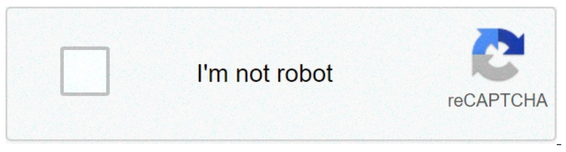

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The forked tongue

The serpent's forked tongue has intrigued humankind for millennia, but its function has remained obscure. Theory, anatomy, neural circuitry, function, and behavior now support a hypothesis of the forked tongue as a chemosensory edge detector used to follow pheromone trails of prey and conspecifics. The ability to sample simultaneously two points along a chemical gradient provides the basis for instantaneous assessment of trail location. Forked tongues have evolved at least twice, possibly four times, among squamate reptiles, and at higher taxonomic levels, forked tongues are always associated with a wide searching mode of foraging. The evolutionary success of advanced snakes might be due, in part, to perfection of this mechanism and its role in reproduction. Many people think a snake's forked tongue is creepy. Every so often, the snake waves it around rapidly, then retracts it. Theories explaining the forked tongues of snakes have been around for thousands of years. Aristotle reasoned that it provided snakes with "a twofold pleasure from savours, their gustatory sensation being as it were doubled". Italian astronomer Giovanni Hodierna thought snake tongues were for cleaning dirt out of their noses. Some 17th century writers claimed to have watched snakes catch flies or other animals between the forks of their tongues, using them like forceps. It is a common myth even today that snakes can sting you with their tongues. But none of those hypotheses is likely. Most animals with tongues use them for tasting, to clean themselves or others, or to capture or manipulate their prey. A few, including humans, also use them to make sounds. Snakes do not use their tongues for any of these things. Over the past 20 years, Kurt Schwenk, an evolutionary biologist at the University of Connecticut, has been working on understanding the function of snake tongues, and "smelling" is the closest description of what snakes do with their tongues. Tongues that smell Snakes use their tongues for collecting chemicals from the air or ground. The tongue does not have receptors to taste or smell. Instead, these receptors are in the vomeronasal, or Jacobson's Organ, which is in the roof of the mouth. Once inside the Jacobson's Organ, different chemicals evoke different electrical signals which are relayed to the brain. It was once thought that the tongue delivered chemicals directly to the Jacobson's Organ, because both the organ and the pathways that lead to it are paired just like the tips of the tongue. But X-ray movies have revealed that the tongue does not move inside the closed mouth, it simply deposits the chemicals it has collected onto pads on the floor of the mouth as the mouth is closing. It is most likely that these pads deliver the sampled molecules to the entrance of the Jacobson's Organ when the floor of the mouth is elevated to come into contact with the roof following a tongue flick. The case for this is strengthened because geckos, skinks, and other lizards lack deeply-forked tongues but still deliver chemicals to their vomeronasal organs. colneljohnbritt, CC BY-NC-SA Smelling in 3-D Because it is forked, the tongue of a snake can collect chemical information from two different places at once, albeit places that are fairly close together by human standards. When snakes spread the tips of their tongues apart, the distance can be twice as wide as their head. This is important because it allows them to detect chemical gradients in the environment, which gives them a sense of direction – in other words, snakes use their forked tongues to help them smell in three dimensions. Owls use their asymmetrical ears in this way to detect sound in three dimensions. Snakes and owls use similar neural circuitry to compare the signal strength delivered from each side of the body and determine the direction that a smell or a sound is coming from. Humans do this with their hearing too, but not as effectively. This makes it possible for snakes to follow trails left by their prey or potential mates. In the 1930s, before guidelines on the ethical use of animals in research were as strict, German biologist Herman Kahmann experimentally removed the forked part of snakes' tongues and found that they could still respond to smells, but that they had lost their ability to follow scent trails. These results were refined and confirmed during the 1970s. Sniffing out sex Tongue sizes in Copperhead snake males (left) and females (right). Smith et al/Journal of Zoology In the 1980s, snake biologist Neil Ford at the University of Texas at Tyler watched how male garter snakes used their tongues when they were following pheromone trails left behind by females. He found that if both tips of the male snake's tongue fell within the width of the trail, the snake continued slithering straight ahead. However, when one tip or the other fell outside the edge of the trail, the snake turned his head away from that tip and back towards the pheromone trail, and his body followed. Following this simple rule allowed the snakes to perform trail-following behaviour that was both accurate and directed. If both tongue tips ever touched the ground outside of the trail, the male would stop and swing his head back and forth, tongue-flicking, until he relocated the trail. Snake ecologist Chuck Smith at Wofford College found evidence that male Copperheads have longer, more deeply-forked tongues than females, which presumably enhances their ability to find mates. Although sexual dimorphism – where one sex is markedly different from the other – is rare in snakes, differences in tongue size are likely to be present in other species as well. Scent-trailing is probably also quite helpful to snakes tracking down prey, including for sit-and-wait predators like vipers, which have evolved smelly but non-toxic venom components to help them relocate their bitten and envenomated prey. Dagfhous et al/Chemical Senses When following a scent-trail, snakes simply touch their tongue tips down to the ground to pick up the chemical information lying there. But snakes can also use a different type of tongue-flick to sample airborne chemicals. Snakes often wave their tongues in the air without putting them in contact with anything. The tongue creates air vortices, such as those formed in the water behind a boat. These vortices drift away from the boat as they form. Bill Ryerson, a student in the Schwenk lab, found that vortices created in the air by snake tongues have a special property – they do not drift away but rather stay in the vicinity of the tongue, where they can be sampled repeatedly as the tongue skirts the part of each vortex where the air velocity is the highest. Oscillating tongue-flicks are unique to snakes. They allow snakes to sample 100 times as much air as the simple downward extension of the tongue. The tongue then transfers these molecules to the Jacobson's Organ via the mouth floor. Evidence suggests that male Copperheads can also find and follow females using oscillating tongue-flicks to detect airborne pheromones, although the details of how they determine direction using such dispersed and transient odours are still poorly understood. I wish they'd all go away. That this damned Operation Escape would end. That the neighbourhood would be emptied of those who live and who don't live in Pedralbes. Bruno runs off and I panic. I run out to look for him. It's Friday, the weekend of the festival of Sant Joan. I find myself swallowed up by a massive traffic jam and a collective unbridled joy. 4x4s, vans, motorbikes, Renault Twizys all overexcited to get on the move, to pick up, to pack. To clear off who knows where. Girls with pleated skirts and knee-high socks laden with heavy ring-binders. Little lads swapping the latest pokemons with their school friends. Young, pretty, happy mothers. Dads spilling over with energy. I am a character that is out of place, pushing against the current, frustrated that I can't shout 'Bruno, Bruno, come'. I swerve around the cars parked by the Creu de Pedralbes and run into the Plaça del Monestir. A couple of tourists taking photos and more kids with red rucksacks jumping up and down the steps with wild enthusiasm. I hear the bells ringing and twist my ankle on the flagstones. I get to Parc de l'Oreneta and here I do yell and cry and no-one sees me. I curse the disobedience of my dog. The faulty gene that makes my Labrador so unlike a Labrador. I reach the gazebo that in times past sheltered well-to-do lovers from upper-class families, now abandoned and graffitied, where Bruno likes to stop, sniff around persistently until he licks something I don't want to know about, and round off his pleasure by cocking his leg. I leave the park. I think about what Bruno will do if he happens across a female boar ready to defend its young, one of the those mothers that has been coming down with her whole family for years, crossing Passeig de la Bonanova looking for dinner in the rubbish containers. I see the Ronda jammed in both directions and feel relief that I will not be leaving, not today, nor tomorrow, nor the next day. That in this place, I am a rarity who doesn't leave the neighbourhood when there's long holiday weekend. I cross the bridge engulfed in that permeating, endless noise that envelops every house in the area. I walk past the petrol station, the carwash, the recycling station and the garden centre, devoid of customers. The thought of Bruno crossing the street fills me with anxiety. I remember the tag that he never tried to pull off, with my mobile number engraved on it. I think of his docile nature, his big sloppy licks on my face when I feel like I'm disloyal to him. Like when I clean his infected ear, scratch a weeping wound, or we get him vaccinated. When my children were born and he knew he was losing his place. I start to cry again. I think I'd better go home and make a poster and paper the whole neighbourhood with it. That's what I do. Bruno's majestic head looking out and LOST DOG in Interestate Black Condensed cos 135. I stick the poster up around the university and on I don't know how many lampposts. I walk under the stirring pine trees of the Jardins de William Shakespeare. I go along the artificial stream where no swimming is allowed and to where Bruno the Disobedient insists on dragging us time and time again. I get to the Güell stables and under the impassive eyes of a Japanese couple, I stick the A4 sheet onto the copper-coloured bricks. Bruno's black eyes next to the forked tongue of Gaudí's dragon. And it's only then that I wonder if what I'm doing is illegal. Sticking up posters of someone you love and that you've lost. I suddenly feel utterly dejected. I return home, dragging my feet. I see a nun in a brown habit and think about a cloistered life. I'm passed by a group of men with success etched on their faces, in full happy hour mode. I wish they'd all go away. That this damned Operation Escape would end. That the neighbourhood would be emptied of those who live and who don't live in Pedralbes. My mobile rings. Bruno is OK. On Carretera de les Aigües. With two girls who ask me if they can keep him with them on their run. I say yes and thank them. I enjoy every second of the long Sant Joan weekend. The emptiness after the hysteria. The state of gentle abandonment that my neighbourhood is in. With Bruno home. Did you ever use your hands to scoop the air toward your nose when someone takes a pie out of the oven? Snakes are doing the same thing when they flick their forked tongues."They are manipulating the air, bringing chemicals from the air or the ground closer so they can figure out what kind of habitat they're in, whether there are any predators nearby, and what food items are around," explained biologist William Ryerson. This time of year, a number of our native species may also use their tongues to track the pheromone trails of potential mates, sometimes over long distances.Ryerson began researching snake tongues as a Ph.D. candidate, working with evolutionary biologist Kurt Schwenk at the University of Connecticut. In 1994, Schwenk published a study on why snakes have forked tongues. According to Schwenk, snakes' tongues do not have taste receptors, and instead are used for a type of three-dimensional smelling.The forked tongue allows snakes to sample air molecules from two different points, and this information is delivered to two separate organs in the roof of the mouth. The dual signals help snakes determine the direction that a scent is coming from. A snake may spread the tips of its tongue as it investigates a scent – as far apart as twice the width of its head. Unlike mammalian sniffing, this type of smelling is not limited to breaths; as long as the tongue is out, a snake is gathering information.Ryerson, who has a background in physics and fluid dynamics, teamed up with Schwenk to investigate why snakes don't simply hold their forked tongues still when they're sampling the air.Theories for tongue flicking have existed for centuries, Ryerson explained. "People thought it was to clean out their noses, to catch flies, or hypnotize mice — but we didn't have a good handle on its function until recently."On average, snakes' tongues can flick at a rate of three meters per second—or, six or seven flicks in a third of a second. To see the behavior in detail and observe differences between species, Ryerson used a high-speed video camera. To understand the air movement around the snakes' tongues, he directed a laser beam through a series of lenses. These lenses took the narrow beam and converted it into a flat sheet of light. Ryerson then dispersed dust particles into the air. As they floated, they reflected the laser light. He placed a snake near the laser light (while guarding its eyes) and watched it flick its tongue. As the snake's tongue passed through the sheet of light, the dust was disturbed, and its movement was captured by the high-speed camera.Ryerson's experiments showed that flicking increases the tongue's exposure to air molecules, and therefore, its potential acuity of smell. He believes that a snake can gather information 100 times faster this way than if it simply extends its tongue downward to touch the ground.Even among ophidiophobes (people scared of snakes) there may be reasons to appreciate snakes' way of smelling. "If we can design a refined odor detection system with the ability to detect left and right, there are tremendous security applications," said Ryerson.Ryerson, who now teaches biology at St. Anselm College in New Hampshire, continues to study snakes. He collects wild specimens, brings them into the lab for a few days, then releases them at the site of capture. Although he has plenty of practice picking snakey spots, and spends many hours tromping through the woods, he still often comes back with an empty canvas sack. His enthusiasm remains unabated. "Snakes are absolutely fascinating animals," he said. "Even if it's one I've seen a hundred times, like a garter snake, I'll jump into the lake after it."Laurie Morrissey is a writer in Hopkinton, New Hampshire. The illustration for this column was drawn by Adelaide Tyrol. The Outside Story is assigned and edited by Northern Woodlands magazine and sponsored by the Wellborn Ecology Fund of New Hampshire Charitable Foundation: wellborn@nhcf.org