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Episode 170: Something in the air: Chemical communication via pheromones

VOICEOVER

Welcome to Up Close, the research talk show from the University of Melbourne, Australia.

DYANI LEWIS

I'm Dyani Lewis. Thanks for joining us. When we speak to the person next to us or perhaps wave to someone across the room, it's usually clear to all involved that we have a message we wish to communicate. But throughout the natural world a far more sophisticated system of communication predominates, and it's based on chemical messages known as pheromones. Despite their ubiquity and their stunning diversity, we are still discovering the multitude of messages that pheromones can convey and, indeed, the behaviours they can elicit. To tell us more about the roles pheromones play in social animals, everything from insects to human beings, we are joined on Up Close by Professor Mark Elgar, who is Professor of Zoology, and head of the Animal Behaviour and Evolution Lab in the School of Zoology at the University of Melbourne. Welcome to Up Close, Mark.

MARK ELGAR

Thank you.

DYANI LEWIS

Now, Mark, I thought perhaps you could start just by giving us some background on pheromones. What type of molecules are we talking about?

MARK ELGAR

Pheromones comprise chains of carbon atoms together with oxygen and hydrogen. They come in a great diversity of types, and also have a great diversity of function ranging from providing an individual's information about who they are and where they're from to information about their sexual receptivity and, thus, indicating their location to interested parties. They are extraordinarily ubiquitous and thought to be the most ancient form of chemical form of communication. They are, or have been in been in the past thought of in much the same way as we think about hormones, which are clearly also chemicals that modulate and modify the internal workings of an organism. The key thing, of course, about a pheromone is that this is information that's being broadcast from one individual to another.

DYANI LEWIS

How are these pheromones transmitted then?

MARK ELGAR

In a variety of ways. Pheromones can either move through the air, so obviously they are volatile, and can move extraordinary distances - with very small amounts of them moving great distances - or they can sit on the surface of the organism, but they still have the same function of telling another individual something about the signaller.

DYANI LEWIS

When we think of the messages that are being conveyed, is it a matter of one chemical molecule for each message?

MARK ELGAR

No, a message can be highly specific, but it can also vary and tell individuals a slightly different story. Individuals may have - for example, in ants - on their surface a particular chemistry that tells other individuals the origin of their nest. The overall cocktail of chemicals that they have on their cuticle or on the surface of their body may, broadly speaking, be specific to that particular species but, nonetheless, the concentration of the different elements of what makes up that cocktail, would then tell individuals something about the nest, for example, that they come from. If the species we're thinking about are ants, then those chemicals or cocktail of chemicals can tell other ants whether an individual comes from the same nest, a different nest from within the same colony if the colony comprises lots of different nests, or an individual from a different colony. Even though the cocktail may be roughly the same, it's the concentration of the elements in it that might differ.

DYANI LEWIS

If you take, for example, ants, how do you actually know that a message is being conveyed between individuals, and then how do you know that the message is being conveyed via a chemical?

MARK ELGAR

Well, I think this is part of the reason why we are, perhaps, a little behind the eight ball in terms of research on chemical communication compared with visual and auditory communication. The ways in which we've been able to discern chemical signals or the techniques that we can use to discern those chemicals are relatively recent. You can do very simple experiments to demonstrate the role of a pheromone. If, for example, you put a female moth in a cage and turn all the lights out, and hang the cage in such a way that it's not possible for any vibrations to emanate from that particular cage, and put a whole lot of male moths in the room, you'll find that quite quickly the cage will be covered with all of the moths. Clearly, they're not using visual cues, they're not using auditory cues, they can only be using chemical cues to locate the female. In fact, roughly speaking, that was how the very first sex pheromones were discovered. That, in a sense, provides us with an insight into how you actually go about trying to evaluate whether it's a chemical signal. In our own work with ants, we were able to determine that ants were using simply a chemical signal and not a visual or auditory signal by taking a bunch of ants and putting them, dropping them into a chemical called Hexane - which, effectively, strips off the outer chemistry of the cuticle - evaporating that cocktail down so it's really concentrated, dropping some little bits of filter paper into that cocktail, and then presenting ants with filter paper that's been lined with this particular chemistry. We find that the behaviour of the ants towards the filter paper is qualitatively similar to that as if it was a live ant. In other words, they're simply reacting to the chemistry on the filter paper. If the filter paper has the chemistry from ants from a different nest, then they'll attempt to attack that little piece of filter paper. If it's from the same nest, then they'll gently caress it with their antennae.

DYANI LEWIS

It's quite dramatic then?

MARK ELGAR

Yes, it's a very dramatic difference and it's simply based on chemistry.

DYANI LEWIS

Now, Mark, how widespread are pheromones in the animal kingdom?

MARK ELGAR

Arguably, they're the oldest form of communication. The reason we think that, of course, is because they are so widespread taxonomically, ranging from essentially single cell organisms right up to the most complex multi?cellular organisms. They are phylogenetically, if you like, very old and they are probably derived mostly as an extension of hormonal systems where much of our bodily function is regulated by the release of hormones from one part of the body that then diffuse round to another appropriate part of the body unless it's some kind of reaction.

DYANI LEWIS

You've worked predominantly on insects. Is there are particular reason for this? I mean, do insects make particularly good model organisms for studying pheromones?

MARK ELGAR

Well, insects are obviously great to work with, quite apart from the fact that they are such a diverse and fascinating group of animals. It's also relatively easy to do these kinds of experiments on insects than other ones from a behavioural level. For example, if you were trying to work out whether a particular individual is responding to a particular pheromone that might be produced at a particular time, then you can set up so?called Y maze experiments in which you provide the animal of interest with a choice between moving up a tube that leads to a source of a particular smell or odour or another tube that doesn't. This is very easy and convenient to do. You can't do that on kangaroos, for example, quite so easily although we've certainly done some field experiments looking at the role of particular odours and how that impacts on their behaviour. They're just a terrific group of animal to investigate in that context but I think the other thing, too, is that insects utilise these chemical signals in such a variety of contexts. Females will release so?called sex pheromones to indicate that they are sexually receptive, so you can look at these signals in the context of sex. Some insects have deeply cooperative, profoundly cooperative relationships, the social insects. So again, you can look at these forms of chemical communication in a context of cooperative behaviour. Others aggregate, so there's a great deal of interest, for example, in many beetles that cause enormous damage to forests because they also aggregate, so lots of different ways in the context in which these chemicals occur and, of course, enormous diversity of organisms.

DYANI LEWIS

Presumably, there is an abundance of pheromones across different species and even within one species; there are different pheromones for different purposes. What are some of the evolutionary pressures that drive what pheromones a species might produce?

MARK ELGAR

There is terrific diversity of pheromones; there's also extraordinary convergence of pheromones. The sex pheromone of the Asian elephant is a particular chemical, and that particular chemical is called (Z)?7?dodecen?1?yl?acetate. You might think, well, that's a beautiful chemical to produce. It's also produced by about 140 different species of moths. One might, of course, predict that female African elephants will have a large retinue of male months fancying their chances. Of course, that doesn't happen and ditto, you don't see male elephants chasing after moths or at least there have been very few reports of such behaviour. There's also a great deal of convergence where a similar chemical is used in lots of different contexts. Some work that we undertook looking at the alarm pheromone produced by a locally common ant, Iridomyrmex purpureus, is, in fact, freely available on the chemist shelf. We were a bit surprised by that, and it meant that we could do our experiments to see the impact of this particular chemical and, in fact, in this context how it was used by a spider to locate these ants. We could simply buy this from our local chemist - that's the Chemistry Department, of course - and use drops of that compound as a means of doing our bioassays, rather than relying on the ants themselves. The evolution of this diversity is still really poorly understood. There are two reasons for this. It's only until quite recently that we've begun to accumulate a large body of evidence or a large body of information about all of the different chemical compounds that are used for pheromones, for example, in insects. If you're going to try and understand the mode of evolution - that is, whether the diversity of compounds that we see or cocktails that we see has evolved gradually or whether it's gone in leaps and bounds - relies on both that body of information and also, of course, a set of information about the evolutionary relationships of the insects that you're looking at. A colleague of mine, Matthew Symonds, and I have been investigating those patterns. Where species are closely related and are producing a sex pheromone, we would expect those different species to have very, very different sex pheromones as a means of ensuring that males don't start chasing the wrong female or females don't get chased by the wrong species of male. In a couple of groups of species that we've looked at, that does seem to be the case but it's not really clear cut. In other contexts, for example, looking at the pheromones on the cuticle of ants, the requirement for closely related species to be very different from each other is, perhaps, much less obvious. In those species, we see much more gradual diversification of cocktails from closely related species, but I think it's still a little bit too close to call at this stage

DYANI LEWIS

It sounds like there's obviously the ecological as well as behavioural influences, how these chemicals evolve?

MARK ELGAR

Absolutely, and not unlike any other kind of signalling system, so whether it's a visual signalling system or an auditory signalling system. The reality is that the data only is starting to accumulate in such a way that we can start addressing these kinds of questions.

DYANI LEWIS

I'm Dyani Lewis, and my guest today is Professor Mark Elgar. We're talking about pheromones here on Up Close coming to you from the University of Melbourne, Australia. Now, in natural selection, there's often a trade off between the cost for producing a particular strategy - in this case, pheromones - and the benefit to an individual in terms of its survival or reproductive benefit. Do pheromones cost anything to the individuals producing them?

MARK ELGAR

I think the short answer is we don't really know. If a signal is getting to convey the right information - what I mean here is that there is always a tendency in certain communication contexts for individuals to be somewhat dishonest about the nature of the signal that they are producing. For example, there might be strong selection for males to convey to females that they are bigger, better, stronger or whatever than they really are so, obviously, there's strong selection for females to be able to discern the bluffing or dishonest male from the male that's providing honest information. In visual signals and in auditory signals, it's nicely established now that these signals are costly to produce and so they provide honest information. This is a big question that people ask in terms of pheromones as a communication system: are they actually costly to produce? The thing is a pheromone can be very effective in very, very small amounts. On the face of it, you'd think, well, producing a tiny amount of chemical can hardly be deemed to be particularly costly at all. That's where, in a sense, the controversy lies and the difficulty, of course, is trying to undertake experiments where you could actually demonstrate that producing more or less pheromone is, in fact, going to have a fitness cost - that is to say, it'll have an impact on the male or female's capacity to do whatever else it's doing in life. I suspect the cost of producing the chemical may, in fact, be not great. The key thing to remember, of course, is that there is the cost of producing the chemical, but there's also a cost of the consequence of producing that chemical. The thing about chemical signals is that they're really good cues for other animals to work out the location of whoever is producing the signal. Producing a chemical signal that's intended, for example, for a female puts the male at risk because other individuals, other animals, might see that as a large advertisement for, "There's a piece of prey here and I'll go after it," and that's probably where the costs lie.

DYANI LEWIS

Now, Mark, we've spoken about the pheromones themselves but what do we know about how those messages are received?

MARK ELGAR

Well, I think - and this is slightly outside of my comfort zone - our understanding of the genetics and the molecular biology of the capacity of individuals to receive signals are reasonably well understood. The nature of the receptors and how that chemical attaches itself to particular receptors and then initiates particular activities, that fine level is reasonably well understood but I think that at the broader scale, we actually have a much less clear understanding of the receptor side of the signal. And the key thing here, of course, is that a signal goes nowhere if it's not received. For chemical signals, if a particular chemical is intended to have a particular reaction, then the receiver needs to be able to detect that particular chemical and, of course, that's perhaps the challenge. Even more broadly, I think we are still at an early stage of understanding, if you like, the receiver biology in chemical communication systems. For example, one of the key features of insects is that they have antennae. Many of us, when they first think of insect antennae, just think of two stick?like things that come out of the head. You'd be very mistaken to think that that actually is the way insects have antennae. There is extraordinary diversity in insect antennae. I mean, even just looking at moths, they range from a single pinnate antennae - a single pincer?like antennae - through to the absolutely gorgeous feathery antennae that you might see on something like the Emperor Moth. Even in other taxonomic groups, there's extraordinary variation in the structure of antennae, and we simply haven't got a clue as to how to explain that variation. It's a big open question at the moment.

DYANI LEWIS

We can't actually determine or, I guess, make predictions about the types of behaviour or the types of pheromones that pinnate antennae species have compared to species with more elaborate antennae?

MARK ELGAR

I think the conventional wisdom is that the more elaborate antennae are required in those species where females might produce rather less pheromone. We might then, for example, predict that species that have larger females - let's say, for example, in moths - should have a capacity to produce much more pheromone and, therefore, the need for males to have more elaborate antennae might be less severe. Smaller moths, tiny little moths, because they're so small can't produce such large amounts of pheromone and, therefore, you would expect in those species the males to have much more elaborate antennae because that would help them detect these small amounts of chemicals that are floating through the air. In fact, the comparative analyses that we've done on moths shows that the opposite is the case. The more elaborate antennae are far more commonly found in species that are very large than they are for those that are very small. I think, undoubtedly, ecological factors are coming into play, but exactly what those ecological factors are we don't really know. Part of that may well sit around the nature of the way in which these pheromones are dispersed as well.

DYANI LEWIS

Now, when we age, our ability to detect things like visual and auditory cues declines as our eyesight and hearing deteriorates. Does this happen with pheromone production and perception as well?

MARK ELGAR

It's an obvious question to ask but surprisingly, as far as I'm aware, it hasn't really been investigated, or certainly not published as far as I know. Like any kind of receptor organ, you expect some kind of deterioration particularly, of course, if the activities of the animal are likely to damage it. For example, in ants, they use their antennae to brush or tap other ants or other objects to discern information about it. It might be whether it's food, whether it's a nest mate, whether it's a non?nest mate or whatever. This constant brushing and tapping, you might imagine, would actually create some wear and tear on the antennae. The question then emerges: well, does that actually have an impact on the insect's or an individual's capacity to read the right message? Now, this is something really interests us at the moment. We're currently investigating and I certainly hope to come back to you with an answer on it sometime soon.

DYANI LEWIS

I'm Dyani Lewis and my guest today is Professor Mark Elgar. We're talking about pheromones here on Up Close coming to you from the University of Melbourne, Australia. Now, Mark, we've spoken about chemical signalling and pheromones in insects, but how important are pheromones in animals such as ourselves, particularly given that our visual cortex has really evolved to be far larger than what our olfactory cortex is?

MARK ELGAR

There are a number of fascinating studies that have been conducted in the last, perhaps, 10 or 15 years that have attempted to investigate the role of chemical signals or pheromones in human behaviour. I think what is remarkable is that these chemicals are floating around and we are, apparently, quite unaware of their impact. I'm very aware of, for example, the colour of the shirt that you're wearing but completely unaware of any odours that you might be producing, other than perhaps any artificial odours, perfumes or whatever, of you or anyone else that one might be around. I think this is a particularly interesting aspect of human behaviour. Chemical signalling has been around for so long, but I think that there are certain inefficiencies with it as a mode of communication that may explain why in humans, as we have evolved alternative mechanisms of communication, that they've become more important. I think that we may well still have the capacity to receive these signals, and we may well still have the capacity to react in particular ways that we're unaware of, but there's really strong selection, I think, on our capacity to respond to auditory and, obviously, visual signals but they're much more efficient and they're much more precise. For example, a smell can tell you something but you also need to be extremely discerning to know where that smell comes from if the information has something to do with a particular individual. The same, of course, is true of visual signals as well. It's no particular surprise, I think, that our auditory form of communication, our vocal language, has evolved from a more visual form of language which would have been through the form of gestures, in that we can be far more precise about where the signal is coming from and, of course, we can multitask. I can yell at you, "Look out behind you," and as you hear me say that, you can turn around and see what the danger is. You couldn't do that of course, if I was making that signal through using my hands.

DYANI LEWIS

We learn very specific signals as we develop. Is it the same for chemical signalling in insects, say? Do they learn these signatures for, say, a nest mate for instance or are the signals innate?

MARK ELGAR

A combination of both, so some signals will have a very specific meaning. In some species of ants, the ants will return from a successful foraging trip, and have on them or exude from their body a particular odour that tells other ants, "Pull your socks up; it's time to go out and do some foraging" in exactly the same way, of course, functionally as the waggle dance or the bee language, the language of bees, that people are much more familiar with. There are other chemicals, however, that individuals can actually learn. For example, we know that in many ants, as I mentioned before, they will distinguish between individuals from the same nest from other individuals by particular odours. It turns out that ants are capable of learning those particular odours. The way we do that is simply using the same experiment in exactly the same style as Pavlov's dog by a conditioning experiment, so if they learn a particular odour, they get a reward and if they don't learn a particular odour, then they don't get a reward. In this case, it's a reward of food, and we know whether they know about it by the ants particular behaviours. Using those kinds of experiments - and they've been done also successfully in other social insects as well - it's quite clear that they have a capacity to actually learn particular odours and, in particular, those odours that appear to be associated with nest mate discrimination, so it's clearly a combination of both. In some instances, the response is a knee jerk response, as it were, and in others it actually involves an element of learning.

DYANI LEWIS

Especially in the case of sex pheromones, it seems you've got a couple of levels of competition here. You've got females competing with other females to produce the signal, and you've also got males competing with other males to find those females, and not all flock to the one female at the one time. Is that right?

MARK ELGAR

Yes, this is actually a very interesting question because it really gets to the nub of the question: how much pheromone should a female produce? If she produces a lot, then she may well get large numbers of males arriving to her, and an unseemly scramble happening as a consequence of that. There's also a problem for a male in that if he detects a very concentrated form of pheromone, then it's likely that lots and lots of other males have also detected that pheromone. It may, in fact, be to his advantage not to follow that particular pheromone trail but to follow a pheromone trail that is, perhaps, a little less concentrated; the idea being that, of course, there'll be fewer males going towards the female that's producing a less concentrated or less intense odour, or less detectable odour, I guess, is probably technically the right way to say, and so there'll be less competition there, and so he's much likely to actually end up mating with the female. There's a question, from the female's perspective, how much odour should she produce in terms of attracting the best male? In fact, what we think may be happening is something that turns that question slightly on its head. What we think is that there may, in fact, be selection for females to produce just enough pheromone for at least one or two males to visit her whilst she's signalling. She producing not buckets of the stuff in order to attract lots and lots of males but, in fact, very small quantities of pheromone in order to attract only those males that are particularly capable of detecting that pheromone. In fact, we think that this may have acted as a selection pressure favouring the elaboration of antennae, for example in moths, so that the feathery and beautiful antennae of particular moths have evolved as a result of this process of sexual selection where females are producing rather less pheromone, and those males that can produce the largest and antennae are the only ones that then could detect her. Males that can produce nice elaborate antennae may well have lots of other attributes that's attractive to the female as well.

DYANI LEWIS

So the females are getting the cream of the crop?

MARK ELGAR

We always expect females to get the cream of the crop. That's very much the way selection operates.

DYANI LEWIS

Well, thank you for being our guest today on Up Close, Mark.

MARK ELGAR

Thank you, a great pleasure.

DYANI LEWIS

That was Mark Elgar, Professor of Zoology and head of the Animal Behaviour and Evolution Lab in the School of Zoology at the University of Melbourne, Australia. Relevant links, a full transcript, and more info on this episode can be found at our website at upclose.unimelb.edu.au. Up Close is a production of the University of Melbourne, Australia. This episode was recorded on Monday, 7 November 2011. Our producers for the episode were Kelvin Param and Eric van Bemmel. Audio engineering by Gavin Nebauer. Up Close is created by Eric van Bemmel and Kelvin Param. I'm Dyani Lewis, until next time, goodbye.

VOICEOVER

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