COMMUNICATION PERFECTED OVER SEVERAL MILLION YEARS OF EVOLUTION

Commonly, the word *communication* may be associated with everyday conversation, news services, lectures, and email exchanges. Meanwhile, in our close proximity, in the grass, on tree leaves, and sometimes even in our homes, there exists a constant exchange of data that has nothing to do with human conversation. It is a world where 'words' take the form of chemical molecules and touch is replaced by the precise systems of microscopic levers. We are thus entering the territory of insects, specifically the fascinating and little-known sensory reality of hemiptera, or true bugs.

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Member of the Fulgoridae family – a large group of bugs, particularly numerous and diverse in the tropical regions, comprising over 125 species worldwide.
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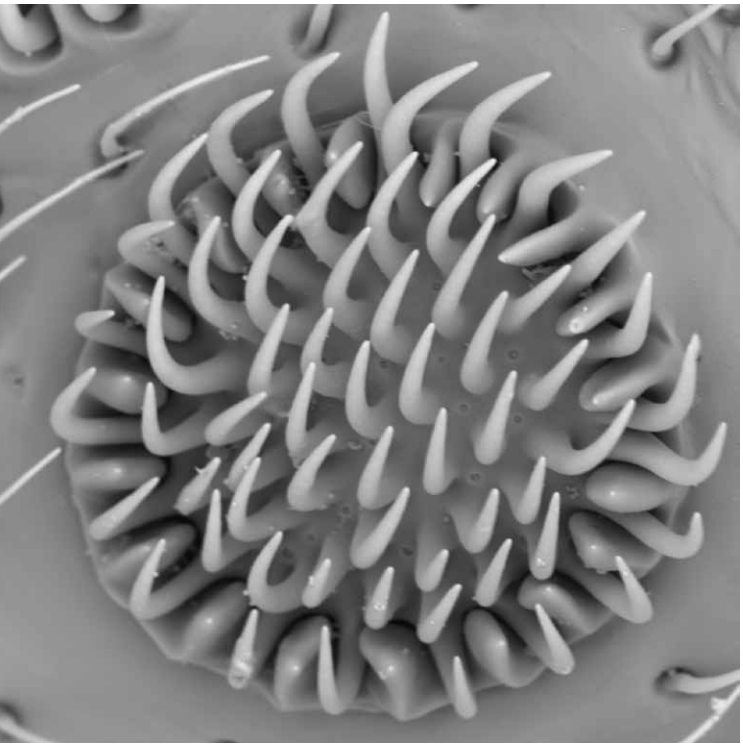
MORE THAN JUST CONVERSATION

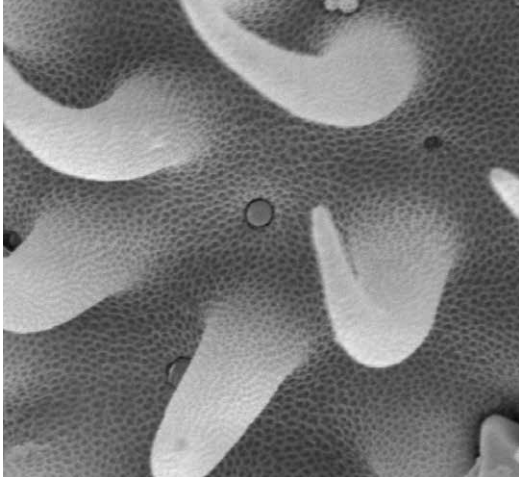
Generally speaking, communication is the transmission of information. In the world of insects, this concept refers not only to the exchange of signals between individuals of the same species but also to the reception of various stimuli from their surroundings. Of course, insects do 'talk' to each other.

'Cicadas and crickets are masters of intraspecies sound communication – they are able to recognise each other by specific tones and frequencies unique to each species. Even in an environment as species-diverse as the jungle, they can find each other without any problems at all', says Jolanta Brożek, PhD, DSc, Associate Professor at the Faculty of Natural Sciences of the University of Silesia in Katowice, an entomologist who studies the comparative morphology and functional anatomy of bugs.

As the researcher emphasises, communication with the external environment is equally, or perhaps even more, important for the survival of insects. It is a constant reception of stimuli: chemical, mechanical, thermal, and related to humidity levels. An insect must know whether the leaf it lands on is edible, for example, or if it fell and landed on its back. In order to process all this information, evolution has equipped it with sensory systems whose precision fires the imagination of modern engineers.



Sensillum with numerous cones | Photo: Jolanta Brożek



Visible pores in the olfactory sensillum | Photo: Jolanta Brożek

ANTENNA, OR A CHEMICAL MAP OF THE WORLD

In order to smell, humans need noses, or more precisely, nasal cavities with an epithelium equipped with several million receptors. Insects also perceive odours, but instead of noses they have sensilla – small organs located most often on the antennae, legs, and mouthparts, although they can also be found on the wings or thorax. Inside them are sensory neurons (or nerve receptors) that receive not only the aforementioned odour stimuli but also taste stimuli. The outer part is formed by a hair-like cuticular protrusion. Its base is embedded in the cuticle, which is connected to dendrites (receptors) and sheath cells.

Depending on the species and family, the sensilla might take on amazing, almost cosmic shapes. They can look like corrugated plates, round plates (Latin: placodea), or protruding cones. Although they differ dramatically in morphology – sometimes even within closely related groups – their function remains similar.

'Scientists have described at least 16 shapes of chemosensory organs on the antennae of bugs of the infraorder Fulgoromorpha. Such diversity may seem excessive, but the more we investigate individual mechanisms, the more we understand that each solution makes sense', says the biologist.

In order for an insect to perceive odours or tastes, a molecule must physically enter the chemoreceptor, which is located under or within the cuticle – the outer layer covering the insect's body. Olfactory chemoreceptors perceive volatile substances, while gustatory chemoreceptors react to liquids. And this is where nature's engineering excellence comes in: porosity. The walls of the olfactory sensilla are densely covered with pores. It is through these pores that odour molecules penetrate inside, where special binding proteins await them in the lymph, transporting them to the dendrites, i.e. special projections of nerve cells. Interestingly, there are many such neurons in the olfactory sensilla, and their dendrites often branch out, reaching almost every pore to maximise the sensitivity of the entire mechanism. This system allows insects such as bees (the mechanism itself is universal) to find food sources from distances of up to several kilometres.

TASTING WITH THE FEET

Chemical communication is also needed to answer the question: 'To eat or not to eat?'. Insects are divided into monophagous (eating only one species of plant), oligophagous (choosing plants from a single family) and polyphagous (omnivorous). In order to make the right decision, an insect uses its sense of taste.

Gustatory receptors work slightly differently than olfactory ones. The cuticular hairs leading to the receptor often have only one opening at the top through which fluid must enter. Surprisingly, insects do not 'taste' only with their mouthparts. Research indicates the presence of chemosensors on their feet as well. When an insect lands on a plant, its first contact is mechanical and chemical. It checks not only the texture but also the chemical composition of the leaf. If the test is successful, the proboscis and deeper gustatory sensilla come into play. If the plant does not taste good, the insect simply flies away, continuing its search.

In many insects, especially females, this mechanism serves not only to search for food, but above all to protect their offspring. By 'stomping' on the leaf and tasting it with its feet, the female checks whether it is a suitable host plant for laying eggs. If the plant contains toxins harmful to the larvae, the mother will find out through her feet.

EVERY HAIR MATTERS

'An entomologist once said: "There is not a single hair on an insect that does not serve a purpose". This statement is the key to understanding mechanoreception, or the sense of touch, says Jolanta Brożek. 'In theory, touching the cuticle should not be felt by an insect, in practice, however, this layer is full of mechanoreceptors. The simplest are hair embedded in an elastic membrane, acting as a lever. When something touches it or moves it, e.g. the wind, the hair bend in its 'nest', pressing on the dendrite of the nerve cell at the base. This is how the sense of touch works.

It is a mechanism of extraordinary precision. Bending the hair by just a few nanometres opens ion channels in the cell membrane. This is the moment when mechanical energy (the aforementioned lever movement) is converted into a nerve impulse. This process occurs faster than any conscious thought process, making the insect's response to danger almost instantaneous.

Transmission electron microscopy (TEM) allows us to look inside this structure.

'We are able to see the so-called tubular body filled with microtubules. Their number (from 40 to over 100, and in some insects even 1,000) determines the sensitivity and specificity of a given receptor. Can an insect feel the wind? Can it feel the vibrations of a leaf on which a predator is currently walking? It all depends on the structure of this one microscopic element', says the biologist.

Some of these sensory organs are even more spectacular. Those called coeloconica (hidden in depressions) form triads of receptors responsible for thermo- and hygroreception, which also play a large role in the lives of insects.

FROM BIOLOGY TO TECHNOLOGY

This unimaginable complexity of nature has become an inspiration for engineers. Contemporary science is more and more frequently turning to biomimetics, which involves observing evolutionary solutions and using it as a basis for technology.

'The article in which my colleagues and I published the results of our research attracted the interest of engineers from Kaunas University of Technology (Lithuania). It started by chance – a doctoral student came across articles about the sensory organs of insects and decided to translate these biological structures into the language of mechanics', says Jolanta Brożek.

And just like that, a research cooperation was born with the goal of creating super-sensitive air flow detectors. Engineers analyse the shape, length, and mounting of insect sensilla, and then calculate the loads, deformations, and stresses that arise on mechanosensilla under the influence of wind. Biology provides the model: scientists use scanning and transmission microscopes to study the structure of the receptors in a specific species of true bugs.

'We check, among other things, where the dendrite ends, how many microtubules it has and how the hair is attached to the cuticle. Engineers take this data and create a sensory model that can be used in the future to precisely monitor the smallest changes in air circulation', explains the scientist.

Thanks to this research, we gain access to solutions that evolution has perfected over millions of years.

Insect specimen from the Ricaniidae family | Photo: Jolanta Brożek