



JACOBSON'S ORGAN

AND THE REMARKABLE
NATURE OF SMELL

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and the Remarkable
Nature of Smell



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The most mysterious, the most human thing, is smell ...

COCO CHANEL, in *Her Life, Her Scents*

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Right under our noses

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We have a nose for things. We sniff out problems and follow our noses, moving to a successful conclusion in directions that are often far from obvious. And yet we persist in belittling our olfactory abilities, dismissing the human nose as a blunt instrument.

It is true that most animals have a more acute sense of smell. Dogs are a million times more likely to pick up social scents, hedgehogs ten thousand times better equipped for finding food. But, even with olfactory centres that occupy just one-thousandth of our cranial capacity, we humans are remarkably good at detecting, recognizing and remembering odours.

We can identify our relatives by smell alone, or follow the menstrual cycles of our friends and lovers. We can diagnose disease, detect danger, and distinguish between good and bad food just with our noses. We know, along with Rousseau, that 'Smell is the sense of memory and desire.' We realize, with Diderot, that smell is the most voluptuous sense. And we acknowledge the truth in Helen Keller's contention that smell, while representing the 'fallen angel' of the senses, nevertheless remains 'potent wizard that transports us across thousands of miles and all the years we have lived'.^{95*}

So why the ambivalence? It seems we are missing something. I think we are, and I believe I know what it is. It is an obscure body part. One that has been there, right under our noses, all the time. Science has known about it since 1811. Biologists are familiar with it as the structure in the roof of a snake's mouth which 'tastes' molecules collected by the reptile's flickering tongue. And a few dedicated anatomists have tracked down something similar in the nasal passages of possums, anteaters, bats, cats, rabbits, and even a white whale. But, though this body part was also discovered and described in humans a century ago, it has since mysteriously disappeared from the textbooks.

There are passing mentions of it in medical and technical journals dedicated to comparative anatomy and olfactory physiology, where it tends to be dismissed as something vestigial, an anatomical ghost that makes a transitory appearance in the human embryo, vanishing well before birth. And yet it still exists: a study in 1991 of a thousand randomly selected adult human subjects found it in the noses of almost every one.

This elusive feature is the Organ of Jacobson, named after the sharp-eyed Danish anatomist who discovered it nearly two centuries ago. It is easy to miss. The external evidence consists simply of a pair of tiny pits, one on either side of the nasal septum, a centimetre and a half above every human nostril. But the fact that it does exist changes everything. With it, we reinherit the possibility of a powerful and ancient chemical sense: an ability to enter once more into a system of subliminal signalling that continues to give other animals access to a world we thought we had lost as a result of our emphasis on sight instead of smell.

Jacobson's Organ rescues our most underrated sense from obscurity. But it is not simply a supercharger, making us more sensitive to odours. What it seems to do is to open up a channel quite separate from the main olfactory system. It feeds an older, more primal area of the brain, one that monitors airborne hormones and a host of other undercover patterns of information, making physiological changes that have profound effects on our awareness, on our emotional states and on our most basic behaviours. Recent research suggests that this system could be the mechanism necessary for operating a true 'sixth sense', one that may account for our sometimes apparently supernatural ability to receive information not normally available to the traditional five faculties.

If all this is true, Jacobson's Organ could be the most important key to unravelling the mysteries of our minds since the discovery of the unconscious. As an evolutionary biologist and anthropologist, that possibility excites me enormously.

Aristotle associated the four fundamental elements of earth, air, fire and water with the four basic senses of sight, hearing, touch and taste. But he also recognized a fifth element, the most essential substance of all, called *quintessence* – and connected this to the sense of smell. That, he suggested, lay at the heart of perception, linking the other four senses. Ever since then, five has been the established number of the senses in Western culture. I have no argument with Aristotle, but I believe it is time to extend his fifth sense, already at the centre of awareness, into new areas, expanding smell in ways that give our Cinderella sense its proper due.

Lyall Watson
Castlemehigan, Ireland, November 1999

PART ONE

GETTING ORGANIZED

Smell is the forgotten sense. There are no agreed measures of its nature, no societies dedicated to its appreciation, no descriptions of it except those borrowed from our overbearing sense of sight.

Smell is our most seductive and provocative sense, invading every domain of our lives, providing the single most powerful link to our distant origins. But it is also mute, almost unspeakable, defying description and collection, challenging the imagination. All that stops it slipping entirely through the net of language is a few brave attempts to pin it down – beginning with the work of a very tidy-minded Swede.

Carolus Linnaeus (1703–78) was the Great Indexer. He studied medicine at Uppsala University, but his heart was always in botany. He began his green studies with a survey of all the flowering plants of Lapland, completing this task in 1737 with the aid of a revolutionary new system of defining and describing every species. And during the next twenty years he engineered a huge expansion in natural history, publishing his *Systema naturae* and docketing everything in sight, changing for ever the way we think about the world around us.¹¹⁴

Knowing the names of things gives us power over them: the power to isolate them from nature. This separation remains artificial but also extraordinarily useful, making it possible for us to set the tree aside for a moment and concentrate instead on the composition and coexistence of the forest. Labelling is an essential first step in coming to terms with ecology, and Linnaeus, in his feverish catalogue of existence, applied his art even to the elusive world of smells, scents and stenches. There were, he decided, seven major classes of odour, ranging from the pleasant to the unpleasant, from those he described as ‘kindly and desirable to our nerves and even to life itself’ to those that were patently ‘repellent to life’.¹¹⁵

Linnaeus published *Odores medicamentorum* in 1752 and there have been dozens of attempts during the last two and a half centuries to refine this system, approaching it from the vantage points of psychology, chemistry, physiology and perfumery. Some of these refinements are convenient for cosmetic chemists and those working in the fragrance industry, but even the most sophisticated new taxonomies are unsatisfactory and inconsistent in the end. They founder on the accidental nature of most smells and on the lack of a specialized vocabulary for the act of smelling in any language.¹¹⁵

There is no semantic tradition, no critical study of the origin and function of words used to describe smells in any country, and no learning process in any culture assigned specifically to the sense of smell. So I find myself returning, time and time again, to the classification provided by the man whom novelist John Fowles calls ‘The Great Warehouse Clerk of Nature’.⁵⁷ And finding solace, even a surprising new depth of meaning, in the resonant succession of *Fragrantes* (fragrant), *Hircinus* (goaty), *Ambrosiacos* (ambrosial), *Tetros* (foul), *Nauseosos* (nauseating), *Aromaticos* (aromatic) and *Alliaceos* (garlicky).



Linnaeus was far more than just a pigeon-holer. He was a master organizer, sorting out and tidying up the unruly strands of life in all its guises. But he was also wonderfully intuitive at it, coining names and creating patterns which for the most part still work, and which help to reveal real relationships and affinities where none are immediately obvious. He enriched sight with insight and gave tantalizing glimpses of a grand design. It was he, of course, who gave us a place in the natural world.

He allowed us to be *sapient* – which refers to someone who is not necessarily ‘wise’, but more properly and modestly ‘would-be-wise’ – perhaps by coming to our senses.

In the Andaman Islands, the Ongee people consider smell not as an isolated sense, but as a fundamental cosmic principle. For them, odour is the source of personal identity. It produces life and causes death. When Ongee – or anyone in modern Japan – refer to ‘me’, they put their forefinger on the tip of their nose. That is where the spirit resides, and too much or too little of it can cause problems. A healthy person is one who has their smell ‘tied tightly’. Losing your odour entirely can kill you.²⁹

The ideas of life and breath and spirit and smell are intertwined in many cultures. Some Mexicans still believe that the smell of a man’s breath is more responsible for conception than his semen is. And in the Andamans, they tie everything very tidily together in a tradition of communication by smell which they call *mineyalange*, which literally means ‘to remember’.

Nothing is more memorable than a smell. Ask anyone to recall a childhood home or friend, and the details are likely to be sketchy. But provide just one whiff of a familiar scene, and the memories come rushing back, not piece by piece, but as a whole, with all the flavours of the original experience miraculously intact. And the effect is explosive. As Diane Ackerman says, ‘a complex vision leaps out of the undergrowth’.¹

Indeed it does. Perhaps this is because smell is the only sense you can’t turn off. You can close your eyes, cover your ears, refrain from touching or tasting. But we smell all the time and with every breath, twenty thousand times a day. And if I am right about Jacobson’s Organ, all that information is filed away somewhere – not in the grey matter of the conscious brain, which is far too busy with things of the moment, but in the warehouses of long-term memory, in those parts of the brain more touched by sensibility than mere sensation. There is a big difference between sense and sensibility. And because my exploration of a possible sixth sense will take in several kinds of olfactory experience, it is important here, at the outset, to know something about how smell works.



Noses are conspicuous. They hold centre stage on our faces, reaching out into the world, demanding attention. We don’t count mouths, we count noses. We look down them, pay through them and run the risk of having them put out of joint.

We breathe through our noses, warming incoming air, but any simple opening would have sufficed for that. What we have instead is an exaggerated profile involving a canopy supported by a clear purposeful piece of cartilage. This keeps the rain out, deflects water when we swim, and may even add resonance to our speech, but functionally it has most in common with a ventilator hood – something like an air scoop fitted to the deck of a boat. The nose projects away from the olfactory confusion of the face, avoiding self-smelling, inhaling the rest of the news. Testing the air for early warnings gives those who stand guard, usually the men, noticeably larger nasal structures.

All our noses are alike inside, opening into a pair of cavities separated by a septum. These are surprisingly large vaults, occupying almost as much space in the skull as our famously big brains. Most of this is air-conditioning apparatus, divided up into three horizontal chambers by thin, scroll-like bones covered in vascular tissue which expands and shrinks in tune with a variety of reasons and

seasons. So the flow of air through the left and right nostrils is seldom equal, giving us alternating rather than parallel passages, and creating conditions which are always turbulent. Perhaps, again, with good reason.

High on the roof of the two upper chambers, roughly on a level with our eyebrows, there is a patch of yellowish tissue in a pair of clefts. Each patch is just one centimetre square. Put together, the patches would fit on a postage stamp, but both are richly endowed with several million fringed receptor cells. This is where smells are collected.

The position of these olfactory epithelia, hidden away in the back of the nose, seems awkward. Logically, they ought to be out there where the action is, bathed in a constant stream of air. But like the other sense systems, the olfactory organ needs variety. Just as spontaneous tiny eye movements provide an essential variation of stimulus to the retina, so the nose thrives on subtlety and change. It lies in wait for a whiff of something new and interesting, and then it demands attention – and we wrinkle up our noses and sniff.

Smell is a chemical sense. What the receptor cells in the nose do is translate chemical information into electrical signals. These travel along olfactory nerves into the cranial cavity, where they gather at the olfactory bulbs. These, in turn, feed the cerebral cortex, where association takes place and nameless signals become transformed into the fragrance of a favourite rose or the musky warning of an irritable skunk.⁵

Trained noses can identify hundreds of thousands of odours, far more than our minds can describe. Smells sit right on the tops of our tongues and linger there, because we cannot utter their names. It is almost impossible to describe even the most familiar scents to someone else who has never smelled them. And part of this confusion exists, I believe, because of the way we ourselves experience them.

The odour-to-nose-to-brain sequence I have just described in very bald terms is *not* the only way we smell. Our nasal chambers are connected to the outside air directly through the nostrils, and indirectly through the throat by ‘inside air’ that comes perfused with the flavours of food and drink, and the products of digestion. All this information goes to the olfactory bulbs of the brain. But riding on the inside of each of these swellings in our heads are other smaller lobes called the accessory bulbs, which get their news of the world from an altogether different source: the twin-tubed Organ of Jacobson.



Twenty years ago, hardly anyone believed in such a thing. There were old reports from Victorian anatomists, but the modern anatomical consensus was that humans don't have such an organ. All that changed at the University of Colorado in 1991. Bruce Jafek was a practising surgeon then, specializing in nose jobs, until he became curious about Jacobson's Organ. He and microscopist David Mora devised a simple nasal speculum to help in the search, and by laying people on their back and shining a light up their nose, they discovered the organ in every one of the two hundred people they examined.¹²⁹

Once you know exactly where to look, finding it isn't difficult. The openings can usually be seen with the naked eye as tiny, pale pits, near the front of the nasal septum, about a centimetre and a half in from each nostril, just above the floor of the nose. Sometimes the pits are relatively large, a couple of millimetres across; sometimes a binocular microscope is necessary to find them. But everyone

regardless of age, sex or race, has a pair – unless you have had the sort of cosmetic surgery which removes that part of the nasal septum entirely.

These pits lead to two short tubes equipped with sensory cells quite different from those in normal olfactory tissue. Moran said, ‘They don’t look like any other nerve cells I have ever seen before in the human body.’²¹⁴ But in 1990, physiologists Luis Monti-Bloch and Larry Stensaas, of the University of Utah, examined a further four hundred subjects and found that all of them had such twin tubes, and every one they tested was indeed using these organs to send messages to the brain.¹²⁸

But the most interesting thing is that Jacobson’s Organs are not receptive to ordinary odours. They respond most often to a range of substances which have large molecules, but often no detectable odour. And they communicate not with the olfactory bulbs and the cortex, but with the accessory bulb and that part of the brain that coordinates mating and other basic emotions. Recent evidence suggests also that the two separate and parallel systems of odour detection cooperate in surprising ways to produce novel sensibilities not achievable by either of them on their own.

Moran, Jafek, Stensaas and Monti-Bloch are now part of a small group of distinguished scientists who believe they have discovered a new sense organ, one that detects chemical signals previously thought to be beyond the scope of human sensitivity. They call it the *vomeronasal organ*, rather than Jacobson’s Organ. But by any name it has put them at odds with conservative physiologists and neurologists who want more concrete evidence, preferably from humans willing to have dyes injected into their systems, so that their brains can later be scanned to see where the tracers end up. Such foot-dragging in the face of facts has a familiar feel to it. The last time I saw anything like it was in the 1960s, when diehard geologists made last-ditch stands against the tide of continental drift.

I am impressed by the evidence we already have for an organ I continue to credit to its Danish discoverer, and I am fascinated by the potential it has for all students of the unusual. The Organ of Jacobson seems to feed the primitive brain. It is not our olfactory link to consciousness, but rather a chemical clearing house for subliminal impressions, for all the things that lead to what science writer Karen Wright calls ‘bad vibes, warm fuzzies, instant dislikes and irresistible attractions’.²¹⁴ Just the sort of will-o’-the-wisps with which any decent sixth sense ought to be concerned.

But before exploring the stranger fringes of the sense of smell with this in mind, I want to do what a good evolutionary biologist should, and look back, with the help of Linnaeus, on how it all began.

Fragrantes

For this group of odours, Linnaeus specified floral sources such as jasmine, saffron and wild lime all of which are distinctly perfumed.

But there is something in his description which suggests that, as a Latin scholar, he was aware of possible confusion between the verbal roots fragrare ('to smell'), and flagrare ('to burn') and felt that both were appropriate.

Saffron is not just fragrant, but also fiery, glorious, even gaudy, giving Alexander Pope good reason to describe the fleet in which Odysseus set sail as 'a cruise of fragrance, formed of burnished gold'.

Saffron is a crocus. Crocus is the Chaldean name for the iris family. And Iris is the Greek goddess of the rainbow and messenger of the gods.

There is more than enough biological and mythological coincidence in all this to keep a classicist scholar happy and to augur well for the evolution of a sense able to appreciate something both bright and beautiful.

A nose is born

Smell was our first sense. It is even possible that being able to smell was the stimulus that took primitive fish and turned a small lump of olfactory tissue on its nerve cord into a brain. We think *because we smelled*.

The argument is simple. Before sight and sound hijacked our attention, we shared with all life a sort of common sense, a chemical sense that depended on direct contact with matter in the water or the air. And for 90 per cent of our time on Earth, that was how things worked.

Then the emphasis shifted. We learned to live instead with waves of energy, making sense of chaos and becoming conscious. Which, of course, was a good thing ... but we need now to go back and pick up some useful talents that we abandoned on the way.

Four hundred million years ago, in the Devonian period, fish were the most important and advanced animals on Earth. And the most abundant of them were jawless, heavily armoured forms, filtering their food out of thick coastal muds. Theirs was a world of direct sensation. Behaviour was simple. Any unusual stimulus, a bright light, a loud sound, any abrupt contact, produced much the same response: one of aversion. They pulled back and tried again later, taking life one taste at a time.

In the beginning, it was difficult to separate taste and smell. In the mud, sensation followed contact. You bumped into things and then tested them to see whether they were worth avoiding or eating. The tests were chemical ones, made by cells designed to analyse molecules dissolved in the water.

Many crustaceans still work this way, using cells on their legs which respond only to amino acids, providing a ready distinction between organic and inorganic matter. Filter-feeding fish didn't need to be much more discriminating, extracting what was useful from the mud and rejecting the rest. But instead of just oozing around everywhere with their jawless mouths wide open, it would have helped these mindless pioneers to have some way of finding the most nutritious muds. What they needed was the ability to test and taste from afar – and that is where smell comes in.



Smell is a long-distance sense, a way of stretching time and finding out in advance what lies ahead. It expands both awareness and opportunity, providing a need for analysis that normally never touches the lives of bottom feeders. But it was, in fact, one of those mudsuckers that made the big leap. As the result is visible still, frozen in the life histories of a few modern species of jawless, limbless, boneless and often blind hagfish and lampreys.

Hagfish are patient scavengers, spending most of their lives embedded in soft mud with only the blunt snouts protruding, waiting for the same chemical signal that attracts crustaceans to putrid fish.

But these primitive fish have an advantage over lobsters and shrimps. They have a single opening above the mouth that leads to a paired chamber in which scents can be isolated, analysed and perhaps even located. They have, it seems, the world's first noses.



Armed with these secret weapons, hagfish have flourished. At least twenty species survive, some so well that they have become a nuisance to modern fishermen, burrowing into catches of haddock and cod and consuming netted fish from the inside out, turning them into bags of bones. Hagfish smell nothing, but clearly smell very well, swimming up a gradient of fishy flavours, travelling with undulating movements, turning always in the direction of the strongest stimulus, choosing the right odour corridors, keeping on going until they get there.

Their relatives the lampreys have refined the process even further, responding instinctively to just one aromatic chemical that forms part of the normal body odour of live schooling fish such as trout. Sensing this, they left their muddy larval haunts, developed functional eyes, and now actively pursue and parasitize such hosts. Once within range, the swift eel-like lampreys use their rasping teeth to hold on to any soft part of a trout, sucking out its body fluids like aquatic vampires, keeping their victims' blood flowing just as bats do, with anticoagulants in their saliva.¹⁰²

The unpleasant habits of round-mouthed hagfish and lampreys are vividly described as 'suctorial'. Theirs is a mode of life made possible by having gills which open directly into the throat, so that they can continue to respire while still sucking blood. They are sufficiently well adapted in this respect to have survived for over four hundred million years, despite their many other primitive features. But there is one important way in which they have changed: they have not only noses, but also a *new brain*.



The nervous system of these suckers is rudimentary. There are no sympathetic or autonomic nerves at all: none of the networks which, in more modern vertebrates, serve the intestine, the liver, all glands and the heart. But the nerves from the nose gather in a bundle in the head which is already substantial and beginning to spread out sideways, expanding in direct proportion to its employment. The most exciting feature of this growth is that, even in this early stage, it is starting to take on the shape of something new. It is a burgeoning forebrain, bursting into life in direct response to an olfactory need.

In a habitat where sight is limited and sound cannot be localized, only smell can pick up traces that provide solid information from afar. But smell on its own is not enough. There has to be a way of telling where a smell is coming from. Hagfish and lamprey put themselves into an odour corridor by swinging their bodies from side to side, sampling water on a broad front with their single nasal opening. But most later fish have two external 'nares', or nostrils, and practise 'stereo smell', which improves with the distance between the openings. The wider the head, the better the chance of smelling in stereo. And somewhere in the space between the nostrils, there was room for

coordinator: a place where information about smells could be analysed and acted upon.



Fish live in an environment where even substances that are only partially soluble find their way to chemically sensitive areas of the body, making it possible for extraordinary feats of detection. The Common European eel, for instance, has been shown to have a very uncommon affinity for some alcohols, responding to just a few molecules at a time in concentrations as low as one part in 10^{11} . This represents the sort of dilution you would get by tipping a single shot of vodka into a body of water the size of Lake Erie.¹⁸⁹ These eels are, of course, teetotallers. But they spawn and die in the depths of the Sargasso Sea, leaving leaflike larvae to make their own way, unguided, across five thousand kilometres of open ocean, back to ancestral haunts in the pools and lakes of Poland and Germany, in a journey that lasts three years. How they do this remains mysterious, but it seems to have something to do with smell.

Experiments with salmon show that they are able to distinguish between plain water and water in which an aquatic plant has been briefly rinsed. Young salmon probably imprint on the particular flavours captured by their home streams from the unique combination of plants that grow only in that watershed. It is difficult to imagine how young eels manage without such crucial early experience, yet they do. They are driven by instinct, and by the presence or absence of just a few special molecules, to make decisions on which the very survival of their species is at stake.⁷⁴

Smell is stimulating. It stirs things up and makes us nostalgic – a wonderful word which literally means ‘ache for home’ – which serves to inspire new circuits in the brain. Enough, in simpler species, to form a simple nose-brain. In migratory fish such as salmon, this centre has split into a paired organ more befitting species that have begun to perceive and to perform bilaterally. These are the *olfactory bulbs*.



Many sharks find their food by smell. If water in which live fish have been kept is siphoned into a shark tank, the residents respond with hunting behaviour. And if the stream comes from injured or dead fish, they can be provoked into a feeding frenzy. The excitement of the sharks increases directly with signs of stress from their prey. They detect and respond to the smell of trouble, and do so with extraordinary accuracy. In one experiment with a white-tip shark, an injured fish was allowed to swim the length of a tank before taking cover. When the shark was released soon afterwards, it followed exactly along the same zigzag line, duplicating every movement made by the now-invisible prey.¹⁹⁰

It seems that smell leads these predators to their prey from a distance, but the final move, the kill, may be triggered by another sense. For some species, in clear water and in daylight, this is often vision. In others it may be pressure waves detected by sensory cells along the flank. But in small, bottom-living sharks such as the spotted dogfish, the focus appears to be a weak electrical field.

produced by another fish's muscles. And all these impressions seem to be enhanced by smell, even linked with it in some strange way.⁹¹

Such synesthesia, the blending of one sense with another, is vital. Even in the lives of fishes sensation is seldom a matter of one thing or another. Senses overlap. The lines between them often tend to be blurred, and the best that we can manage, by way of description from the outside, is to say that the senses of fishes appear to dominate one at a time.

In the case of the spotted dogfish, smell slides seamlessly into an awareness which, if the fish could tell us, it might have to describe as a flavour rather than an odour. I find it fascinating that this very dogfish is renowned for having a forebrain which is not only large, but also equipped with a pair of swollen olfactory bulbs, each proportionately larger and better differentiated than those of almost any other fish. It is well prepared for blurring sensory boundaries in the same way that we, when faced with perceptual confusion, resort to metaphors, talking of 'loud smells' or 'bright sounds'.¹⁷⁷

Dr Johnson experienced the colour scarlet as 'the clangour of a trumpet', and the poet Rimbaud described the sound of the vowel *a* as 'a black hairy corset of flies'. And it can be no coincidence that natural synesthetes, those who experience intense sensory crossovers on a regular basis, have problems with their limbic systems – those areas of the brain that, in mammals, grew out of the olfactory bulbs.

One physiologist has even described human sensory blenders as 'living cognitive fossils' displaying a memory of how our early vertebrate ancestors once saw, heard, touched, tasted and smelled.¹¹⁹ It is a fact, too, that our cerebral hemispheres, those walnut-folded swellings of grey matter that dominate the forebrain and now control most of our conscious behaviour, also developed directly from olfactory tissue.

The limits of sensory evolution in fish are defined very largely by their habitat. Water is physically supportive, carries some kinds of odour well, and is kind to sound – letting it travel several times faster than air will allow, but it inhibits other more personal kinds of communication. Much more becomes possible when scents are released into the air. Breathing air is a liberating experience. It freed our ancestors from the constraints of staying wet or having to remain within easy reach of water for refuge, respiration or reproduction. But the biggest change it made in our lives was to expose us to a whole new range of sensory experience.



Air is traditionally 'thin', but the more we learn about our atmosphere, the more substantial it becomes. In some places it is so filled with inorganic flotsam that it is almost thick enough to plough through. In others, it has become so primed with the by-products of life that it comes close to being a living tissue in its own right. Even the cleanest air, at the centre of the South Pacific or somewhere over Antarctica, has two hundred thousand assorted bits and pieces in every lungful. And this count rises to two million or more in the thick of the Serengeti migration, or over a six-lane highway during rush hour in downtown Los Angeles.

Most airborne material consists of minute particles of salt, clay, and ash from forest fires and distant volcanic eruptions. And mixed in with, or growing on, or simply being carried along by them, the fertile soil is a garden of exotic flora and fauna. Every lungful of air we borrow from this gruel

likely to contain a few stray viruses in transit between their hosts; four or five common bacteria; five or sixty fungi, including several rusts or moulds; one or two minute algae drifting in from the coast and possibly a fern or moss spore, or even an encysted protozoan.²⁰²

All of which is inevitable. This is, after all, the stuff of life. We share our planet quite naturally with a permanent aeroplankton; a buoyant ecology too soft to hear, too small to see, but heavy with mood and meaning. Imagine being aware of all these airy inclusions – and you can begin to understand how it might feel to be able to smell really well.



Air-breathers do things differently. Their olfactory sense cells lie, not in isolated nasal sacs, as in fish, but strategically placed in a nasal passage, a thoroughfare through which air passes on its way to the lungs. And that simple fact gives noses a new slant. The difference is most dramatically demonstrated in an intermediate animal, one that has a nose in both worlds, something like a frog or toad that is amphibious, literally leading a double life. The African clawed toad is the white rat of the arena.

Every gynaecological laboratory has one, largely because it provided the first reliable way of testing for human pregnancy. An unfertilized female toad lays eggs within hours of being injected with urine containing hormones that are characteristic of newly pregnant women. But these smooth, streamlined, strange-footed toads – whose triple claws are used for digging for food on the bottom of South African ponds – are rapidly becoming equally popular with geneticists.

At the Institute of Zoophysiology in Stuttgart, work on the toad genome has revealed that ‘Strange Foot’ has an equally strange genetic repertoire. This includes hundreds of genes that code for the way in which its olfactory sense cells (called *receptor cells*) can function. That is no great surprise: mammals have thousands of such genes while fish have very few, so it was predicted that amphibians would be intermediate between the two. And so they are. Their olfactory genes fall into families of two distinct kinds.⁵⁸

Aquatic animals are exposed to water-soluble molecules such as amino acids, while air-breathers have access to a far greater variety of more volatile odorants. And as an amphibian, adapted to both aquatic and terrestrial life, the clawed toad was expected to have roughly equal numbers of both genes and receptor cells. It doesn't. There are far more cells of the mammalian air-breathing kind, probably because there are far more airborne than waterborne odours. But the big surprise is that the two kinds of receptors are found in separate areas. Strange Foot has two noses and two senses of smell: one for use underwater, the other for life in the air.

The toad's nose is neatly divided into two separate sacs or chambers. Just inside each nostril there is a flap of tissue which acts like a valve between them. Underwater, the flap swings to seal off the main chamber, exposing another one, a cul-de-sac filled with receptors sensitive to water-borne odours. And when the toad surfaces and raises its nose into the air, the flap swings the other way to seal off the aquatic chamber, exposing the main one, which is lined with cells sensitive to volatile odours in the air. And after serving this chamber, the airstream passes on to provide oxygen to the lungs.

Living in the air demands more of the sense of smell. But the challenge seems to be one that even

the most primitive amphibians are ready to meet.



Mexican toads, in the process of learning to negotiate a maze, have been trained to remember alien scents such as geraniol, vanillin and cedarwood.⁷⁰ Both the spotted chorus frog and Strecker's chorus frog have shown that they can pick up the odour of their own breeding ponds many hundreds of metres away.⁶⁹ North American leopard frogs, blinded by severing their optic nerves behind the eye, can nevertheless navigate their way back to a familiar pool, whether they are released upwind or downwind of their homes.⁴¹ But it is the olfactory skill of the Californian red-bellied newt that takes one's breath away.

This newt is lizard-like, with large dark eyes and tomato-red markings that warn of a poisonous secretion in its skin. It has few problems with predators in the coastal mountains where it lives, but has been persecuted instead by local biologists interested in its almost unbelievable navigation skills. It can be taken away from its usual damp haunts in one valley, carried across a mountain divide three hundred metres high, and still make its way unerringly back home.¹⁹³ If moved in any direction it will succeed, even in totally strange territory, in orienting itself quickly and directly towards home.

Blinding this nostalgic little animal doesn't slow it down for a moment. And squirting formaldehyde into its nose to kill the epithelium – the thin lining of tissue that contains olfactory sense cells – results only in what has been described as 'a significant loss of orientation ability'.⁶⁷ The only way, it seems, to prevent it from getting home is to sever its olfactory nerves entirely. Such invasive studies distress me. But the fact that they were thought to be necessary is a measure of our frustration when faced with behaviour for which we have no easy explanation. Such mysteries lie in every part of natural history. Even the simplest creatures have the capacity to surprise us when we think boldly enough to ask them the right kinds of questions. And the answers are never easy, except in hindsight.

In the case of the wandering newts, however, there may be a clue. There is something I have so far failed to mention about amphibians, something that began with those frogs and toads whose noses have divided into the two chambers appropriate to their schizophrenic lifestyle. It is this: some of them, including this newt, also have a third nasal space which is not directly involved in detecting smells, either underwater or in the air. And this could be involved in a new and different kind of awareness.



The olfactory sense cells of all vertebrates are, on the whole, surprisingly alike. And also very strange. They are, for a start, unique in that they are in direct contact with the outside world. Most other sense organs lurk under the skin, embedded deep in protective tissue, picking up sensations by remote control. But smell cells go unadorned: naked neurons, each one right out there in the open, like

unicellular organism, meeting molecules, making its own way in the world. And, strangest of all, small cells wear out after a few weeks and need to be replaced on the front lines. They regenerate ways no other nerve cells in our bodies ever do.¹⁸⁴

The number of olfactory sensory cells operating at any one time varies from one species to another depending on the emphasis a species places on having a good sense of smell. Humans, for example, have about six million cells; rabbits fifty million; and sheep dogs over two hundred million.

In all species the cells are thin, with projections, or processes, at either end. One of these extends inside the body, usually through a hole in the skull, to make contact with the brain. The other process is far shorter and stays on the outside in a knob topped with a tassel of fine sensory hairs, called cilia. The number of cilia varies too, according to the species. Domestic cattle, for example, all have exactly twenty-seven microscopic lashes on each sensory cell. Tiny newts have fewer such hairs, but theirs are four times as long.⁵²

It is generally agreed that the function of these frills is to bind odour molecules and convert the chemical signals into electrical ones for transmission to the olfactory bulb in the brain. So it is interesting to discover that, in addition to typical sensory cells in the main and side chambers of some amphibian noses, there are other cells in a deeper chamber that look very different. They are flask-shaped, with long necks. They have no cilia, but have knobs decorated with a tuft of short bristles, sometimes called microvilli, that makes them look like sensory cells with a crew-cut. And the tissue in which these bristle cells lie has none of the glands which, in normal olfactory sensory epithelium, produce the mucus that helps to trap and hold airborne chemicals.⁵³

No one knows exactly what these strange cells do. I suspect that they give air-breathing animals a new sensory edge. This extra faculty may be related to the sense of smell, and might even partially replace it, but it has a different, more multi-sensory bias, and a whole new perceptual agenda that becomes truly obvious only in the first fully terrestrial vertebrates – the reptiles.



Some reptiles differ very little from amphibians in both their lifestyle and their nasal structure. Marine turtles are as water-dependent as clawed toads and have very simple nasal passages that run almost in a straight line, from the external nostril to an internal opening in the throat. Land tortoises possess larger olfactory structures, and crocodilians have a surprisingly sophisticated series of chambers and sinuses which provide additional surfaces for the usual olfactory sense cells.

Marine snakes, tree-living lizards and chameleons are all conservative about smell, but it is among ground-living lizards and snakes, those closest to the source of many scents, that the greatest changes have taken place. And the most dramatic of these is a concentration of the mysterious bristle cells in a pair of separate chambers of their own.¹³⁹ This, finally, is Jacobson's Organ.



The discoverer of the organ, Ludwig Levin Jacobson, was born in 1783 in Copenhagen. He qualified in surgery at the age of just twenty-one and went to study in Paris with the great anatomist Baron Georges Cuvier, who believed that the habits of an animal determine its form. Cuvier also refined the taxonomic system of Linnaeus by showing how all organisms could be classified on the basis of their anatomical differences. And it was probably he who drew Jacobson's attention to the work of Frederick Ruysch, a Dutch embalmer who in 1703 described the anatomy of a number of animals, including a snake with unusual pits in its palate.¹⁶¹ So Jacobson looked for, in 1809 discovered, and in 1811 published a report on the organ which still bears his name.⁸⁴

The Organ of Jacobson remained a zoological curiosity until the late nineteenth century, when interest in it was revived by one of the most charismatic figures in Victorian science. Robert Broom was a Scot and a physician with a very curious mind. One of the last great individualists, he found no fault with a place or a practice only if it offered 'too much medicine and too little natural history'. In later life he became one of the world's great palaeontologists and physical anthropologists, doing pioneer work on the origins of humans in Africa, but his first enthusiasm was for reptiles, their origins and the significance of Jacobson's Organ. In between practising medicine he scoured museum collections and studied animals in the wilds of Australia and South Africa for material to include in his doctoral thesis, 'On the comparative anatomy of Jacobson's Organ', which he submitted to Glasgow University.

'It would seem,' said Broom, 'that the Organ of Jacobson is the organ in the body that is least liable to become altered by change of habit. I can almost identify an animal by examining this organ and often tell of its affinities.'¹⁶ He went on to do just that for the mammal-like reptiles that once roamed South Africa, most of which he found himself and modestly described as 'the most important fossil animals ever discovered' because 'there is little doubt that among them we have the ancestors of mammals and the remote ancestors of human beings'.¹⁷

Recent research confirms Broom's suspicions about Jacobson's Organ. Signs of it appear, like portents, in the embryos of all higher land mammals, although in some, such as tree-living lizards, aquatic turtles and nearly all birds, it never actually materializes. There is no need for it. In others, such as ground-living lizards and most snakes, the organ comes into being, not simply as pouches on the nasal cavity, but as a pair of blind chambers that open directly into the mouth.⁴⁷ Why should this be? What happened to make this development not just useful, but necessary?

Robert Broom, who could put flesh on the bones of a fossil even while it was still in the ground, described minute channels on the skulls of some of his finds in the fossil beds of the Karroo Desert, marks which suggest that Jacobson's Organ arrived on the scene during the Triassic, perhaps two hundred million years ago. It appeared, he believed, to meet a need that could best be understood by looking at lizards or snakes that live today in similar habitats.¹⁸



The most obvious sensory feature of all living snakes is that they have two olfactory systems. In one, external nostrils lead to nasal cavities containing sensory cells with cilia, embedded in a tissue containing glands. The other consists of cells without cilia, in a tissue without glands or mucus.

housed in a pair of dome-shaped structures on either side of the nasal septum. Access to this second system is restricted to a pair of tiny pits in the roof of the mouth, leading to ducts that pass through the bony palate.

The first system is the main olfactory apparatus, often simply known as the organ of smell, though neither of those descriptions is totally accurate. It is not the only organ, nor even necessarily the main one, involved in smell. The second is Jacobson's Organ, comprising a rival chemical sense system that is becoming the focus of very active research and debate, much of it based on one common little snail that has been studied in the field by David Crews and his colleagues at the University of Texas.³⁷

Garter snakes are the most widely distributed reptiles in North America. They can be found at all altitudes, ranging from coast to coast and from Canada all the way south to Costa Rica. They are slender, graceful snakes, seldom more than sixty centimetres long, marked with dark spots and longitudinal red stripes, giving them some resemblance to those fancy coloured garters that once supported every gentleman's socks. But their appeal to biologists in the last two decades is more sensory than sartorial.

Plains garter snakes in cool areas have the habit of gathering, ten thousand at a time, in dens established in underground caverns where they spend the long winters in hibernation. At these times their blood becomes as thick as mayonnaise, and they barely move for up to six months. But in May, as soon as the outside temperature reaches 25°C, dormancy ends and the tangle of bodies stirs and turns into a writhing mass that flows out of the den.

First the males emerge en masse and wait near the entrance, sunning themselves, showing no interest in food or drink. Then the slightly larger females come out, one at a time, to find themselves heavily outnumbered and soon entangled in a mating ball of perhaps a hundred hopeful suitors. Fifteen minutes later, carrying a load of sperm in her oviducts, each solitary female sets off on a migration to summer feeding grounds, where she will restore her body fats and give birth to up to thirty live young garters in the autumn. And by late September, she and thousands of her kind gather once again in the familiar scent of some shelter or hibernaculum.³⁶

This busy cycle of mating, migration, feeding, gestating and returning to hibernation, spans little more than the three summer months and presents a number of zoological problems. Some are easily resolved. The sperm each female receives in spring is stored in her oviduct for up to eight weeks, until her follicles are ready to be fertilized in midsummer. The male's reproductive organs also build up post-nuptially, expanding rapidly during the summer, when the living is easy, and he goes into hibernation packed with sperm, ready for the following spring, when the population is concentrated once more and mating is most likely to succeed. Other questions raised by the behaviour of garter snakes took longer to answer.



John Kubie and Mimi Halpern at the State University of New York have spent twenty years setting up a series of eloquent experiments designed to find out exactly how garter snakes feed and communicate.¹⁰⁶ They began with the common observation that snakes follow odour trails to locate their prey. Newborn young snakes of several species have been found to follow the scent of the usual prey of their species without any experience or instruction. Their ability and willingness to do

seems to be under genetic control. And when exposed to such a scent, their immediate response is to put their heads down close to the ground, flick their tongues out to actually touch the trace, and to go on doing so more and more rapidly as the stimulus grows in strength.

Kubie and Halpern set out first to establish whether a snake in such a situation uses its nose or its mouth, its olfactory epithelium or its Jacobson's Organ. They trained plains garter snakes to follow an extract-of-earthworm trail through a maze ending with the reward of an actual worm. Then they cut the nerves leading from Jacobson's Organ to the brain of some of their trainees, and found that the snakes failed all the tracking tests dismally. Their ability to follow a scent was totally disabled, while control snakes that went through the same surgical procedure, but without having the nerves cut, performed as well as they had before the operation.¹⁰⁸

In a second experiment, the same researchers severed the nerves from the olfactory sense organ in the garter snake's nose, and found that this operation had absolutely no effect. These snakes followed the trail and fed as successfully as they had before the surgery, and there was no sign of any ill effect or compensation for the loss of the nasal system.

Garter snakes without their noses carry on feeding as though nothing has changed. It seems clear that snakes can follow and find their prey without their nasal apparatus, but not without the Jacobson's Organ.



While searching for a scent, most snakes are exploratory, moving slowly, swinging their heads from side to side, taking the long view, flicking their tongues out only once in a while. But once a scent has been found, the tempo changes. The snake then moves more quickly, keeping its head close to the ground, touching the surface with its tongue on almost every quick flick. There is a perceptible general change from one mode to another, a shift perhaps from reliance on the nose and smell, to the way things 'taste'.

This shift may also represent a move from volatile scents that blow by to heavier non-volatile scents, the sensing of which depends on actual contact. It is even possible that Jacobson's Organ may have evolved specifically to deal with the sort of large molecules and heavy odours that the nose cannot handle. This is an important idea. It suggests that smell operates at two levels, that it involves two parallel systems with different functions, different receptor systems and different sites in the brain. There is certainly a growing body of neurological evidence to support such a dichotomy.¹⁵³

In all vertebrates so far studied, the olfactory nerves that run from the nose to the brain go to the main bundles in the olfactory bulbs, while those that leave Jacobson's Organ travel instead to the accessory olfactory bulbs. The fact that information collected by Jacobson's Organ in the garter snake does go to the accessory bulbs, has been nicely demonstrated by attaching electrodes to its head. Every time the tongue is flicked at a trail containing prey scent, an electrical charge can be recorded in the bulbs.¹²⁴

If the main bulb is the 'nose' brain, then the accessory structure, in snakes at least, is a sort of 'face' brain, collecting information that lies somewhere between taste and smell. Beyond the olfactory bulb, nose news goes to the olfactory cortex for assessment; while face feelings move to another neural swelling called the *nucleus sphenicus*, about which we know very little. It seems, however, to be analogous to that part of the mammalian brain in which old impulses may be integrated with mo

recent experience.

In this light, Jacobson's Organ begins to look like an unconscious partner to the nose. It deals with the hypothalamus rather than the more modern thalamus. It is in touch with what neurophysiologist Paul Maclean at the National Institute of Mental Health has called the 'reptilian brain', rather than the 'mammalian brain'.¹¹⁷

Jacobson is the name of the brain's olfactory autopilot.



Reptiles have relatively simple brains. In most of them Jacobson's Organ appears to provide all the information a cold-blooded animal needs to go about the daily business of finding its way about and feeding. The organ also seems to play a vital role in successful mating.¹⁰⁷ In the orgies of spring, male snakes approach an emerging female and explore her with tongue flicks before rubbing their lower jaws all along her back and sides in fervent courtship. Something they find there excites them, despite the fact that the skin of garter snakes has no known glands. And as soon as one of the male snakes succeeds in mating, the other suitors immediately disperse and leave the pair to themselves. None of this happens for snakes without working Jacobson's Organs.

Careful research on intact animals has shown that the male interest is sparked by a fatty substance that females produce as a precursor to egg yolk. This substance seeps from the bloodstream into the skin, and is released from gaps between the scales that open when females breathe deeply during courtship. And the substance that switches off the interest of rival males turns out to be produced by the kidneys of the mating male and to be abundant in the gelatinous plug he leaves in her cloaca. This not only acts as a mechanical obstruction to further mating, but it makes the mated female positively unattractive to other males, even rendering impotent those who happen to come into close contact with her.⁷¹

Mimi Halpern and John Kubie conclude that garter snakes 'depend on a functional vomeronasal system, but not on a functional main olfactory system'.⁷² The simple fact is that no snake behavior has yet been discovered which depends in any critical way on the nose.



This is a startling finding. No naturalist has ever doubted that snakes and lizards have a sense of smell. You only have to watch one explore its surroundings, flicking its tongue out to test the ground ahead, speeding up the response as it encounters anything of interest, to be certain that this is an olfactory process. Western whiptail lizards shoot their tongues out 700 times an hour, which represents a serious expenditure of energy – something not to do without good reason.¹⁷³ Smell is reason enough, and the fork-tipped tongues with matching pits in the palate are clear evidence of an oral route to chemical sensation. But none of us guessed that this was the main organ of smell, that the nose didn't really matter any more.

It looks as though ancestral reptiles were faced with a choice. On emerging from the water, they already had two-chambered noses. They also had good tongues. And as far as chemical sensitivity concerned, evolution seems to have been equivocal. The nasal route was followed, up to a point. But for ground-living species at least, the existence of a highly elastic tongue provided an attractive alternative, and soon hijacked the rival bristle-cells in their nasal pouch, and re-routed their ducts to the mouth.

Today there is a clear division of olfactory solutions among reptiles. Aquatic turtles stuck with the simple amphibian solution. Land tortoises have slightly larger and better developed noses, but also show some development of Jacobson's Organ. And ground-living snakes and lizards have gone all the way with Jacobson, to the apparent exclusion of the nose. Crocodiles are complex, showing both systems at an equivalent level of development, as befits a group that spent time on land before becoming secondarily aquatic.

But the most interesting adaptations show up in tree-living snakes and lizards. Up off the ground, smell becomes less useful, and heavy odours and most contact scents disappear altogether, and with them the need for Jacobson's Organ. Chameleons don't have one. And neither, it seems, do birds. So why do we?

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