Spider ecology, behavior, and learning

Spiders at the Cinema

MACIEJ BARTOS
Faculty of Biology and Environmental Protection
University of Łódź
bartos@biol.uni.lodz.pl
Dr Maciej Bartos studies the behavior of jumping spiders

In spite of severe brain size limitations, many spiders are able to solve complex problems, recognize their prey with great accuracy, and learn new hunting techniques

To most people, spiders are hairy creatures that lurk in dark corners behind the cupboard. They are widely disliked, and in some people even trigger panic fuelled by tales of the creatures' terrible venom. However, arachnophobia can be cured: those afflicted simply need to find out more about spiders and get to know them better. In reality, apart from the genuinely scary ones, many spiders are as colorful as the prettiest butterflies, have better eyesight than many birds or mammals, and exhibit more complex behavior than many higher animals. Their excellent vision and small brain size make them a good model for research into learning and decision making processes in animals. Perhaps surprisingly, some such studies involve setting up miniature cinemas for the spiders, allowing researchers to study how they perceive their world and how they make decisions based on the information available.

In light and darkness

Spiders form a large and diverse group of predatory arthropods. The majority of the over 42,000 described spider species have poor eyesight and are mainly active at night. The sensory world they live in is made up of different kinds of vibrations: airborne, those transmitted by the substrate, their nests or webs, and tensions in their cuticle triggered by various mechanical stimuli. Their extremely receptive sensory organs allow them to perceive those signals accurately, helping them construct complex webs and remotely localize insects flying or scuttling nearby. Eyesight and sensory organs used to perceive chemical stimuli also play an important role in orientation and communication between individuals. Most spiders' simple eyes, like those of insects, are not capable of perceiving complex images. They allow them to notice motion, changes in light intensity, and to a lesser degree allow them to identify a partner or prey. As such the majority of spiders exhibit relatively simple behavior. However, not all spiders are limited by low acuity of vision.

There is in fact a large group of diurnal spiders whose world is dominated by visual stimuli. They see color, including wavelengths in the UV range, they are able to differentiate complex configurations of viewed objects, and their visual acuity exceeds that of

There are plenty of spiders that are as colorful as the prettiest butterflies, have better eyesight than many birds or mammals, and exhibit more complex behavior than many higher animals. Pictured: American Cardinal jumper (*Phiddippus cardinalis*)

Keith Stewart/bugsinthenews.info


Maciej Bartos

Dune jumping spider examining its prey

many vertebrates, even ones with vision as good as cats or pigeons. This is the family of jumping spiders (Salticidae), owing their name to their ability to jump to escape enemies or while hunting prey. They are the largest and most diverse spider family. Although only 60 species of jumping spiders can be found in Poland, there are over 5300 different species worldwide. It is worth noting that the majority have been described by Polish taxonomists, Prof. Jerzy Prószyński, Prof. Wanda Wesołowska, and Prof. Marek Żabka.

Extraordinary eyes

Despite their name, the most extraordinary thing about jumping spiders is not actually their ability to jump – which is, after all, shared by certain other spiders. They are truly distinguished by their extremely well developed vision, centered in one of their four pairs of eyes, which represent a unique evolutionary adaptation in the animal kingdom in terms of structure and function. The eyes are all located around the cephalothorax, giving the animal an almost 360° visual field. Three pairs are secondary eyes; like the eyes of most insects, they are only capable of perceiving changes in light intensity and movement, and they do not allow the spider to recognize complex patterns. This ability is provided by their principal eyes situated at the front of the cephalothorax. When an object appears in the visual field, the spider first notices its movement using the secondary eyes; it then turns round to face it and examine it more closely using the principal eyes. The eyes have several important structural features differentiating them from secondary eyes and making them extremely effective visual organs. Behind the corneal lens there is a long tube reaching far into the cephalothorax. At the end is the retina, with another lens in front, magnifying the image 1.5 times. The long, tubular eyes, the narrow retina and the additional lens mean that the spiders are as if looking through a telescope – the image is magnified, although the field of vision is very narrow (approx. 10°). Despite this and the fact that the corneal lens is immobile, making it impossible to look around, jumping spiders have developed a unique muscular system moving the retina inside the cephalothorax while the lens stays fixed. The system of six muscle pairs attached to the surface of the visual tube provides the retina with relatively free movement inside the cephalothorax, increasing the visual field to around 60°. In order to see an object in full, the spider must first examine it closely – scan it bit by bit – and assemble the images to form a whole. The retina has a distinct, narrow V shape of densely spaced receptors, with the arms of the V facing towards the lens. This arrangement provides sharp resolution of objects at various distances from the observer, even without adjusting the eye. The retina is built of four layers of cells; each layer is sensitive to a different light wavelength, enabling jumping spiders to see color.

Huge eyes, small brain

Jumping spiders have an extremely good visual acuity and exhibit highly complex behavior, even though they have very small brains (no larger than a pinhead). Such a small brain size severely limits computational ability and, as a consequence, the animal's behavioral complexity. It should be remembered that neurons in invertebrates are larger than in vertebrates. There is huge variation in cognitive abilities of different groups of vertebrates, even just among mammals; comparing their brain sizes and structures to those of jumping spiders makes it clear how limited the latter's "wiring" must be. But paradoxically, the behavior of jumping spiders – among the smallest in the order – is undoubtedly the most complex of all spiders, marking them out from other invertebrates.

All invertebrates, spiders included, have until recently been regarded as simple, preprogrammed animals that show no behavioral flexibility or ability to learn. However, this view – persisting since Cartesian times – has gradually changed as our knowledge and research methodology improved. Under closer scrutiny it turned out that certain social hymenoptera are able to communicate with each other to transmit diverse, often complex information such as the relative location and distance between the nest and food source. Although bees and ants have been studied for many years, it is only recently that researchers have started to use contemporary methodology and creative experimental settings in which the animals are set problem-solving tasks or are required to make a decision under controlled conditions, allowing scientists to see invertebrates in a new light: as animals with a good ability to use information available to them and solve complex tasks.

Maciej Bartos

Research carried out in recent years has brought significant progress in our understanding of the complexity of spider behavior. Pictured: dune jumping spider with its prey

Primates among spiders

In recent years there have been significant advances in our understanding of spider behavior, mainly as a result of work carried out by Robert Jackson and his team in New Zealand. For example, jumping spiders from the *Portia* genus hunt their prey not only using innate, fixed tactics, but are also able to learn new hunting methods. *Portia* specializes in hunting a very dangerous prey – other spiders – often "impersonate" sexual partners of the host of the web they are entering, sending signals interpreted by the host as encouragement for mating. The host is usually fooled and approaches the intruder unawares, allowing itself to be caught at a suitable moment. However, this allows *Portia* to capture only certain spiders using innate hunting strategies. Since each species has its own distinctive set of mating signals, on entering the web of an unknown prey *Portia* uses trial and error to determine the correct code – sending out a wide range of vibrations of varying frequency and intensity, selecting those that elicit a response from the host. They frequently approach the host spider, although in order to remain unnoticed they move only during gusts of wind preventing them from being detected. If there is no wind, they twitch the web themselves to imitate air motion. They create this cover to allow them to approach their prey undetected.

These small spiders' cognitive ability is well demonstrated in situations when *Portia* sees its potential prey, but is unable to reach it directly. In this scenario it uses the spatial arrangement of its surroundings to plan and prepare a route and select the one which will eventually lead it to the prey. This happens even when the selected route leads in the opposite direction to the prey, and the object of the assault temporarily disappears from *Portia*'s visual field. The behavior described here requires the spider to create a mental cognitive map, a skill which until recently had been thought to only be present in higher vertebrates. Analyzing *Portia*'s behavior, we are faced with the question: how do these animals with relatively simple nervous systems manage to analyze and make decisions based on the wealth of information they receive from the environment? How is it possible for them to focus their attention on a specific element of their environment, interpret it accordingly, and use it to maximize their chances of survival and reproduction? These questions fall under the realm of a new branch of ecology combining the analysis of information processing and decision making processes, known as cognitive ecology.


Maciej Bartos

The true distinguishing feature of jumping spiders is their excellent visual acuity. Their eyes are placed around their cephalothorax, providing the spiders with an almost 360° visual field

I have been studying the behavior of jumping spiders for many years, working to define the traits the spiders use to differentiate potential partners from enemies and prey, and the features used to recognize individual prey. This categorization is relatively easy to observe, since different types of prey with different features are captured in different ways. The lab rat equivalent I work with is a small species of jumping spider – *Yllenus arenarius*. This tiny spider uses very different strategies when hunting fast-moving prey, such as grasshoppers, leafhoppers, or flies, than for those unable to escape, such as caterpillars. The differences involve key aspects of the hunt, such as speed, direction of approach to the prey, and the distance of attack. The differences are so clearly marked that it is sufficient to watch how a spider approaches its prey to establish whether the prey will be able to escape or not. Furthermore, soon after hatching, young, inexperienced spiders consistently select the same hunting strategy for specific types of prey as do adult individuals. This means that not only is complex hunting behavior innate, but also that the mechanisms used in prey recognition have a similar basis.

Spider cinemas

How do inexperienced spiders respond to signals they have never previously encountered? How do they differentiate potential prey from enemies and inedible objects? After all, they have not been equipped with any kind of "catalogue" to refer to. Even if this was the case, the sheer range of all objects the animals encounter in their environments is so huge that the only reasonable solution is selective sensitivity to some features common to all prey from each type. Although the types of fast-moving prey listed above seem very different on a superficial level, they do share certain characteristics which can be regarded as likely indicators of the prey's ability to escape. Those traits were defined during the first stage of research; the next issue was to enable the researchers to manipulate one such characteristic independently of the others.

We took advantage of recent achievements in computer graphics and modern projection technologies: we constructed a miniature cinema for spiders, projecting animations of virtual prey with varying test characteristics. During the early stages we were unsure whether the spiders would attack the animated prey at all, it being stripped of most of its features to produce forms that never occur in nature. We discovered that the animations were attractive to inexperienced spiders with no previous hunting experience; however, they were no longer of interest to older, experienced individuals. Ongoing research is testing for specific features such as body proportions, type of movement, presence of legs, wings or antennae, and head position. Preliminary data analysis shows which characteristics the spiders use to identify prey: the most important traits in distinguishing prey with different abilities to escape are body proportions, rather than means of locomotion or the presence of wings. Certain features are key stimuli which fundamentally change the spiders' response; others have a cumulative effect and improve the ability to recognize prey gradually and in combination with other traits.

Our preliminary research, aiming at the development of a set of symbols to communicate with spiders, is almost completed. This is to be followed by the most interesting stage of the research: manipulating symbols with known properties. The aim of the manipulation is to discover how spiders cope in a variable environment and how they make decisions based on diverse, frequently contradictory information. The results should at least partially help us see the world through the eyes of jumping spiders, and help us understand how their tiny brains process the variety of information perceived through the eyes.

In my view, spiders really do improve on closer scrutiny. Moreover, when looking at them we should be aware that at least some of them are staring right back at us. So just try not to scare them! ■

Further reading:

Foelix R. F. (1996). Biology of spiders. *Oxford University Press*.
Herberstein E. M. (2011). Spider behaviour: flexibility and versatility. *Cambridge University Press*.
www.maciejbartos.pl