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Behavioral Significance of Vibrations in Coleopteran and Hemipteran Insects : Applications and Implications

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ABSTRACT

Insects utilize various modes of communication, including touch, smell, sound and sight. Among these, vibrational communication emerges as a pivotal signaling mechanism in coleopteran and hemipteran insects, influencing behaviors such as mating, territoriality, and parent-offspring interactions. This review delves into the mechanisms, types and behavioral significance of vibrational signaling in these insect groups. Vibrational signals are produced through mechanisms like tremulation, drumming, stridulation, and tymbalation, transmitting through both airborne and substrate-borne pathways. Sensory receptors such as femoral chordotonal organs play crucial roles in perceiving vibrational cues. Understanding the behavioral significance of vibrations unveils novel avenues for eco-friendly pest management strategies, such as disrupting mating or territorial behaviors, using artificial signals and vibrational cues to monitor and manage pest populations in agriculture, which reduce the reliance on chemical pesticides and promote more sustainable pest management tactics. Furthermore, emerging technologies utilizing low-frequency vibrations hold promise for eco-friendly pest management strategies, species identification and conservation efforts. This review underscores the importance of investigating the neural mechanisms underlying vibration perception and processing in insects, alongside the development of bio-inspired vibration sensors for applications in fields such as earthquake detection and structural health monitoring. By leveraging the intricate language of vibrations in insects, we can advance both fundamental understanding and practical applications in pest management and conservation efforts.

Keywords Communication, Substrate borne vibration, Coleopteran, Hemipteran, Vibration exciter, Pest management.

INTRODUCTION

Communication may be defined as any exchange of information between individuals. The English word communication comes from the Latin word communicare, which means to share or come to a common understanding (Abasenga 2023).

It can also be referred to as the process of understanding and communicating a common meaning

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(Pearson and Nelson 2000). It is the exchange of information between individuals, the one that transmits the message (emitter) and the other that receives and processes that message (receiver). For members of the human species, it is an essential part of all social interactions. Similar to humans, insects can communicate in a variety of ways, but their "language" is almost innate. Each individual has a unique "vocabulary" at birth that they only share with other individuals in their own species. The ability to generate or comprehend these signals is largely independent of learning. Insects, like all animals, rely on their senses to understand their environment. These senses-touch, smell, sound and sight—serve as channels for communication and gathering information. Therefore, an insect might transmit a communication signal through actions such as producing a sound, releasing a chemical, or emitting light. Insects do communicate for Kin recognition, mate identification, courtship facilitation, resource guidance, spatial regulation, territorial establishment, danger warning, presence advertisement, threat/submission expression and deception/mimicry. Insects have different four types of communication viz., visual, chemical, tactile and vibrational. Among these, communication through vibration is known to be an important and common signal for insects that cause behaviors such as repellence, attraction, mating, feeding, oviposition.

Vibrational communication

Vibrational communication is a form of communication in insects that involves the production and reception of sounds or vibrations. Many insects have evolved the ability to produce and perceive sounds for various purposes, including mating, warning of danger, defending territory, and locating resources.

There is much information available on visual, chemical and tactile communication but there is little information available on vibrational communication. Here, we try to elaborate on vibrational communication. Among these, communication through vibration is known to be an important and common signal for insects that cause behaviors such as repellence, attraction, mating, feeding, oviposition. The number of species that use vibrations is estimated to be 1,95,000 or more. Therefore, it may be possible to control the

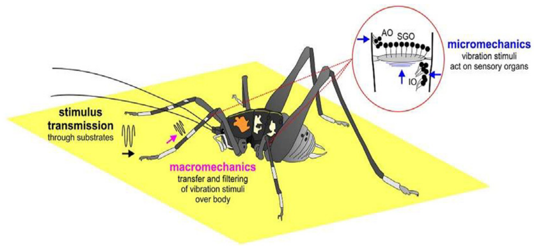


Fig. 1. Transmission of vibrational stimulus in insect.

behavior of various insect pests like mating, territory establishment, alarm signaling and social coordination by artificially controlling a vibration signal (Cocroft and Rodriguez 2005). Plants are the most widely used substrate for transmitting vibrational signals by insects. They used vibration for a wide range of purposes, including mating, territory establishment, alarm signaling, and social coordination.

Vibrational communication shows itself, as mechanical vibrational stimuli received through the substrate and transferred to all over the insect body, where sense organ like subgenual organ is present, through which insects receive vibrational stimuli and respond to them (Fig. 1).

Mechanism and type of vibrational signaling

Insects produce vibrational signals through various mechanisms like tremulation, drumming, stridulation and tymbalation (Fig. 2) (Low *et al.* 2021).

Stridulation **:** A single chirp produced by an *Ips pini* bark beetle. Chirps are produced using a file and scraper mechanism located between the head and pronotum.

Percussion **:** A *Macrotermes natalensis* termite communicates through a sequence of drumming signals created by tapping the substrate with its head.

Tymbalation **:** An Eubaphe unicolor moth generates a series of clicks using a pair of tymbals positioned on each side of the prothorax.

Tremulation **:** *Apis florea* bees produce a group piping signal through vibrations of their flight muscles,

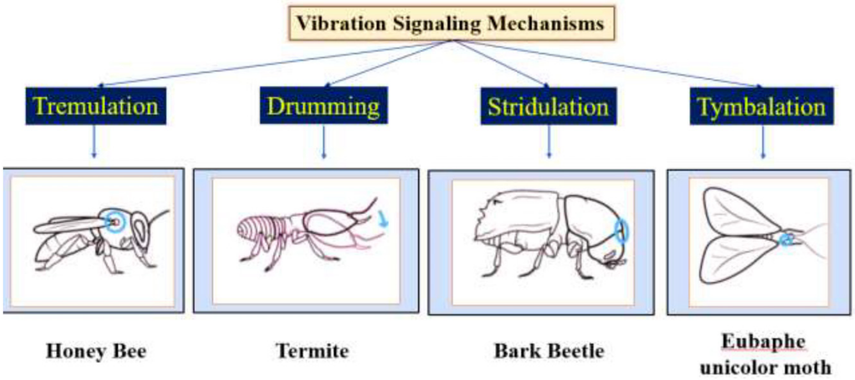


Fig. 2. Type of vibrational signaling mechanism.

creating piping sounds.

Forced Air **:** An *Amphion floridensis* caterpillar emits a single vocalization through airflow from its alimentary canal.

Among all vibrational signaling mechanisms, tremulation and drumming occur in most insect orders, with tremulation occurring in 68% and drumming in 39% of the signaling families (Fig. 1). Such widespread use of these mechanisms reflects the ease of producing signals with them, without evolving specialized structures (Virant-Doberlet *et al.* 2023).

Kind of vibrations

In insects, vibrations produced by individuals can pass through in two ways (Hager and Kirchner 2019). On the basis of transmitted through there are two kinds of vibration (Fig. 3).

Airborne vibrations **:** Travel through the air as pressure waves.

Substrate-borne vibrations **:** Transmitted through solid surfaces such as leaves, branches or the ground.

Purposes of vibrational signaling

Insects produce vibrational signals for various purposes like Sexual Signaling, Agonistic Signaling, Social (Cooperative) Signaling, Defense, Foraging, and Mutualistic Signaling (Low *et al.* 2021).

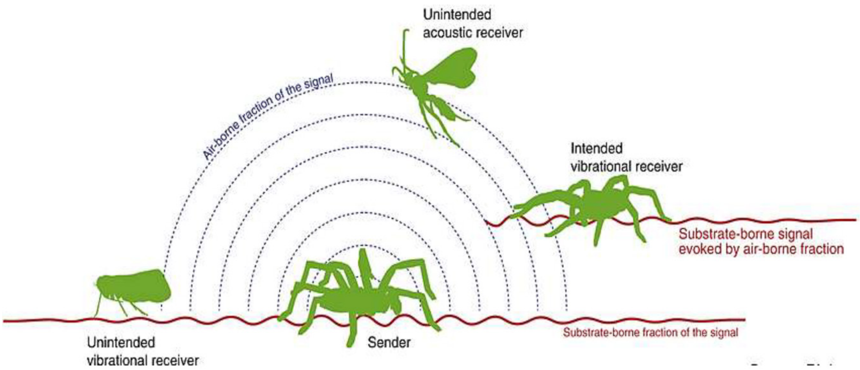
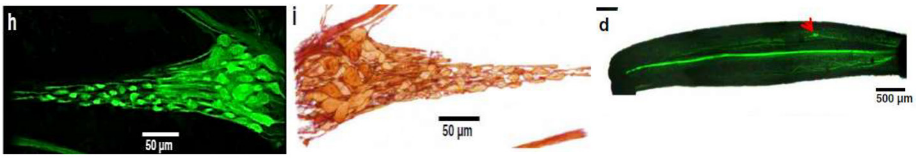


Fig. 3. Kind of vibrations on basis of transmitted through.



4b

Fig. 4a. Adult of *Monochamus alternatus*. **Fig. 4b.** Neuronal mapping.

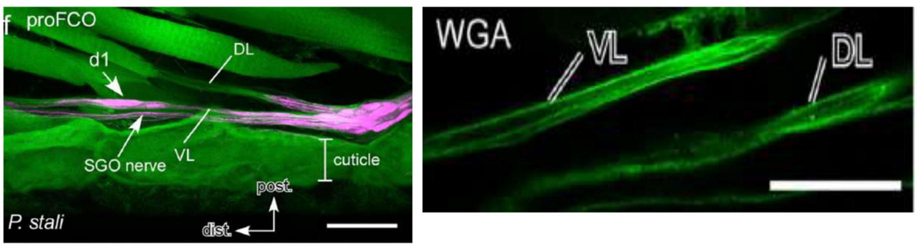
The most common type of vibrational signals are sexual signals, which are primarily used in calling and courting. 76% of families that use vibrational communication describe using these types of signals. In addition, being species-specific, these signals and signal repertoires are typically sex-specific.

In 34% of the families where vibrational signalling is observed, antagonistic vibratory signalling has taken place as part of male rivalry over long distances, territoriality, or close quarters. When males fight for access to females, they often show aggressive behavior in direct encounters. However, females and larvae that are fighting for similar resources also exhibit this behavior (Low *et al.* 2021).

Vibration sensing receptors

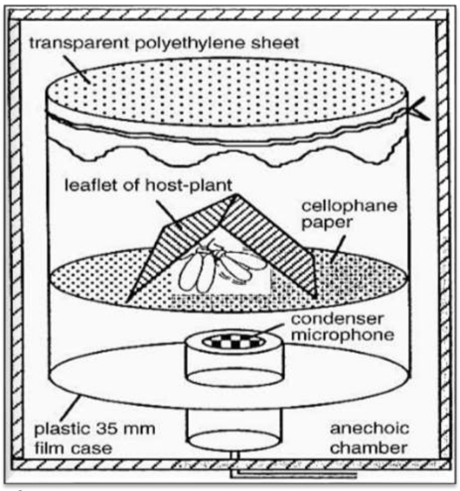
Johnston's Organ (Detection of airborne vibrations at the base of antennae), Tympanal Organs (Sensing airborne vibrations for communication and predator detection in thorax, abdomen and leg), Trichoid Sensilla (Detect vibration for mating, found on antennae and other body parts), Campaniform Sensilla (Serve as sensory structures for detecting vibrations, sound, and mechanical stimuli in various body parts), Subgenual Organ (Detect substrate-borne vibrations for communication, mate location, predator detection, and environmental perception on the ventral side of the head), Chordotonal Organ (Detect a wide range of mechanical stimuli in leg and wing joints) are major

5a



5b

Fig. 5a. Adult of *Plautia stali*. **Fig. 5b.** Neuronal mapping.



6a

6b

Fig. 6a. Anechoic chamber. **Fig. 6b.** Laser Doppler Vibrometer.

vibration sensing receptors.

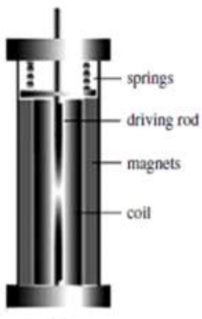
In coleopteran insect

Takanashi *et al.* (2016) in Tokyo, Japan studied on Japanese pine sawyer beetle (*Monochamus alternatus*) (Fig. 4a) and they showed that beetle gave startle responses, stridulation, freezing and walking in response when apply Vibrations below 1 kHz. Which indicates that they can detect low-frequency vibrations. To investigate the reason, they conducted neurological mapping (Fig. 4b) and discovered that the femoral Chordotonal Organ (FCO), situated in the mid-femur, contains 60–70 sensory neurons. It is distally attached to the proximal tibia through a cuticular apodeme.

In hemipteran insect

Likewise, in hemipteran, Nishino *et al.* (2016) in Tokyo, Japan stated that in stink bugs (*Plautia stali*), the Femoral Chordotonal Organ (FCO) includes both ventral and dorsal scoloparia (Figs. 5a–5b). The ligament of the dorsal scoloparium is distally attached to the accessory extensor muscle, whereas the ventral scoloparium is attached to a specialized tendon.

7a



7b

7c

Fig. 7a. Giant magnetostrictive material. **Fig. 7b.** The schematics magnetostrictive actuator. **Fig. 7c.** The schematics of prototype.

8a 8b

Fig. 8a. Vibration exciter made using Giant magnetostrictive materials. **Fig. 8b.** Piezo elcectric Buzzer / Electromagnetic Shaker.

Behavioristic significance of vibration

Mating behavior

Vibration in substrate occurred by the abdomen of female brown plant hopper elicited mating excitation in males (Ichikawa and Ishii 1974). Cokl *et al.* (1999) at Brisbane (Australia) found that male southern green stink bugs (*Nezara viridula* L.) use substrate-borne vibrations to locate females.

Deterrent behavior

Manrique and Schilman (2000) at Wurzburg (Germany) found that Female kissing bug produce substrate borne vibration to deter male. Female beetles produce substrate-borne vibrations using a stridulatory groove located on the post-sternal region, even when they are not ready for mating. The pupa of the soil-dwelling Japanese rhinoceros beetle, *Trypoxylus dichotoma*, emits vibratory signals to deter burrowing larvae as a means of self-protection (Kojima *et al.* 2012). Female of Indian cowpea beetle use vibration cues in egg-laying decisions as compared with Brazilian cowpea beetle species (Guedes and Yack 2016).

Conspecifics behavior

Synchronize hatching of brown marmorated stink bugs was observed due to vibrations produced by cracking of the eggshell (Endo *et al.* 2019).

Maternal behavior

Cocroft (1999) at New York (USA) studied on parental defense behavior of thorn hoppers (*Umbonia crassicornis*) and they observed that Nymphal *Umbonia* are subject to intense predation in their exposed locations on plant stems. Females defend their offspring by approaching the predator, fanning their wings and kicking with their hind legs and the disappearance of the female results in greatly increased predation on nymphs. *U. crassicornis* nymphs communicate to obtain maternal defense against predators. When approached by a predator, nymphs at the site of disturbance produce substrate-borne vibrational signals. These signals trigger a response from neighbors and signaling sweeps rapidly through the aggregation. Group signals evoke the mother's defensive behavior. Nymphs of *Parastrachia japonesis* gathered more when females pass of provisioning call (Nomakuchi *et al.* 2012). Mukai *et al.* (2018) at Kagoshima (Japan) studied on sub social burrower bug (*Adomerus rotundus*). They observe that there is sibling cannibalism observed in sub-social burrower bugs. Sibling cannibalism is the killing and consumption of conspecific. Females produce vibration during the pre-embryonic development stage on egg clutch and its leads towards synchronization. Maternal synchronization of hatching function to prevent cannibalism among siblings.

Instruments use for measuring vibration in insects

Anechoic chamber for measuring insect vibrations is a specialized room designed to isolate insects from external vibrations and environmental disturbances. It provides a controlled environment with vibration sensors to precisely measure the subtle vibrations produced by insects during various behaviors, allowing researchers to study insect behavior and communication more accurately (Fig. 6a).

Laser doppler vibrometer (LDV), also known as a Laser Vibrometer, is an advanced instrument used to measure vibrations in various objects, surfaces, or structures. It is a non-contact measurement device that uses laser light to detect and analyze the motion of a target's surface or a specific point on the target. LDVs are highly precise and are commonly used in research, engineering, and industrial applications for various purposes, including vibration analysis, quality control, and material characterization (Fig. 6b).

Plausible application

Coleopteran control

Bioacoustic pest management

In IPM programs for the control of the Colorado potato beetle, playback systems can emit recorded vibrations associated with the beetle's mating and feeding behaviors. This disrupts beetle activities, reducing their feeding damage to potato crops.

Precision pesticide application

In agricultural fields affected by beetles, IPM practitioners can use drones equipped with vibrating dispensers. These drones apply pesticides precisely to areas with high beetle infestations, minimizing chemical usage and collateral damage to non-target organisms.

Early detection through vibrational sensors

Grain storage facilities prone to infestations by beetles like the red flour beetle can install automated vibrational sensors in grain bins. These sensors detect increased pest activity, enabling early intervention and preventing widespread infestations.

Management of bark beetle, *Dendroctonus frontalis* through vibrational signals

Hofstetter *et al.* (2014) at Arizona (USA) conducted an experiment to reduce bark beetle, in which they took phloem sandwich and give three treatments into it like beetle sounds, radio treatments and no sound and result shows that Playback of modified biological sounds reduced the number of eggs and tunnels length of bark beetle, *Dendroctonus frontalis*.

Hemipteran control

Vibrational disruption of mating

In vineyards affected by the grapevine leafhopper, vibrational devices can emit disruptive vibrations that interfere with the mating signals of male leafhoppers. By disrupting mating behaviors, this approach can reduce the population of leafhoppers and decrease damage to grapevines.

Detection of infestations

In the case of bed bug infestations in residential or hotel settings, acoustic sensors can be employed to detect the presence of these blood-feeding insects. Bed bugs produce characteristic vibrations while moving and feeding in their hiding places. Specialized sensors placed near common hiding spots, such as under mattresses or in furniture, can pick up these vibrations. When infestations are detected early, pest control professionals can be alerted to treat the affected areas promptly, preventing the infestation from spreading and reducing the need for extensive pesticide use.

Vibrational monitoring

Brown marmorated stink bugs are a notorious agricultural pest known for damaging a wide range of crops, including apples and peaches. To detect the presence of these stink bugs, farmers and orchard managers employ specialized vibrational sensors. These sensors are attached to the branches and trunks of trees within orchards. Brown marmorated stink bugs produce specific vibrational patterns when feeding, mating, or moving within trees. The sensors can detect these patterns and transmit data to a central monitoring system. When increased stink bug activity is detected, it triggers an alert to farmers, prompting them to implement targeted control measures. This technology helps protect orchards from stink bug damage while reducing the need for broad-spectrum pesticides.

Vibrational deterrents

In organic farming systems, vibrating devices placed near crops can emit vibrations that deter true bugs like leafhoppers from settling on plants. This reduces feeding damage without relying on chemical pesticides.

Management of grapevine leafhopper, *Scaphoideus titanus* through vibrational signals

Eriksson *et al.* (2012) conducted an experiment and transmitted Transmission of MCS (Male calling song) through a grapevine plant. They reported that vibrational signals applied through an electromagnetic shaker in grapevine plants reduced the mating frequency of the leafhopper, *Scaphoideus titanus* and recorded a higher number of virgin females in semi-field conditions with potted plants and in field conditions.

Management of neotropical brown stink bug, *Euschistus heros* by disrupt the mating behaviors through Substrate-borne vibrations

Laumann *et al.* (2018) investigated the effect of background noise on substrate-borne vibratory communication, mating, and copulation of the brown stink bug *E. heros*. They observed that abiotic noise disrupts insect communication. Frequencies of 75–200 Hz reduced communication and copulation of this stink bug and also female fecundity and fertility.

Control greenhouse whitefly, *Trialeurodes vaporariorum* and increase pollination efficiencies in though substrate-borne vibration in tomato

In a study by Sekine *et al.* (2023), they applied substrate-borne vibrations at frequencies of 30 Hz and 300 Hz to tomato plants in a greenhouse. They found that applying 30 Hz vibrations increased the number of tomato fruit sets, while applying 300 Hz vibrations decreased the number of *T. vaporariorum* pests. This suggests that substrate-borne vibrations could be effective for both pest control and pollination purposes.

Takanashi and Kojima (2021) stated that Low-frequency vibrations known to have disruptive effects on feeding and other behaviors in Cerambycidae and Scarabaeidae family of beetle. Hence, low-frequency vibrations could also be beneficial for pest control purposes.

Based on the discovery of vibrational sensitivity in these insects, scientists are now developing a new technology for pest management. This involves using low-frequency vibrations with large amplitudes, generated by a vibration exciter made from giant magnetostrictive material (GMM), (Fig. 7a).

GMM is an alloy comprised of iron and rare metals like terribium and dysprosium, exhibits a large magnetostrain, namely a strain caused by orientation of the magnetic field (Liu *et al.* 2005) (Figs. 7b –7c).

This exciter generates low frequency vibrations at high acceleration, and these vibrations are expected to manifest enough power to disrupt the behaviors of target pests (Takanashi and Kojima 2021) (Figs. 8a – 8b). Using vibrations intermittently can help prevent insects from becoming habituated to them.

Furthermore, a vibration exciter that uses GMM technology is able to generate vibration on various substrates (e.g., crops in greenhouses).

Concluding remarks and future perspectives

In conclusion, the behavioral significance of vibrations in coleopteran and hemipteran insects unveils a sophisticated communication system deeply embedded in their ecological interactions. Through vibrational cues, these insects navigate complex social structures, locate mates, defend territories, and detect predators and prey. The applications of understanding these vibrational signals extend beyond fundamental biological research, offering potential avenues for pest management strategies, agricultural enhancements, and biomimetic technologies. By deciphering the intricate language of vibrations in coleopteran and hemipteran insects, we gain valuable insights into the dynamics of their ecosystems, paving the way for innovative approaches to conservation and sustainable agriculture.

Moreover, recognizing the behavioral significance of vibrations underscores the interconnectedness of organisms within ecosystems and highlights the importance of preserving biodiversity. As we delve deeper into the intricate world of insect communication, we uncover novel opportunities for bio-inspired technologies and ecological management practices. Harnessing the power of vibrational signals not only enhances our understanding of insect behavior but also opens doors to innovative solutions for addressing environmental challenges. Ultimately, acknowledging the applications and implications of vibrations in coleopteran and hemipteran insects underscores the importance of interdisciplinary research in advancing our understanding of the natural world and leveraging this knowledge for the benefit of both ecosystems and human societies.

Future thrusts in the study of the behavioral significance of vibrations in Coleopteran and Hemipteran insects hold promise for both fundamental understanding and practical applications. Investigating the neural mechanisms underlying vibration perception and processing in Coleopteran and Hemipteran insects holds promise for understanding how these organisms decode vibrational signals. Such insights can lead to the development of innovative pest management tools utilizing vibrational cues, offering environmentally friendly alternatives to conventional methods. Additionally, leveraging vibrational signals for species identification and conservation efforts can enhance biodiversity monitoring and habitat preservation. Furthermore, bio-inspired vibration sensors based on insect physiology have potential applications in various fields such as earthquake detection and structural health monitoring, offering efficient and resilient solutions inspired by nature's design.

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