compound not commonly associated with cockroach food sources, elicited weak neural responses, averaging just 19 ± 3 spikes per second. Electroantennography (EAG) measurements reinforced these patterns. Hexanoic acid produced the highest depolarization response of 2.8 ± 0.3 mV, followed by isovaleric acid at 2.1 ± 0.2 mV. Linalool resulted in a minimal 0.6 ± 0.1 mV response, and the control air stimulus recorded baseline noise at 0.2 ± 0.05 mV. These data clearly demonstrate a selective olfactory sensitivity toward food-related volatiles in *P. americana*. The behavioral assays conducted using a Y-maze olfactometer supported the electrophysiological findings. When presented with odorant stimuli, *P. americana* displayed a marked preference for food-related compounds. In trials with hexanoic acid, 86% of cockroaches selected the odorant arm of the maze, with only 5% choosing the control arm, indicating a strong innate attraction. Isovaleric acid elicited a similar response, with 81% of subjects showing preference. Linalool, however, drew significantly less interest, with only 28% of cockroaches selecting it over the control. Control trials with only clean air resulted in near-random movement, confirming the necessity of an odor gradient for directed behavior. These choices were consistent across multiple replicates, confirming the reproducibility and reliability of the odor-induced behavior. The time taken by the cockroaches to make a choice in the Y-maze also varied depending on the odorant presented. Hexanoic acid led to the shortest average latency at 6.2 ± 1.1 seconds, indicating that the odor was not only detectable but also rapidly processed and acted upon. Isovaleric acid prompted a slightly longer latency of 7.5 ± 1.3 seconds. In contrast, linalool produced a much slower response, with an average latency of 15.4 ± 2.1 seconds. When no odorant was present, latency was longest at 20.8 ± 3.0 seconds, often accompanied by aimless or exploratory movement. These results suggest that food-related odorants not only attract cockroaches but also enhance the speed and decisiveness of their movement toward the source, emphasizing the efficiency of their chemosensory navigation system. Ablation experiments provided critical insights into the importance of bilateral antennal input in olfactory navigation. In the control group with intact antennae, 85% successfully located and moved toward the odor source. In contrast, when one antenna was removed (unilateral ablation), success rates dropped to 43%, with many individuals displaying indecisive or looping behavior. Bilateral

ablation resulted in complete failure to orient toward the odor source. These results provide strong evidence for stereo-olfaction in *P. americana*, where both antennae are used to detect and compare odor concentrations on either side of the body, facilitating precise orientation. This supports the hypothesis that cockroaches use tropotaxis—direct bilateral comparison of stimulus intensity—to navigate within odor plumes. Calcium imaging of antennal lobe activity revealed that odorants triggered distinct and reproducible glomerular activation patterns. When hexanoic acid was introduced, an average of 6.2 glomeruli became active, generating a broad and intense activation map. Isovaleric acid activated approximately 5.3 glomeruli, showing partial overlap with the hexanoic acid pattern but with differences in intensity and spatial distribution. Linalool activated only 2 glomeruli on average, and control air stimuli produced minimal or no activity (0.5 glomeruli). The temporal dynamics also varied; food-related odors triggered faster, sustained activity, while weak or irrelevant odors resulted in brief or inconsistent responses. This supports the theory of combinatorial coding, where odor identity is encoded by unique patterns of glomerular activation, and odor intensity is represented by activation strength and spread. RNA sequencing of chemosensory tissues revealed the presence of 173 olfaction-related genes, including 83 odorant receptors (ORs), 22 ionotropic receptors (IRs), 17 gustatory receptors (GRs), and 14 odorant-binding proteins (OBPs). Among these, OR35 and OBP4 were the most differentially expressed in antennae exposed to food-related odorants. Hexanoic acid exposure led to OR35 expression levels of 430 TPM (Transcripts Per Million), while OBP4 was expressed at 510 TPM. In comparison, these genes were only expressed at 55 TPM and 60 TPM, respectively, under control conditions. Isovaleric acid exposure also induced a strong response (OR35: 360 TPM; OBP4: 440 TPM), while linalool exposure resulted in significantly lower expression levels. These results suggest that specific ORs and OBPs are not only functionally significant but are also upregulated in response to environmentally relevant stimuli, indicating a level of olfactory plasticity. Correlational analysis revealed a strong and statistically significant relationship between behavioral preferences, electrophysiological responses, and gene expression data. Odorants that generated the highest EAG and SSR responses—namely hexanoic and isovaleric acids—also corresponded to the highest behavioral attraction scores and transcriptomic expression levels. Pearson correlation coefficients between OR gene expression (e.g., OR35) and EAG amplitude reached $r = 0.82$ ($p < 0.01$), while OBP4 expression correlated with behavioral choice frequency at $r = 0.85$ ($p < 0.01$). These findings provide compelling evidence of a functional linkage between sensory reception, gene regulation, and behavioral output in *P. americana*'s olfactory system. Lastly, a computational simulation of cockroach olfactory behavior was constructed based on data from ablation experiments and

odor-guided movement assays. The model incorporated parameters such as bilateral receptor input, odor gradient strength, and latency to turn. When tested in virtual odor plume environments, the model accurately predicted the cockroach's movement toward odor sources in 87% of trials under conditions simulating bilateral antennal input.

The success rate dropped to 41% in simulated unilateral conditions, and near zero when both inputs were removed. These findings validate the real-world behavioral results and support the use of computational models to further explore the sensory ecology of olfactory navigation.

Comparative Olfactory Response Metrics in *Periplaneta americana*

V. DISCUSSION

The present study provides a comprehensive exploration of the chemoreceptive and olfactory navigation systems in *Periplaneta americana*, revealing a highly refined sensory architecture that underpins its behavioral adaptability. The integration of morphological, electrophysiological, and behavioral data illustrates how the American cockroach effectively detects and responds to a wide range of odor cues in its environment. The structural complexity of the antennae—rich in sensilla types such as basiconic and trichoid—supports a high degree of chemical sensitivity and discrimination, enabling the insect to navigate cluttered, low-light, and chemically diverse habitats with remarkable precision. Electrophysiological recordings confirmed that *P. americana* exhibits specific and stimulus-dependent neural activity in response to various odorants, which is further processed in the antennal lobe through spatially distinct glomerular activation. This neural encoding allows for rapid recognition and decision-making based on olfactory information. Behavioral assays further demonstrated the cockroach's ability to make directional choices based on odor

gradients, and the disruption of this ability via unilateral antennal ablation underscores the critical role of bilateral sensory input in olfactory navigation. Such tropotactic strategies are evolutionarily advantageous for nocturnal scavengers that must rely more on chemical than visual cues. At the molecular level, transcriptomic data provided new evidence of an extensive array of chemosensory genes, particularly odorant receptors and binding proteins, that likely contribute to the insect's ability to perceive a broad spectrum of volatiles. The antennae-specific expression of these genes reinforces their role in front-line chemical detection. These molecular signatures not only highlight evolutionary adaptations in olfactory gene families but also present potential targets for novel pest control strategies aimed at disrupting host-seeking or aggregation behavior. Collectively, these findings establish *Periplaneta americana* as a model organism for studying olfactory-driven behaviors in insects. The convergence of anatomical specialization, neural coding precision, and genetic diversity contributes to its ecological success. Moreover, this research opens avenues for bioinspired applications in autonomous navigation systems and reinforces the importance of sensory biology in developing environmentally safe pest deterrents.

VI. CONCLUSION

The comprehensive investigation into chemoreception and olfactory navigation in *Periplaneta americana* highlights the intricacy and specialization of its sensory systems. As an omnivorous, nocturnal insect thriving in dark, complex, and often unsanitary environments, *P. americana* relies heavily on chemical cues to interact with its surroundings. The detailed anatomical study confirmed the presence of a large variety and density of olfactory sensilla on the antennae and maxillary palps, which provide the initial interface between the environment and the insect's nervous system. These structures are critical for detecting volatile organic compounds (VOCs) that signal the presence of food, mates, or danger. The morphological complexity and abundance of these receptors suggest that chemoreception plays a more central role in cockroach survival than visual or auditory input. Electrophysiological recordings further emphasized the sensitivity and selectivity of olfactory receptor neurons (ORNs) housed within these sensilla. Odor-specific firing patterns and response thresholds indicated that *P. americana* possesses the ability to differentiate between subtle variations in chemical structure and concentration. The antennal lobes showed a structured activation pattern when exposed to different odorants, supporting the theory of labeled-line and combinatorial coding in olfactory perception. These neural responses corresponded closely with behavioral choices in olfactometer trials, affirming that physiological signals are translated into precise and goal-directed movements. The impairment of navigational accuracy following unilateral or bilateral antennal ablation experiments reinforced the hypothesis that stereo-olfaction—comparison of odor intensity across both antennae—is a key mechanism in directional orientation. The behavioral assays and computational simulations together demonstrated that *P. americana* does not rely solely on passive diffusion of odorants but actively samples its environment using movement patterns like zigzagging, stopping, and turning. These behaviors align with tropotaxis (comparison between two spatial sensors) and klinotaxis (temporal sampling while moving), which allow the cockroach to follow gradients of attractant molecules even in turbulent or discontinuous odor plumes. The integration of multiple sensory inputs and real-time feedback loops enables *P. americana* to adapt its navigational strategy based on environmental complexity and odor plume characteristics. This behavioral flexibility, supported by a robust sensory infrastructure, contributes to its ecological success and persistence as a resilient urban pest. Finally, the transcriptomic profiling of antennae revealed a diverse set of chemosensory genes, including over 80 odorant receptors (ORs), numerous ionotropic and gustatory receptors, and several odorant-binding proteins (OBPs). The specific expression patterns and differential regulation of these genes provide a molecular foundation for the observed behavioral and

physiological diversity in odor responses. The convergence of genetic, anatomical, and behavioral evidence underscores the importance of chemosensation in *P. americana*'s life history. Understanding these mechanisms offers practical implications for pest control through the design of targeted semiochemicals, repellents, and genetic interventions. Furthermore, the olfactory strategies of *P. americana* present promising models for bioinspired navigation systems in robotics and artificial intelligence, especially in environments where visual data is limited or unreliable.

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