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Unravelling the enigma of insect communication

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Abstract
Palaeontologists have determined that the earliest evidence of life on Earth dates back 480 million years. During this extensive evolutionary history, life progressed from microscopic cellular forms to complex multicellular organisms. This advancement would not have been possible without the ability of cells, tissues, and systems to communicate with one another through specific mechanisms. A particularly interesting area of study is the communication methods used by insects, which employ a variety of signals to convey different types of information. Insects utilize a broad range of communication mechanisms, including acoustic, visual, chemical, and tactile communication. Understanding how animals have evolved to use signals for communication about predators and the availability of food sources is of great significance.

Keywords: Insects, communication, acoustic, tactile, vision

Introduction

“There is a universal language shared by all living things. From single cells to the most intricate plant and animal civilizations, communication is essential for organising groupings, locating food sources, avoiding danger, and possibly most importantly reproduction. In general, communication is the sharing of information between two or more people, usually a sender and a recipient” [1]. “The difference between verbal and non-verbal communication is crucial in human communication. Linguistic messages are exchanged during verbal communication. Sign language is used in addition to written and spoken communications in verbal communication. Nonverbal communication occurs without a language system being used. Non-verbal communication can take many different forms, such as body language, tone, touch, and location” [2]. A channel is typically defined as the path that connects a sender and a recipient. Animals communicate in a variety of ways and with a wide variety of information types. Animal and plant communication are examples of non-human communication. Scholars working in this area frequently develop further standards for their definition of communicative conduct, such as the need that the behaviour be advantageous to natural selection or that an observed response to the message be made. For many species, animal communication is crucial to mating and courtship, parent-child relationships, social interactions, defence, and territoriality. For instance, communication is used to locate and entice possible mates during courtship and mating.

A dashing firefly makes its way through the dusk shadows. A caterpillar pauses in its munching and sways back and forth in a tree. A cricket chirps behind a stone, and surrounding ants move in neat little packages. Simply put, behaviour is defined as what animals do. More accurately, it refers to the manner in which an organism interacts and adapts to its entire surroundings. “Therefore, an insect's interactions with other insects, members of its own species, and the natural world are all included in its behaviour. For a species to thrive, its individuals must live and for the species to be successful in terms of evolution. Movement, learning, feeding, communication, reproduction, migration, and many more activities are all included in the broad category of activities that are referred to as "behaviour." An insect's well-being is maintained by these actions, which often have minimal impact on other insects of the same sort. Conversely, communicating with others and influencing their actions are central to a wide range of communication tasks. The study of animal behaviour is known as ethology” [3].

Insect communication

"The most diverse group communication, when it comes to insects, has the difficult quality of frequently existing outside the boundaries of human experience or even fiction" [4]. "Despite this, insects display a wide range of communication behaviours that are unparalleled by any other animal class in the animal kingdom and are indicative of their enormous diversity" [5].

"No single species is especially adept at all three modalities, and the relative importance of the olfactory, optical, and auditory transmission routes can differ significantly among insect groups" [6]. "However, olfactory transmission appears to be the principal mode of communication for most insect species that have been studied to date" [4]. "It is believed that this reliance on and strong preference for olfactory communication evolved over the long period of adaptation that followed the ancestral insects' change from primarily aquatic settings to a terrestrial and partially airborne lifestyle" [7]. There is a universal language shared by all living things ranging from individual cells to the most intricate plant and animal communities. Similar to humans, insects can communicate in a variety of ways, but their "language" is essentially instinctive. In solitary species, communication is essential for partner selection and localization. Although acoustic, tactile, and visual signals are frequently employed either independently or in conjunction with chemical signals, chemical signalling is the most popular and well-researched type of social communication. "Four fundamental types of insect communication exist: olfactory (chemical), tactile, auditory, and visual. Their "language," though, is essentially instinctive. Every person is born with a unique vocabulary" [4].

Why do insects communicate?

"Any behaviour requiring the cooperation or participation of two or more people requires some sort of intraspecific communication. Whether on purpose or not, insects can converse with other species. (Interspecific communication)". According to [3] the adaptive value of these communication signals may include:

1. Recognition of kin or nest mates.
2. Locating or identifying a member of the opposite sex.
3. Facilitation of courtship and mating.
4. Giving directions for location of food or other resources
5. Regulating spatial distribution of individuals - aggregation or dispersal.
6. Establishing and maintaining a territory.
7. Warning of danger; setting off an alarm.
8. Advertising one's presence or location.
9. Expressing threat or submission (agonistic behaviour's).
10. Deception / mimicry.

How do insects communicate?

"Insects use their five senses to gather information about their surroundings, just like all other creatures do. Any of these sensory modalities can act as a conduit for information sharing. Since taste and touch are contact senses, communication can only take place when two insects are in close proximity to one another. Hearing, vision, and olfaction (smell) are examples of remote senses where information impulses can travel great distances over the air or water. Insects rely heavily on visual communication, and they use visual cues for defence, territoriality, aggregation, and sexual selection. The majority of insects use chemical signals for communication" [6].

Types of communication

According to [3], Animals communicate between each other by means of

1. Visual communication.
2. Chemical communication.
3. Tactile communication.
4. Acoustic communication.

Visual communication

"In certain insect taxa, visual communication is still very important, despite the fact that insects generally rely more on their other sensory modalities. Perhaps most notably, highly developed colour vision has evolved in the orders Lepidoptera and Odonata. Odonata have adapted visual communication as their primary signalling modality, while Lepidoptera also rely on olfactory communication. This is because Odonata have greatly reduced antennae, which removal does not appear to affect their ability to navigate or capture prey" [3]. "Insect compound eyes are made up of individual units called ommatidia, which are made up of a crystalline cone, a facet lens, surrounding visual pigment cells, and a collection of photoreceptors" [8]. While actual photodetection mostly occurs in the rhabdomeres, a cylindrical structure in the photoreceptors, where the absorbed light is transduced into a brain signal, the spectral sensitivity of the photoreceptors is determined by their visual pigments. "Insect compound eyes interpret perceived light impulses to identify motion, colours, or other patterns of interest. They are directly connected to the optical lobe, the visual centre of the insect brain" [9]. "In order for one insect to communicate with another, it must see them. Active or passive signals may cause it to happen. Among the passive signals are many butterflies utilise visual signals, such as bright actions and colour patterns, to recognise and evaluate possible mates. These cues also help in species recognition" [10].

Mimicry

"Some insects utilise to resemble the appearance of another unappealing species, or to advertise that they can sting. The similarity between one creature and another in terms of colour, pattern, structure, or behaviour is known as mimicry (model). In insects, there are primarily two kinds of mimicry: Mullerian and Batesian" [11].

Müllerian mimicry

Müllerian mimicry is a natural phenomenon in which two or more well-defended species, often foul-tasting and sharing common predators, have come to mimic each other's honest warning signals, to their mutual benefit. The benefit to Müllerian mimics is that predators only need one unpleasant encounter with one member of a set of Müllerian mimics, and thereafter avoid all similar coloration, whether or not it belongs to the same species as the initial encounter. It is named after the German naturalist Fritz Müller, who first proposed the concept in 1878. "Müllerian mimicry was first identified in tropical butterflies that shared colourful wing patterns. Classical model example of Müllerian mimicry in *Heliconius* butterflies: *Heliconious erato* and *Heliconius melpomene*, mimic each other" [12].

Batesian mimicry

Batesian mimicry is a form of mimicry where a harmless species has evolved to imitate the warning signals of a harmful species directed at a predator of them both. It is named after the English naturalist Henry Walter Bates, after his work on butterflies in the rainforests of Brazil. “Perhaps the sharpest contrast here is with aggressive mimicry where a predator or parasite mimics a harmless species, avoiding detection and improving its foraging success. The most common example, the Viceroy butterfly (*Limenitis archippus*), once thought to mimic the Monarch (*Danaus plexippus*), has through further investigation proven to be as distasteful to birds as the Monarch” [13]. Thus, the Monarch and Viceroy are Batesian mimics. That such a disparity could go unnoticed for so long shows to what extent mimicry needs to be studied.

Aposematism - I’m Dangerous

“In Greek ‘apo’ - away; ‘sematic’ - sign. Insects are brightly coloured red or yellow combined with black. Such colouration is a signal to predators that the potential prey is distasteful and should be avoided. Defended (toxic, distasteful etc.) species advertises its unprofitability as prey via warning signals like bright colours. A secondary defense mechanism warns predators of the existence of another primary defensive mechanism” [14].

Thanatosis - I’m Dead

“Appearance of being dead. Example- *Dermestes maculatus* - Where the legs are either partially extended or retracted over the body” [15].

Deimatic behaviour or startle display - I am not what you thought

“To frighten by a sudden shock or surprise - These all are also a part of defence behaviours, visually communicated with predators of these signals are effective only as long as they are visible in daylight” [16].

- Australian katydid *Acripeza reticulata*, raise wings to reveal an abdominal colour pattern.
- Red eyed devil *Neobarrettia spinosa*, present a threat posture when under attack.
- *Cerura vinula* the puss moth larvae when disturbed, they strike a defensive pose raising the red head and waving the twin tails with extendable flagellae.

Bioluminescence

“In the Coleopteran family Lampyridae (Fireflies), numerous nocturnally active species send precisely timed photic signals consisting of unique and plainly visible bioluminescent flakes or glows to attract mates. This is another very well-studied form of visual communication in insects. Active signalling insects, such as fireflies, use energy to create their own light and signals that are visible at night. To attract mates, fire flies continuously emit a yellow-green glow. Every species has distinctive colour patterns that can be used to identify other members of the same species, attract potential mates, warn other organisms of their danger (aposematic mimicry), or operate as a passive defence to ward off predators. 6th and 7th abdominal in adult and 8th in larvae produces light. Click beetle (*Pyrophorus noctilucus*) has two small bioluminescent organs located behind its head. The light of these organs gets more intense when they are in danger” [17].

Chemical Communication

“Among social insects, it is well developed and widespread. The chemical compounds can be carried by currents, deposited on food or flowers, diffused into the air or water, or transferred by trophallaxis. Semio-chemicals are any chemicals that are used to transfer information between organisms. Semeion is a Greek word meaning signal” [18]. “The ability to perceive specific chemical compounds is mostly dependent on the presence or absence of the respective receptor molecules, leading to a tight linkage of sender and receiver” [19]. **“**Semiochemicals are divided into two subcategories” [20];

1. Pheromones.
2. Allelochemicals.

“Another way to categorize chemicals that modify animal behaviour is in terms of the type of behaviour they induce” [21]. This scheme has six categories.

1. **Locomotory stimulant:** A substance that, through kinetic mechanisms, accelerates the rate at which insects leave an area compared to when the substance is absent. The result could be an acceleration of the insects' rate of movement, an induction of avoidance responses, or a reduction in their rate of rotation.
2. **Arrestant:** A substance that, upon touch, causes insects to gather together, including a kinetic mechanism for this aggregation. By decreasing the insects' real speed of locomotion or by raising their turning rate, an arrestant can slow their linear progression.
3. **Attractant:** A chemical which causes insects to make orientated movements towards its source.
4. **Repellent:** A chemical which causes insects to make orientated movements away from its source.
5. **Feeding, mating, or ovipositional stimulant:** A chemical which elicits either feeding, mating or oviposition, respectively, in insects.

Pheramone

“The term pheromone is derived from the Greek *pherein*, to transfer; *horman* to excite.

Pheromones are substances, which are secreted to the outside by an individual and received by a second individual of the same species, in which they release a specific reaction” [22].

Primer pheromones: “Secreted by queens in social insects such as bees, ants, wasps and termites. For example, (E)-9-oxo-2-decenoic acid [9ODA, (I)] which inhibits development of ovary and queen cell construction. Identified as part of the mandibular gland secretion of honeybee queens of *Apis mellifera*. It is transferred by scenting behaviour which means the bees lift their abdomens to expose their pheromone gland, release their pheromones and then fan their wings to direct the smell toward other bees” [23].

Releaser pheromones: Releaser pheromones mediate a wide variety of behaviour. At present they are categorized collectively in a simple and broad classification according to the function or the behaviour that they elicit in the receiving insect into

1. **Sex pheromones:** Produced by one sex attracting other. Mostly by females.
2. **Aggregation pheromones:** Produced by one sex but attracting both sexes. associated with feeding behaviour

and also facilitate mating- bark beetles scolytidae Exo-brevicone, is released through faecal matter of female dendroctonus beetles act as aggregator, attraction more and more beetles to invade the trees.

3. **Dispersal or spacing pheromone:** Stimulate behaviour leading to increasing space between individuals.
4. **Alarm Pheromones:** Which cause alert or alarm response about the attack of parasitoids and predators. Mainly in social insects. Aphids- cornicles secretes. (E) β-farnesene Eg Limonene in termites (Geraniol in tingidae).
5. **Trail pheromones:** "Applied to a surface by an individual, to be followed by another, in ants, the Dufour gland, rectal gland, Pavan's gland, pygidial glands are the source of trail pheromones. are confined to Hymenoptera, Isoptera and a few Lepidoptera as far as is known.
6. **Territorial pheromones:** "Chemicals by which animals mark and recognize their own territories for food gathering or defence (odour in the honey bee hive)" [24].
7. **Funeral pheromones:** "Chemical compounds are produced from dead ants that stimulate a live ant to remove a dead congener to a refuse pile outside the nest" [25].

Allelochemicals

Allelochemicals (Greek *allelon* = of one another) are chemicals which convey information between organisms of different species (interspecific). Allelochemicals are categorized according to the advantage of the behavioural response caused by the releasing compounds.

They have been divided into five categories.

1. Allomones.
2. Kairomones.
3. Synomones.
4. Antimonies.
5. Apneumones.

Allomones: "Allelochemicals are known as allomones (Greek "*allos* + *hormone*" = excite others) if the predators are directly repelled by the odor-releasing individual's protective secretions. For instance, formicine ants use sprays of formic acid to deter predators" [26].

Kairomones: "Kairomones (Greek word "*kairos*" = opportunistic or exploitative): If the receiving individual has the advantage, as with a predator locating its prey using prey odour, the allelochemics are called kairomones" [26]. For example, like in the case of ladybird beetle attracted towards aphids by the kairomone it releases.

Synomone: "Another type of allelochemical is called a synomone" [20] which benefits both the releaser and recipient, for example, floral scents that attract pollinating insects (e.g., honey bees)

Antimones: From Greek word "*a-pneum*" = breathless or lifeless. Any substance produced by non-living material that benefits a recipient species but is detrimental to a different species associated with the non-living material. As in ichneumonid parasitoid *Venturia canescens* attracted by the smell of oatmeal which is the food of its host *Ephestia kuehniella.*

Apneumones: "Detrimental to the releaser and recipient alike. These materials that an organism produces or acquires that, when coming into contact with another individual of a different species in the wild, cause the receiving person to react negatively to both the emitting and receiving people" [27].

Tactile Communication

"Since many insects have low eyesight and hearing, making physical touch with them opens up a crucial channel of communication. A sophisticated and significant communication system that can send out a wide range of messages using different frequencies, pressure levels, and contact times. Ants in a line are already something you've seen! The leader is reassured by this that their follower is not lost. If the touching stops, the leader stops as well, looks for its follower, and reestablishes connection before moving along. This is called "tandem running." Ants commonly use tactile communication through antennal contact when members of the colony come into contact with one another. because they "smell" the pheromones via their antenna" [28].

Treehoppers

"Mothers of thorn bug treehoppers use tactile cues to keep their offspring groups together. The mother stays apart from the group, usually on the side that faces the stem's base. The female raises one front leg and touches the nymph on the dorsum when it tries to move b her and the other nymphs, causing the nymph to turn around and join the group again" [29].

Acoustic communication

"Only insects and vertebrates, out of all terrestrial animals, have developed the ability to create, perceive, and react behaviourally to "sound," which is generally defined as wave motions that originate from a source of vibration and are transmitted through a medium-whether that medium is water, air, or a solid substrate" [30]. "It has been proposed that sound production in insects can be subdivided into five categories" [31]. Numerous insects made sounds that are recognised by their fellow species and are useful for communication. Numerous insect behaviours, including partner attraction, courting, and territorial behaviour, have been linked to acoustic signals, or noises. A very comprehensive and effective method of information transfer is through acoustic signals. They withstand disruptions and readily disseminate. "For instance, the mature unmated female cricket *Gryllus campestris* and long-horn grasshopper *Thamnotrizon apterus*, are attracted by the singing (chirping) of the males" [32].

1. **Intraspecific communication:** "Rivalry as well as territorial actions Some grasshoppers have evolved what is known as the "rival duet" behaviour, one of the most complex singing patterns among insects. When a second male grasshopper shows along and tries to court the female while the first is performing his wooing song to her, the first male grasshopper leaves the female, confronts the intruder, and sings the rivalry song" [33].
2. **Detection and avoidance of predators:** Numerous predators utilize a combination of sensors to hunt insects: vision, olfaction, and hearing are the main ones; with a bias toward vision in diurnal animals and toward hearing and olfaction in the nocturnal predators. Nocturnal acoustic hunters include felids, canids, owls,

rodents, which are all passive listeners. Bats are also passive listeners, but also active echolocators.

3. **Host localization by parasitoid insects:** Animal acoustic signaling uncommonly constitutes a confidential communication channel. Sound tends to propagate in all directions, broadcasting towards hardly predictable destinations and, sometimes, is unintentionally received by predators and parasitoids.

Sound producing mechanism in insects

Insects need specialised communication techniques to bridge the comparatively great distances that separate individuals from possible mates because they are small living species in a vast habitat. The inherent issue of the sexes being separated by comparatively great distances is brought on by their small size. Insects have developed behavioural strategies and communication systems to get around this issue. Because of unique features that they have evolved. Intraspecific acoustic communication is facilitated by the specialised sound production mechanisms and hearing organs found in many groups. Because of unique features that they have evolved, insects are acoustical animals. “Intraspecific acoustic communication is facilitated by the specialised sound production mechanisms and hearing organs found in many groups” [30].

1. Vibration.
2. Percussion.
3. Stridulation.
4. Click mechanisms.
5. Air expulsion.

Vibration: “Sounds produced when an insect's relatively unskilled body parts vibrate, usually the abdomen, either laterally or dorso-ventrally. An insect produces a vibrational sound when its wings oscillate, creating zones of compression and rarefaction. The substrate that an insect walks or stands on receives tremulous sound waves through its legs. For instance, species identification uses the flight sound produced by honey bee and mosquito wings. Drosophila species also use wing vibration in their courtship dances” [34].

Percussion: “Striking one part of the body against another as a communication system for pair formation, as known for example, the Australian moth (Lepidoptera); males produce ultrasonic acoustical long distance signals to attract sexually receptive females and to establish territorial residency in competition with other males” s. “The act of striking a single body part against a surface seems to have developed into distinct communication systems. For example, Stonefly males produce sound signaling by percussion of the substrate with the tip of their abdomen and hind legs to produce patterned sound to attract the female” [36].

Stridulation: “Noises generated by frictional mechanisms, which involve the regular, patterned movement of two specialised insect body parts against one another. Alary type stridulation is the process of rubbing a file of pegs on one forewing against a scraper on the other. The Femo-Alary mechanism of sound production is observed in the case of Short Horned Grasshopper. A row of peg-like structures known as files are located on the inner surface of the hind femora and are rubbed back and forth over the edge of the forewing. In certain Orthoptera, stridulation has been linked to three stages of mating behaviour. The receptive female's orientation and movement toward the male, as well as her response stridulation, comprise the first phase. When the male noticed the female, he sang the courtship song, engaged the genitalia, and copulation took place. The female had approached the male and was stridulating in response to the mate song” [33].

Click mechanisms: “These noises are caused by a modified cuticle area being deformed, usually by the contraction and relaxation of specific muscles in the insect's body. A series of clicks are produced by this movement, and they can be swiftly repeated in different patterns. The specialised area of cuticle known as tymbal is demonstrated by the cacophonous singing of cicadas (Hemiptera). For instance, the tymbal activity of the male *Tibicina* (Hemiptera) cicada species produces a continuous and monotonous calling song. This acoustic signal constitutes the first step in pair formation, attracting females at long distances, and is involved in male-male interactions. In cicadas, the tymbal is a sound producing organ found in the abdomen. Present on the dorso-ventral surface of base of abdomen. Audible upto 1 km to attract mates. Only male cicadas produce sound” [37].

Air Expulsion: “This is an uncommon way for insects to produce sound. Though little is known about its function, this sound is described as an exhalatory sound that is frequently expelled via the tracheal spiracles. The Madagascar hissing cockroach *Gromphadorhina portentosa*, is able to produce audible hisses from a pair of modified spiracles. Adult males hiss in three social contexts: during courtship, during copulation, and during aggressive encounter. Adults and nymphs of both sexes also hiss when disturbed” [31].

Multimodal Signals

Insect signals are frequently multimodal, with different signal components stimulating different sensory modalities in receivers, even though each of the aforementioned modes of communication is crucial to the social interactions of many different species. “The dance language used by honey bees is the most well-known instance of multimodal communication in insects. Frisch discovered the honey bees' dance language. From the buzzing sound of the dancer's wings. The comb's vibrations caused by this buzzing. The follower's antennae pick up the dancer's movements. The dancer's appearance and the scents she exudes” [38]. “Furthermore, particularly fascinating examples of combinations of communication modalities include cases where larger taxonomic boundaries are traversed between very different species, the well-known mutualistic visual and olfactory communication between plants and their insect pollinators” [39].

Dance language of Honey bees

Round dance: “When a food source is 50 metres or less from the hive, the round dance is performed. The bees make two full rotations: one to the left and one to the right. A bee notifies the other bees in her colony about a rich nectar source. There is no direction indication in the round dance. Following the dance, food is once more distributed here or at another location on the comb, and the dance may be performed three or, very infrequently, more times. Two ways that odour aids in the discovery of new flowers by enlisted bees. When a flower is left on a dancing bee, bees observing the dance can detect its scent. Besides, the scent gland on the flower produces an odour that the scout bee uses to direct its new members" [40].

Wag-tail dance: "The waggle dance is a signal for distances greater than fifty metres. It looks like figure of eight. A worker bee performs a half circle in this manner first, then moves in a straight line while wriggling its abdomen to finish the other half circle. The distance of the food has an inverse relationship with the number of wags per unit time. Reduce the distance, increase the wags. Using the sun as a compass provides a unique means of communicating the direction of the food source. The angle formed by the dance in relation to the vertical represents the angle formed by the sun and the food source" [40].

Conclusion

All four types of the insect communication have got their own advantages and disadvantages.

Recent decades have brought about enormous technological advancements, which have substantially improved our capacity to record, analyse, and synthesise various forms of conveyed information. Thus, merging our expertise from these disparate domains may pave the way for novel and fascinating discoveries in understanding insect communication in all of its fascinating facets. In addition to providing us with pure biological knowledge, the study of animal communication is an extremely fascinating field that may be applied to the management of insect pests, which annually damage crops and cost millions of pounds in losses. The communication of animals still has unrevealed mysteries; which future research will help to discover.

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