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The sensory world of bees

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The tale in the sting

Working and sensory lives of bees

BY **DAVE SAMMUT**

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Bees have a well-earned reputation for pollination and honey-making, but their lesser known skills in electrocommunication are just as impressive.

According to the United Nations, 'of the 100 crop species that provide 90 per cent of the world's food, over 70 are pollinated by bees' (bit.ly/1DpiRYF). It's little wonder, then, that bees continue to be a subject of study around the world. More surprising, perhaps, is that so much remains to be learned.

Bee-keeping (apiculture) is believed to have started as far back as about 4500 years ago; sculptures in ancient Egypt show workers blowing smoke into hives as they remove honeycomb. In ancient Greece, Aristotle either kept and studied bees in his own hives or examined the observations passed to him by beekeepers. In doing so, he made some astute conclusions; for example, that there are three classes of bees, one of which is sterile. Along with his better observations, he thought incorrectly that bees do not make honey and instead that it is distilled from dew.

In reality, the manufacture of honey by bees is both complex and elegant. Honey varies in composition depending on many factors (such as the different species of flower from which the inital nectar is collected), but in general terms it is dominated by two key simple sugars: dextrose (glucose isomer) and levulose (fructose isomer), constituting over 70% by mass. It also contains aromatic volatile oils (giving it rich flavour), mineral elements, some proteins, enzymes, vitamins and colouring matter.

Worker bees collect nectar from selected flowers. Containing about 80% water, together with complex sugars, this nectar is stored in a special stomach (the 'honey stomach') where the invertase enzyme secreted by the bee's salivary glands begins the process of breaking down the sucrose in the nectar into simple glucose and fructose. Some of the glucose reacts with a second enzyme, glucose oxidase, to form gluconic acid and hydrogen peroxide, creating conditions of low pH (3.2–4.5).

$$\text{sucrose} + O_2 \xrightarrow{\text{invertase}} \text{fructose} + \text{glucose}$$

Once the worker bee's honey stomach is full, it returns to the hive and regurgitates the partially modified nectar for a hive bee. The hive bee ingests this material to continue the conversion process, then again regurgitates it into a cell of the honeycomb. During these processes, the bees also absorb water, which dehydrates the mixture.

Hive bees then beat their wings to fan the regurgitated material. As the water evaporates (to as little as around 10% moisture), the sugars thicken into honey – a supersaturated hygroscopic solution of carbohydrates (plus oils, minerals and other impurities).

Some researchers think that the hive bees inject a venom into each comb, giving the honey its antibacterial properties; others dismiss this idea, saying that the high concentration of sugars means that fermentation cannot happen. Either way, there seems to be general agreement that the acidic nature of the honey is hostile to bacteria, mould and fungi.

In its entire lifetime (approximately seven weeks, as compared to Aristotle's estimate of seven years), an average bee will produce less than a gram of honey.

But how does the worker bee select its flowers in the first place? In 2013, Professor Daniel Robert and his team at the University of Bristol made a fascinating discovery (*Science*, doi: 10.1126/science.1230883).

It was already well known that bees generate a positive charge as they move, and most particularly as they fly. It was also known that flowers generate a weak negative charge over time. Using a Faraday pail (a sort of electrically shielded bucket, similar to the wire cage in a microwave oven), Robert and his team measured this positive charge on individual bees. They went on to demonstrate that when the bee lands on a flower, this charge is temporarily passed to the flower, and that for a period of minutes after the visit the flower will have a measurably more positive charge.

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Sensational species

The multiple senses that humans and animals possess beyond the 'standard five' are fascinating. In humans, this includes mechanical senses for balance ('equilibrioception') or for locomotion ('propioception'), and many more.

Electroreception is the biological ability to perceive electrical stimuli. In some species of the animal kingdom, these senses are highly developed – particularly in aquatic or wet terrestrial environments where charge is carried better. As an example, some species of shark can detect DC fields as low as 5 nV/cm.

The most common usage is in electrolocation in predation. Living organisms generate small electrical fields in the movement of their muscles and in their nerves, while fish also generate fields from the ion pumps associated with osmoregulation at the gill membrane. Some predators use this to detect their prey (sharks have been shown to attack any source of an electric field, which was a problem for early telegraph cables), while others use the sense to avoid predators.

This has led to an 'arms race', for example in the evolution among some fish species towards more complex or higher frequency electrical fields that are harder for their predators to detect.

Conversely, some species of fish communicate by modulating the waveform of their electrical field, for mating and territorial displays.

This electroception is caused by a multitude of biological mechanisms. Sharks use field sensors called the ampullae of Lorezini: electroreceptor cells connected to seawater by pores in their snout and head. Monotremes (particularly the platypus, but also two species of echidna) use free nerve endings located in the mucous membranes of the snout.

In species with 'active electrolocation', the animal generates its own electrical field using a specialised organ of modified muscle or nerves, and then modifies the frequency and waveform in a manner that might be unique to the species or even the individual.

Most importantly, using artificial flowers with a controlled electrical charge, the Bristol team was able to show that the bees could sense the electrical charge on the flowers, and that they could be trained to use that charge to guide their activities. This was a breakthrough – the first time that electroreception had been documented in an invertebrate species (see Sensational species box).

It now seems that bees also use electrocommunication. In a paper to the Royal Society in 2013, Greggers et al. note that 'the electric fields emitted by dancing bees consist of both low- and high-frequency components. Both components induce passive antennal movements in stationary bees according to Coulomb's law. Bees learn both the constant and the modulated electric field components in the context of appetitive proboscis extension response conditioning.' (*Proc. R. Soc. B*, doi: 10.1098/rspb.2013.0528)

The 'waggle dance' is itself a remarkable note in the journals of science. Much like the Rosetta Stone unlocking the secrets of hieroglyphics, the seminal work of zoologist Karl von Frisch unlocked in the mid-20th century the secrets of the movement of successful foragers returning to the hive. He correlated the dance to directions on flower patches via relative position of the sun and the distance from the hive, with different dances particular to different bee species. It was the first demonstration of non-human communications for learning, and it won von Frisch the 1973 Nobel Prize in Physiology or Medicine. And now we know that electrical fields also play their part in this communication.

However, the waggle dance is not without controversy. Some experts argue that the waggle dance cannot give guidance on a nectar source, and that floral odour is actually the dominant method of recruiting bees to the source. For most of us, this is a matter of nuance. It would seem that most scientists would agree that both mechanisms contribute, and that it is only the relative weighting that is in contention. For the antagonists, it is often a matter of polarised principle, even outright hostility.

The honeybee can see only four basic colours, compared to the 60 distinct colour combinations from the three primary colour photoreceptors in humans.

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Electroreception in bees is associated with a collection of sensory cells in the second segment of the antennae called the Johnston's organ, which detects motion in the flagellum (the final antennal segment). As with other animals, the sense is mechanical, but it represents yet another mechanism for electroreception. It is a truly wondrous demonstration of the ability of evolution to take up every advantage available in the physical world. And because the presence of the Johnston's organ is a defining characteristic that separates the class insect from other hexapods, it opens the possibility of yet undiscovered behavioural triggers in invertebrates.

Returning to the Bristol study, the researchers found that the electrical charge stimulus worked best in combination with colour triggers, and this brings me to another remarkable aspect of bees and the animal kingdom more generally.

The honeybee can see only four basic colours, compared to the 60 distinct colour combinations from the three primary colour photoreceptors in humans. Their visible spectrum stretches from about 300 to 650 nm, and they are red-blind. Yet with their vision in the UV portion of the spectrum, bees can see a quite remarkable amount of detail in flowers that we cannot, which is obviously an evolutionary response between the two organisms. Indeed, the extensive publications of Professor Lars Chittka of Queen Mary University of London suggests that the photoreceptor abilities of ancestral bees pre-dated the existence of flowers by more than 100 million years, and that the colouration of flowers evolved in response to the bees' ability, rather than the other way around.

That there is a topic so thoroughly researched over such a long period, and with so many insights yet to offer, is simply delightful. Given the importance of bees to our global food supply, these advances in our understanding are of more than mere esoteric interest. They might one day become critical to our existence.

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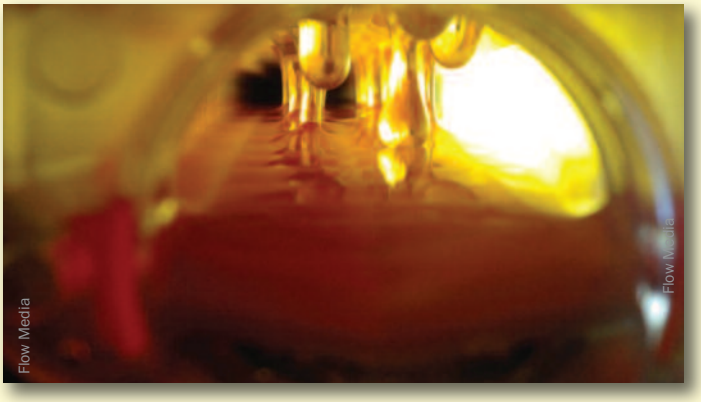
Investigating bee decline

Bee populations, both wild and commercialised, are in decline globally. Current research is largely focused on trying to identify the causes of decline (called colony collapse disorder in the US). The main areas under investigation are bee parasites (most particularly the varroa destructor mite), use of pesticides and the build-up of toxins in the foraging environment, loss of biodiversity and foraging rich environments, spread of the Africanised honey bee (in the US), and extremes of weather associated with changing climates. Work is being done in gene manipulation of honey bees to protect them from mites, as well as research into alternative pollinators that can be used should bee populations fail catastrophically.

Some recent good news in Australia is an innovative beehive design using a slight flexing of a plastic framework to allow honey to flow directly out of the hive (literally honey on tap) for collection. This could have implications in the fight to strengthen bee colonies, by allowing more user-friendly beekeeping set-ups for the rapidly expanding urban apiarist markets. No smoking or bee suits required!

Chantelle Craig



Flow Media

The cells of the honeycomb fracture during this new type of process, allowing the honey to flow down, but they don't actually break.

Honeybees on the plastic beehive framework.