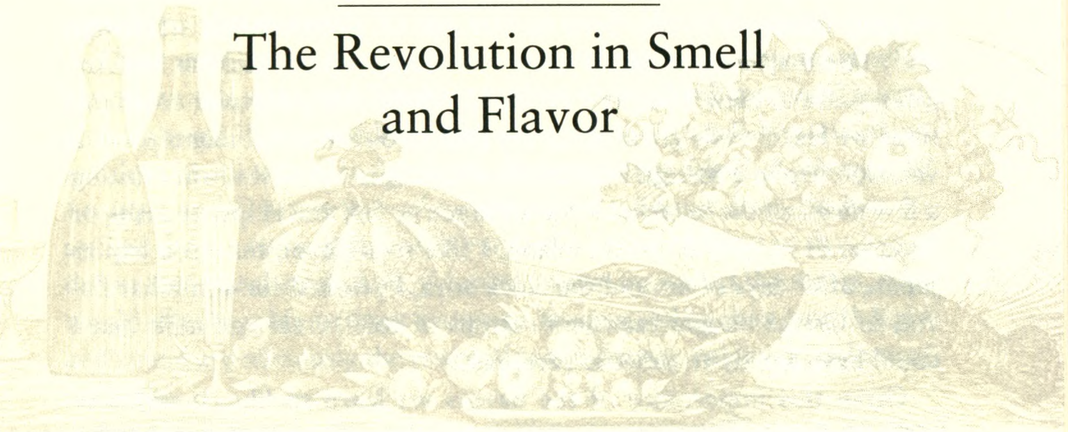
CHAPTER ONE

The Revolution in Smell and Flavor



I met a man from Denmark who had been to Disney World in Florida for a week with his friends.

"How did it go?" I asked. "Did you enjoy American culture?"

"Oh yes," he said. "We had a great time."

My wife is Danish, and I know how much a Dane loves food, so I kidded him by asking, "Did you enjoy eating hamburgers and hot dogs every day?"

"We never touched them," he said.

"What in the world did you live off?" I asked.

"We brought with us a week's supply of *rugbrod* [Danish pumpernickel] and Danish salami and Danish cheese. We even had some smoked eel."

A week's supply of that stuff would have weighed a ton. I know; I've lugged suitcases of *rugbrod* across the Atlantic myself when returning from trips to the Old Country. The deep dark aroma and bouncy chewiness of Danish *rugbrod* is unique. So is a bite of salty, meaty Danish salami, as well as the familiar flavor of Havarti cheese with dill. For me they're a part of my adopted identity when I'm in Denmark. But for my Danish friends they were their native identity.

This story recognizes the old saying "Patriotism is a longing for the food of our homeland." It expresses a loyalty to our home country based on the flavors of the food we were brought up on. When athletes in the Olympics play for the glory of their country, they also in a way play for the flavors of their country's foods. Even in our age of globalization, when our daily fare may include dishes from other lands—think sushi in Los Angeles, pasta in New York, or "McDo" in Paris—the particular combinations we learn while growing up are part of our national identity. On a vacation trip in a foreign country, how strong is our desire, after tasting a few meals of the local food, for a burger, or fish and chips, or sushi, or lasagna, or . . . you fill in the blank. I like soya flavor, but on a trip to Japan, after days of around-the-clock soya, I yearned for a familiar flavor, so Grethe bought me small cartons of cold cereal and milk that I could have for my traditional breakfast.

Given this importance of the flavors we learn to like, it seems to me remarkable, and unfortunate, that most people are unaware that the flavors are due mostly to the sense of smell and that they arise largely from smells we detect when we are breathing out with food in our mouths. Few people know how modern research shows that an odor sets up patterns of activity—"smell images" in our brains—that are the main basis for our perception of flavors. These smell images are hidden factors that determine most of the pleasure we get from eating, and they share the blame for the problems we incur when eating foods that are not good for us. If we can understand better the central role that smell plays, we can understand better how to reduce the problems and increase the joy.

To appreciate the importance of retronasal smell in our lives, let's step back and look at how far we've come in changing ideas that go back to the ancient Greeks.

Most people regard the sense of smell as not very important. The legacy of thinking of smell in this way began with Aristotle. In discussing the senses in *De Anima* (*On the Soul*), he observed that "our sense of smell is inferior to that of all other living creatures, and also inferior to all the other senses we possess."

If you're laboring under this misapprehension 2,500 years later, you're not the only one. Like almost everyone else, you probably enjoy pleasant scents, such as attractive perfumes, fragrant flowers, and a steak barbecuing on the grill, and you do not like unpleasant smells, such as body or bathroom odors and polluted air. And that is about the limit of how much regard you give to smell.

These impressions seem minor compared with the important roles played by our sight and hearing. Against these, smell can seem trivial, although not if you suddenly lose your sense of smell because of an accident or infection. In her book *Remembering Smell: A Memoir of Losing—and Discovering—the Primal Sense*, Bonnie Blodgett has described the devastating loss of flavor that may occur. Most of that loss is due to retronasal smell. Still, if forced to give up one of the senses, who would choose a life without vision or hearing rather than smell? Sight and sound are obviously the essential senses for normal living and use of language.

But this is putting the question in the wrong way. What are the factors that shape our daily behavior? Which inputs to our brains are the motivating forces that determine the quality of our daily lives and that influence the decisions we make about health, diet, mates, and social relations? If we stick with only our obvious sensations, we miss the deeper factors. Among them, smell plays powerful but hidden roles.

As discussed in the Introduction, the new evidence regarding these roles for smell comes from work in many fields. Taken together, all these studies reflect how the sense of smell and associated flavor engage an astounding extent of the human brain. This work is not only intriguing to the general public, but involves profound insights into our biological nature. Many research workers are realizing that the sense of smell is ripe for investigation as one of the most exciting frontiers in the brain. They are intrigued that this system may hold the key to unlocking many of the secrets of our body. This was already realized decades ago by the physician and essayist Lewis Thomas: "I should think we might fairly gauge the future of biological science, centuries ahead, by estimating the time it will take to reach a complete, comprehensive understanding of odor. It may not seem a profound enough problem to dominate all the life sciences, but it contains, piece by piece all the mysteries."

One of those mysteries is how the brain uses smell to create flavor.

Current studies are already revealing capabilities of human smell that go far beyond the traditional view. Rather than being weak and vestigial, human smell appears to be quite powerful. Some have even suggested that humans and their primate relatives are "supersmellers" among animals. It is time, therefore, for a new appreciation of this much maligned and neglected sense. The aim of this book is to show how the real power of human smell lies in its key role in human flavor.

Flavor as a Force in Human History

Despite the dim view that Aristotle took of the sense of smell, this sense, through its dominant role in flavor, had its revenge by shaping the course of world empires during human history. Eric Schlosser, in *Fast Food Nation: The Dark Side of the All-American Meal*, was very clear about the dominant role of smell in flavor: "'[F]lavor' is primarily the smell of gases being released by the chemicals you've just put in your mouth." And, he was also clear about the spell that flavor exerts over humans:

> The human craving for flavor has been a largely unacknowledged and unexamined force in history. Royal empires have been built, unexplored lands have been traversed, great religions and philosophies have been forever changed by the spice trade. In 1492 Columbus set sail to find seasoning. Today the influence of flavor in the world marketplace is no less decisive. The rise and fall of corporate empires—of soft drink companies, snack food companies, and fast food chains—is frequently determined by how their products taste.

Thus not only is flavor not recognized for the force it has been in human history, but smell has not been recognized for the dominant part it played. This despite the fact that flavorful herbs and spices were essential to Roman cuisine more than 2,000 years ago. As the quotation indicates, the quest for new flavors and aromas was one of the driving forces behind long-distance travel and the opening of trade routes. It is not widely appreciated that a millennium before Marco Polo "discovered" China, the spice trade of the Roman Empire stretched from the Mediterranean to China and the South Pacific, delivering to southern European tables delightful flavors and aromas to enliven their daily fare. The voyage of Christopher Columbus was not embarked on to prove that the world was round, but to find a more direct route to the sources of spices because of their flavors.

The voyagers who followed in the sixteenth and seventeenth centuries were seeking not just gold, but also control of spice trade and production. The atrocities committed over several centuries in the desperate attempts to control those sources are among the worst of any time. On the positive side, the case has been made that the organization of the great sea lanes for shipping tea and spices by fast clippers from Indonesia in the eighteenth and nineteenth centuries laid the basis for the British Empire, followed by the emergence of world powers and their economies in the nineteenth and twentieth centuries. We have inherited and adapted those global trade routes, from controlling the trade in tea and spices to controlling the sources of oil and spreading global capitalism in the past century.

There has thus been a contrast between the received wisdom that smell and flavor are of minor importance and the realities of the high value that humans put on them in their daily lives, as well as of the consequent economic forces that have driven human societies.

This book will provide new insights into why the smell and flavor of the foods we eat have such high value in human affairs. There have been some key steps along the way to our present understanding.

The First "Physiology of Flavor"

It was not until Jean Anthelme Brillat-Savarin that smell began to be appreciated, particularly for its role in taste, equivalent to *flavor*. Born in 1755, Brillat-Savarin was a lawyer and then a mayor. During the French Revolution, he was forced to flee France, spending two years in the United States. He then returned after the defeat of the Jacobins in 1796 to become a judge under Napoleon. His new position gave him plenty of free time to spend on writing about his main passion, eating well, otherwise known as *being a gourmand*. Shortly before his death in 1826, he published his reflections as a book whose full title is *Physiologie du goût; Ou, meditations de gastronomie transcendante: ouvrage théorique, historique et a l'ordre du jour*, Dédiée aux gastronomes parisiens, par un Professeur, Membre de Sociétés Litteraires et Savants (*The Physiology of*

Taste; Or, Meditations on Transcendental Gastronomy: Theoretical, Historical, and Practical Work, Dedicated to Parisian Gastronomes, by a Professor, Member of Literary and Scientific Societies).

As implied by the elaborate title, the book was not strictly a scientific treatise. However, in its thoroughness in considering from many angles the pleasures of eating, and in one delightful anecdote after another illustrating how human society is dependent on the social interactions that take place while eating meals together, Brillat-Savarin's book became a classic. Part of this was due to his way with words; from him came such famous observations (in M. F. K. Fisher's well-known translation) as

> Tell me what you eat, and I will tell you what you are.

> The discovery of a new dish does more for human happiness than the discovery of a new star.

Of most interest for our purpose was his passion for revealing the physiological and psychological processes that are responsible for the perception of taste. The *taste* in his title refers not specifically to the sense of taste, but to the combined perception of taste and smell, which we refer to as flavor. Brillat-Savarin acknowledged the dominant role of smell in taste and flavor:

> I must concede all rights to the sense of smell, and must recognize the important services which it renders to us in our appreciation of tastes; for, among the authors whose books I have read I have found not one who seems to me to have paid it full and complete justice.
>
> For myself, I am not only convinced that there is no full act of tasting without the participation of the sense of smell, but I am also tempted to believe that smell and taste form a single sense.

Brillat-Savarin thus identified clearly the important role of smell in taste, but unfortunately didn't differentiate clearly between taste as a single sense and "taste" as a combined sense of smell and taste. That is why we will call the combined sense "flavor." The close relation between smell and taste has obscured the dominant role of smell. A main aim of this book is to disentangle them.

Brillat-Savarin recognized that smell's contribution to taste could come only from the smell arising at the back of the mouth and being swept into the nasal chamber by what we now call the *retronasal route.* He did not specify this route, however, or that it could be activated only by breathing out. He did declare in a colorful phrase that the back of the throat was the "chimney" of taste.

Recognition that smell's contribution to flavor came from retronasal smell and breathing out was slow in coming. In his book *What the Nose Knows*, Avery Gilbert mentions Henry T. Finck, an American philosopher who in 1886 published the essay "The Gastronomic Value of Odours" in the magazine *Contemporary Review*, in which he described how swallowing pushes the aromas from the food in our mouths into the air in the back of our throats and how exhalation carries it through the nasal chambers as "our second way of smelling." However, most interest in smell through the nineteenth and into the twentieth century was focused on trying to break down inhaled odors into a few basic categories, in analogy with the basic colors in vision. Odors, however, have been too numerous and difficult to categorize for this to be a practical venture.

The role of retronasal smell in flavor was finally put on the map by Paul Rozin, a psychologist at the University of Pennsylvania, in an article in 1982. As he phrased it, we need to recognize that smell is not a single sense but rather a dual sense, comprising orthonasal (breathing in) and retronasal (breathing out) senses. He devised experiments to show that the perception of the same odor is actually different depending on which sense is being used. Subjects trained to recognize smells by sniffing them had difficulty recognizing them when they were introduced at the back of the mouth.

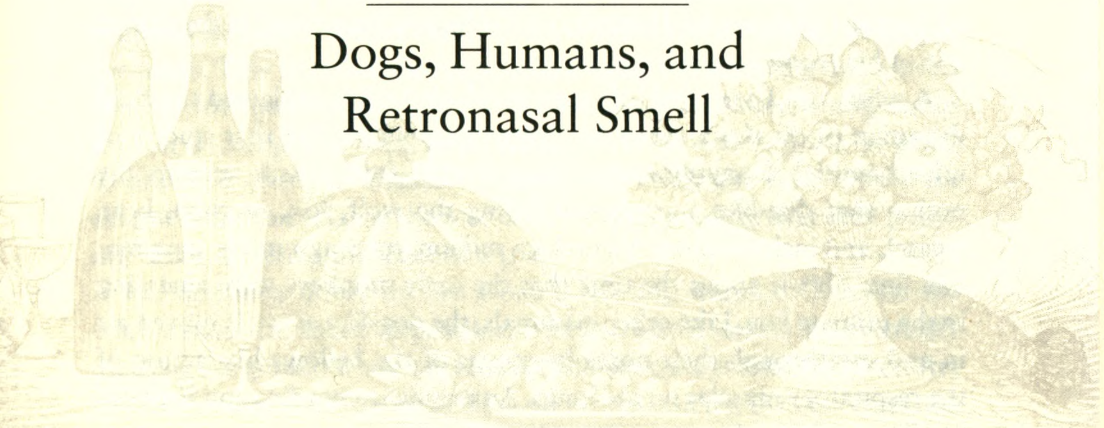
Orthonasal smell is the one we commonly think of, and for good reason. It mediates a tremendous range of stimuli, evoking our sensations of the aromas of food, especially cooking food; the bouquets of wines; the fragrances of flowers; the scents of perfumes; the mysteries of incense. It also mediates the social odors: sweet scents of a loved one's breath; body excretions in sweat; volatile compounds in urine and feces; pheromone-type molecules that send signals about gender, puberty, territory, and aggression. And there are alarm signals such as for fire or gas. With these functions, all of them obvious when we detect them during normal breathing or when sniffing the air, no wonder orthonasal smell has been the main type of smell recognized over the centuries.

Retronasal smell contrasts in so many ways with orthonasal smell that it can truly be considered a separate type of smell. To begin with, it arises from inside the mouth; it is the only distance sense that arises inside the body. Second, because it arises inside the mouth, it is always accompanied by stimulation of other senses inside the mouth, mainly taste and touch. Also, because the food is inside the mouth, retronasal smell always is accompanied by movements of the tongue, the jaw muscles, and the cheeks; it is an active sense by comparison with external smell and the other distance senses, vision and hearing. Chewing releases the smell molecules from the food to be carried in the smell-laden air to the nasal chambers to stimulate the smell receptors. And astonishingly, the sense of flavor produced is a mirage; it appears to come from the mouth, where the food is located, but the smell part, of course, arises from the smell pathway. No wonder it has taken so long to begin to realize what an amazing sense retronasal smell is.

Let us take a closer look at how it works.

CHAPTER TWO

Dogs, Humans, and Retronasal Smell



To appreciate how humans are adapted for retronasal smell, it is useful to compare us with one of the acknowledged champions of smell: man's best friend, the dog. To compare the two, it is necessary to understand how each is engineered to serve its functions best. It will be no surprise that the dog's nose is an engineer's dream. But what about the human's? Are we as poor as Aristotle believed? The take-home message is that dogs are adapted primarily for sniffing in smells of the environment, whereas humans are adapted primarily for sensing smell as the main feature of flavor. Thus the dog's nose is engineered mainly for orthonasal smell, and the human nose is engineered mainly for retronasal smell. This is how the human nose fulfills its role as the key player in neurogastronomy.

Fluid Dynamics of Inspired and Expired Odorized Air

Gary Settles is professor of mechanical engineering at Pennsylvania State University. He specializes in the field of fluid dynamics, which concerns itself with the way that air or water act when passing over wings or forced through tubes. This field involves not only understanding and designing efficient wings for airplanes, nozzles for jet blowers, and ventilators for homes, but also how to draw air into devices used to detect trace substances such as explosives that might be present in cargo in container ships and in narcotics in suitcases. The latter interest led him to study how nature does it through the snout of a dog. "The Aerodynamics of Canine Olfaction for Unexploded Ordnance Detection" is the title of one of his recent research projects.

A while ago I attended a lecture in which Settles explained the fluid dynamics of the dog's snout. He began by pointing out that studies of mitochondrial deoxyribonucleic acid (DNA) from fossils support the notion that dog-like animals—including the wolf, fox, raccoon, bear, weasel, and jackal—arose around 50 million years ago in the mammalian line. This is about the time that the early monkeys were emerging in the primate line. Like other mammals, the dog-like animals moved air in and out through their noses by means of the bellows-like action of the respiratory muscles on the lungs. An exquisite coordination between smelling and breathing was thus required.

Breathing in to sample the scent in the air is what everyone knows as *sniffing*, and the dog is beautifully designed for this function. The design begins with the nostrils, technically called the *nares*. If you look directly at your dog's snout, you will see that its nostril opening has a peculiar shape, with a central round opening encircled by membranes called *alar folds* and a curved slit to the side; it has been likened to the form of a comma lying on its side. When a dog sniffs the ground, it draws in air through the central opening by muscles of the alar folds that enlarge the opening, but it breathes out by contracting other muscles that direct the outflow through the slits to the side. The singular advantage of this arrangement is that the air breathed out does not interfere with the odorized air that is being breathed in. This is particularly important as the tip of the nose gets closer to the ground. Here is how Settles describes it:

> The expired air jets . . . are vectored by the shape of the "nozzle" formed by the alar fold and the flared nostril wings. . . . Thus the external naris acts as a variable-geometry flow diverter. This has three advantages: (1) it avoids distributing the scent source by expiring back toward it; (2) it stirs up particles that may be subsequently inspired and sensed as part of the olfactory process; and (3) it entrains the surrounding air into the vectored expired jets . . . thus creating an air current toward the naris from points rostral [in front of] to it. This "ejector effect" . . . is an aid to olfaction; "jet-assisted olfaction," in other words.

It can be shown that when a dog sniffs the surrounding air, the sniff draws in air from a sphere about 4 inches (10 cm) around the opening of the nares. This is called the *reach* of the nose, for detecting odor molecules at low concentration in the surrounding air. When a dog senses the air, it changes to long inspirations, with its mouth open, in order to draw air over the olfactory membranes inside the nose slowly for careful detection. This is the way smell is used by dogs that are "pointing" after detecting the scent of a prey.

For detecting odors on the ground, the dog wants to decrease the reach distance as much as possible, which is why it has its nose virtually touching the ground when it is keen on following a scent there. The shorter distance makes the lines of air flow denser, enhancing the concentration of the inspired odor molecules. Settles has carefully charted the lines of air flow, converging on the nares inlets in the center and diverging from the slits to the side; it is a beautifully designed system for tracking scents. It enhances the high acuity of smell the way that the central fovea of the eye enhances high acuity of vision.

Settles goes further to analyze the way a dog uses this system in concert with its vision to inspect a new sense source. The dog first gets its nostrils down on the ground and sniffs its way to the scent source, following the increasing concentration until it reaches a maximum and begins to decline. It continues to sniff over and around the source; this action also enables it to inspect the source visually. The expired air plays its own role, with the lateral jets disturbing the source area enough to raise small clouds of particles that carry more odorous substances to the nares for inhaling.

Note that the dog's nose is as much a motor as a sensory organ, carrying out several motor functions: (1) acting on the environment to dislodge odors from their carriers, (2) adjusting the proximity of the nares to enhance the concentration of odors from odor sources, and (3) separating the inspiration from the expiration of odorous air to achieve the most effective balance.

The kinds of odor that a dog smells are very much a reflection of the position of this detector apparatus. In the dog, as in most terrestrial animals, standing on four legs means that the head is not far from the ground, so putting the nostrils to the ground is a natural movement, even in larger animals. The four legs also mean that the head and the hips are about level with each other. This has immediate consequences for social interactions between members of the species, because it means that when two individuals greet each other their odor detectors are not only at the same level for sniffing each other's head ends but also at the same level of each other's rear ends. Thus it is natural for dogs to leave olfactory calling cards at both ends. The same principles of maximizing odor concentration by minimizing distance apply, accounting for the intimate interactions of dogs greeting each other. It is interesting that by this means dogs acquaint themselves not only with mouth odors, signaling what has been consumed, but also with fecal and urine odors, signaling what has been digested and gone out. Through these odors they also learn of hormonal status and sexual receptivity.

So far I have discussed only the nostrils. What happens inside the snout?

Inside the Snout

Nearly all animals have some kind of a snout extending from between the eyes, containing the mouth and a cavity lined with the sensory cells for smell. In fish, frogs, and reptiles this is a simple cavity, with the odor molecules coming in through the water in the case of fish and both water and air in the case of amphibians and reptiles, directly onto the sensory cells. A long nerve tract arising from the receptor cells connects the sac to the olfactory bulb that connects to the brain. By the way, the long snout of the alligator is not long because of a long nasal cavity inside, but because the upper jaw carries a long row of teeth for crunching its prey.

When mammals arose over 200 million years ago, they are believed to have been small animals, like present-day mice or rats. Their snouts were one of their most essential adaptations to terrestrial life. In contrast to those of alligators, these were true snouts, containing an extended nasal cavity all the way out to the tip.

In a modern mammal such as the dog, the olfactory receptors are confined to the back of the nasal cavity, usually lining a series of bony convolutions in order to increase the extent of the sensory sheet (figure 2.1). In between the nostrils and the receptors is a remarkable additional organ, a kind of a cartridge even more highly convoluted and covered by

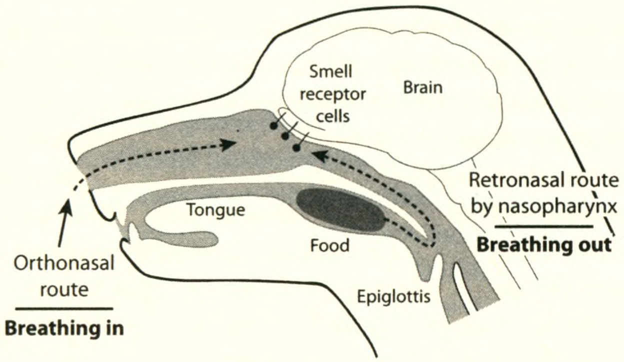


FIGURE 2.1 The head of a dog
The arrows show the pathways for sniffing smells by the orthonasal route and for sensing smells from the mouth by the retronasal route. Note the long length of the retronasal route from the mouth to the smell receptor cells.

respiratory membrane. In technical language, these convolutions are formed by the ethmo- and maxillo-turbinal bones.

Victor Negus, a British specialist in ear, nose, and throat diseases, spent many years writing what is now the classical treatise on the structure of the snout in different animals in order to compare and contrast it with the human nose. He showed that the cartridge serves as a kind of air filter or air conditioning system, with three functions: warming, moisturizing, and cleaning. *Warming* the inhaled air brings it into equilibrium with the temperature of the air in the respiratory tract. *Moisturizing* the air brings it into equilibrium with the moist air in the respiratory tract. *Cleaning* the air removes inhaled materials, such as bacteria, smoke, and particulate matter. Negus examined many different kinds of mammals and found the filtering apparatus to be present to a greater or lesser extent in all of them, with one notable exception: primates, including humans.

Just as the muscles of the nostril manipulate the inhalation of air, so are they coordinated to direct the air streams into the snout. One direction is through the middle of the air-conditioning cartridge during quiet breathing. The other is a redirection more to the side of the cartridge so that air more quickly reaches the olfactory sensory sheet, called the *olfactory epithelium*, at the back of the nasal cavity, where active sensing occurs.

When a dog is actively sniffing an object, the rate of sniffing increases dramatically, from one or two respirations a second to as many as six to eight a second (small rodents like mice and rats can go even higher, to ten to twelve a second). This is much faster than a human can sniff; you can test yourself and see that the limit is about four a second.

In contrast to these adaptations for enhancing orthonasal smell, the diagram shows that the pathway for retronasal smell, from the back of the mouth through the nasopharynx to the nasal cavity, is long and relatively narrow. The dog thus appears to be preferentially adapted for orthonasal smell. What about humans?

Evolution of the Human Nose

The evolution of humans involved lifting away from the noxious ground environment as they adopted a bipedal posture. This reduced exposure of sensory cells to infections. The complicated air-cleaning apparatus thus came under decreased adaptive pressure, reducing the loss of absorbed odor molecules. The large extent of olfactory receptor cell epithelium and abundant numbers of olfactory receptors present in most mammals would have come under reduced adaptive pressure and were accordingly reduced in proportion. The result was the elimination of a snout and nearly all the air cleaning apparatus, leaving our relatively modest outward nose and inside nasal cavity.

Although this explanation seems logical, arguments from evolution are notoriously speculative. Another perspective on the evolution of the human nose is that it had less to do with the reduction of the sense of smell and more to do with the reduction of the maxilla and mandible as primates and early humans adopted a diet with less roughage.

These developments meant that the snout could be reduced in dimensions and complexity without compromising the absolute amounts of odorized air reaching the olfactory epithelium. A widely accepted scenario is that as the snout lessened in size it allowed the eyes to come forward and lie closer together to promote more effective stereoscopic vision. This supposedly allowed human evolution to be dominated by vision at the expense of smell, providing the popular explanation for how we ended up with a weak sense of smell. However, the recognition of the importance of retronasal smell for humans makes this argument irrelevant. In our new view, the reduction in orthonasal olfaction is not the key; the key is, rather, the relation of the nasal cavity to the back of the mouth, which served to enhance retronasal smell in humans.

Comparing the dog and the human shows how dramatically they differ in this respect. The dog is characterized by its elaborate cleaning apparatus for orthonasal smell, and by the long tube, the nasopharynx, connecting its nasal cavity to its pharynx at the back of the mouth for retronasal smell. The human, by contrast, is characterized by the short distance for orthonasal smell and, most importantly, the short nasopharynx for retronasal smell as well (figure 2.2). The latter is the key passageway for enabling odors released from food in the mouth to reach the smell receptors in the nasal cavity. It provides direct evidence that the human is adapted for much more effective retronasal smell than the dog and other mammals.

The retronasal route to the smell organ begins with the food or drink that comes into the mouth. There the food is moved about by the tongue as it is chewed (masticated). It is said that only the human can roll its tongue, an ability that may impart special capabilities in manipulating

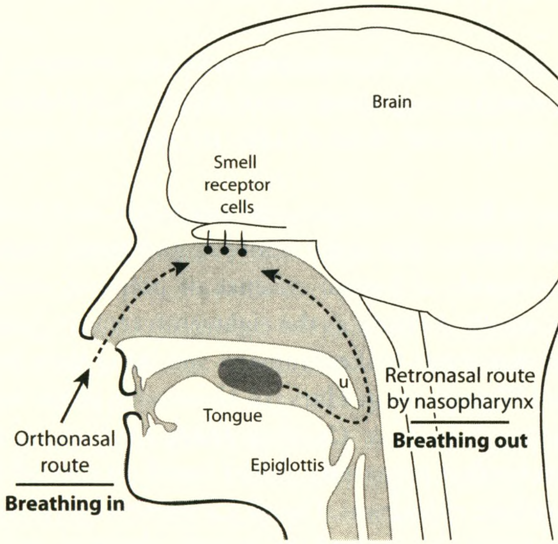


FIGURE 2.2 The head of a human
The arrows show the pathways in humans for sniffing smells by the orthonasal route and for sensing smells from the mouth by the retronasal route. Note that the pathways are relatively direct compared with those of dogs.

food as it is chewed and sensed. At the same time, the taste is sampled by the taste buds on the tongue and the back of the mouth and into the pharynx. When the chewer exhales, air is forced from the lungs up through the open epiglottis into the nasopharynx at the back of the mouth. There the air absorbs odors from the food that coats the walls and back of the tongue and that have volatilized from the warm, moist, masticated mass. Because the mouth is closed, the odor-laden air is pushed into the back of the nasal chamber and out through the nostrils, sending eddy currents within the nasal chamber up to the olfactory sensory neurons to stimulate them.

How might retronasal smell in the human compare with that in the dog? I know of no studies of how effective the passage of air is from the back of the dog's mouth through this long, narrow nasopharynx to the olfactory epithelium, so one can only speculate that the passage is less effective than in the human, where the distance is relatively short and the opening is relatively large. On this basis, one can hypothesize that the human nasopharynx is adapted for enhancing retronasal smell.

There are several reasons why retronasal smell may be especially important for humans, perhaps uniquely so:

1. With the adoption of bipedalism, ancestral humans became increasingly wide-ranging, migrating out of Africa to populate the world, concomitantly diversifying their dietary staples and their retronasal smells.

2. The advent of fire, at least 400,000 years ago, and possibly much earlier, made the human diet more odorous and tasty. From this time one can begin to speak of human cuisines of prepared foods, with all their diversity of smells. As early as the eighteenth century, James Boswell was speculating that what makes humans special is their invention of cooking. Richard Wrangham at Harvard University, in his work and recent book *Catching Fire: How Cooking Made Us Human*, has argued on modern evidence that prepared cuisines based on cooked foods are a defining characteristic of humans. Daniel Lieberman has provided much new insight into how this involved the mouth, pharynx, and retronasal route in his recent book *The Evolution of the Human Head* (for more on this, see chapter 17).

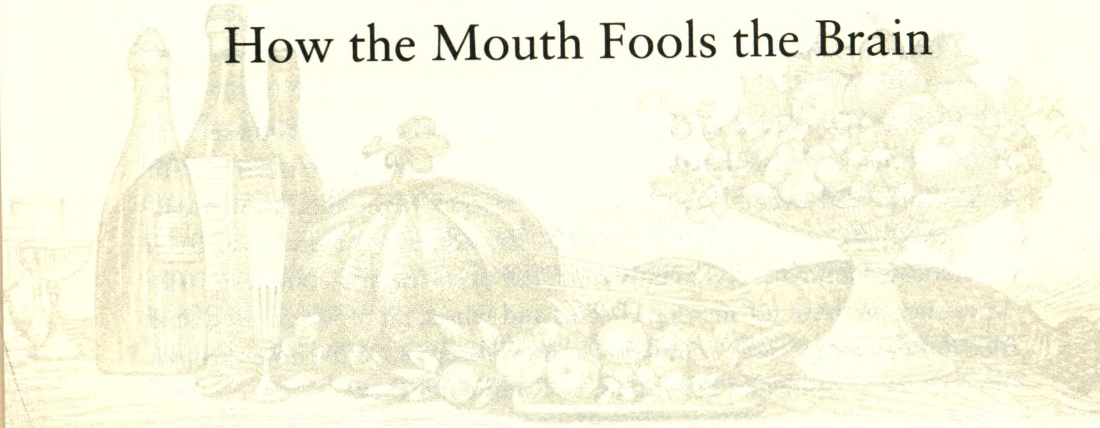
3. Added to the cooked cuisines were fermented foods and liquids, which made foods not only more diversified but also more intense in their tastes, smells, and flavors.

These developments occurred among the early hunter-gatherer human cultures and lasted through the last ice age. With the transition to agricultural and urban cultures around 10,000 years ago, human cuisines expanded and stabilized through the addition of products from domesticated animals, plant cultivation, use of spices, and complex procedures such as those for making cheeses and wines, all of which produced foodstuffs that especially stimulate the smell receptors in the nose through the retronasal route and contribute to complex flavors.

These considerations suggest the hypothesis that the retronasal route for smells has delivered a richer repertoire of flavors in humans than in subhuman primates, dogs, and other mammals. On this basis, I postulate that this system in the human brain played a much more important role in the evolution of early humans than has been realized, as well as a much more important role in our daily lives (including my daily home dinner).

CHAPTER THREE

How the Mouth Fools the Brain



I have claimed that smell is the main component of flavor, and that it is stimulated through the retronasal route. What is the proof?

Psychologists and food scientists answer this question by devising sophisticated methods to introduce food volatiles at the back of the mouth, synchronized with expiration, to show activation of smell responses by the retronasal route. But there is a simpler test, one that is often used by psychologists when visiting schools and giving demonstrations of scientific principles in science class. It's called the *nose-pinch test*, usually done with a piece of candy, but you can use any small, tasty morsel, even a dab of spicy sauce at the dinner table.

The Nose-pinch Test for Retronasal Smell

To perform this test, take the "tasty" bit and, while holding your breath, open your mouth and place the bit on your tongue while pinching your nose so that you can breathe only through your mouth. If you have good control, you can also prevent air from entering your nose by lifting the palate at the back of your mouth while you continue to breathe through your mouth. The requirement by any method is to prevent any air you are breathing out (exhaling) from going through your nose.

With the bit on your tongue, you will be able to identify certain senses. If it is candy you'll be able to detect the sweet taste due to the sugar. You will also know from the sense of touch that the bit is resting on your tongue, and where it is. If it is a morsel of food, your sense of touch will tell you whether it is hard or soft, or maybe hot or cool. If you sense any more than this, you are probably not holding your breath!

Now unpinch your nose, or lower your palate. Immediately you will experience the flavor of the candy or of the meat or other food or spice you may have chosen. The sudden whiff of flavor can be surprising. Almost without realizing it, you will have let the air shoot from the back of your mouth the short distance through the nasopharynx to the smell receptors in the nasal cavity to stimulate your sense of smell. The faintest whiff of outward breathing will produce this result. In fact, the diffusion of the volatile molecules in the air of the nasopharynx will account for much of the sensation.

Flavor Is Mostly Retronasal Smell

This experiment, and others by more scientific methods, tells you several key things about the role of smell in flavor:

1. It is clear that if there is no breathing out, there is no smell or flavor. You can confirm this by breathing in instead of out as soon as you unpinch your nose: there will be no sensation of flavor; it happens only with breathing out. This proves that the smell component of flavor is due exclusively to retronasal smell.

2. The ability to identify the type of flavor, such as lemon or strawberry, is clearly attributable to the sense of smell, which works in conjunction with the sweet taste and the senses of touch.

3. Perception of the retronasal smell is usually fused with the taste and touch so that we are unaware of it as smell. This is why the importance of smell in flavor has gone unrecognized for so long.

4. You have just proved that smell is the major component of flavor. Although sweet is a strong sensation associated with candies and other foods that contain sugar, sugar by itself is sweet and little else. The actual flavor of the candy depends on the sense of smell.

5. Even though by unpinching your nose you proved that the flavor of the candy is due to the smell you sense in your nose, when the smell is fused with the taste and touch of the candy in your mouth it appears to

come from the mouth. Not only is smell not recognized as a part of flavor, the flavor is not even recognized as coming from the nose. Rather, it is perceived as coming from the mouth. The mouth has taken all the credit!

The Mouth Takes All the Credit

Why should this be? Where else do we have a sense that is divided into two and one of them is hidden among other senses? Scientists are only beginning to realize that this is an interesting problem for psychology, for neuroscience in general—and for determining the food we buy and consume.

We do not know the answer, but it will surely involve the fact that when we ingest food, we put it in our mouths. Although we take this simple act for granted, when it is looked at from the perspective of animal behavior it is seen as being symbolically and practically a highly significant behavior. Something is taken from the outside world and inserted into the body. The animal has acquired it as a potential foodstuff—by killing another animal, or consuming some grass, or picking some fruit. The foodstuff looked as though it would be flavorful and nutritious, but it needs to be tested.

The touch system tells us the food is in our mouths; our attention is therefore focused on what is in our mouths as we make an assessment of it. That assessment involves, first, assuring ourselves that this is something we want to take into our bodies. Does it have anything unpleasant about it—a fish bone, a rotten taste? Is it too salty or sour or possess a bitterness that might signal a toxic or poisonous substance? Is it too hot or cold? The list is long. Second, if it passes the aversion test, is it something we like? If so, we lavish even more attention on it, because a desired flavor is one of the greatest of human joys.

Because our attention is on the food in our mouths, our perception follows our attention. It appears that this is what happens to retronasal smell. The attention is on the mouth, and the smell perception, due to the molecules released from the mouth, is merged with the other senses in making the assessment.

Because the smell in the nose is sensed as if it is coming from the mouth, it is a property of the nervous system known as *referred sensation*, which occurs when a sense appears to be in one place but actually arises in another. In this case, the sensation is not only referred to another place, but hidden in the senses from that place.

How to Assess Smell Within Flavor

Does it matter? Assessing smell within flavor gives us new insight into how complicated our sense of smell is. We have seen that smell is actually two senses, one for breathing in and one for breathing out. The one for breathing in is the sense of smell we all recognize as a single sense emanating from our nose. However, the one for breathing out is never recognized as a distinct sense, because it is always fused with two other senses, taste and touch, to form a third sense—flavor, which is referred to another part of the body, the mouth. Retronasal smell is unique among all our senses in these respects. If, as Brillat-Savarin maintained, "Tell me what you eat and I'll tell you what you are" is true, it follows that retronasal smell is the hidden factor that makes us what we are.

From the point of view of flavor, the unique properties of retronasal smell pose new challenges in understanding the flavors of the food we eat. Our nose-pinch test shows that you can explore these challenges yourself to reveal more clearly the contribution of retronasal smell to the flavors of what you are consuming. Separating retronasal smell from overall flavor would seem to be especially of interest to a food scientist or a gourmet cook, who wants to understand the flavor of the dish that is being cooked by analyzing each sensory property and how it arises from the molecular composition of the dish. This is one of the avowed aims of the new field of "molecular gastronomy." I think we can see the beginnings of a close collaboration with neurogastronomy.

Given that retronasal smell is stimulated by the release of smell molecules from our ingested food, one would suppose that we would sense the smell of our food separately from the stimulation of the taste buds on the tongue and the stimulation of touch receptors in the mouth. The nose-pinch test has shown that the smell can be sensed separately only by holding your breath and then releasing it to isolate the smell component of the flavor. Otherwise, the only thing you sense when eating your food is the flavor as a unified sense.

Flavor is thus the unified percept that we strive for in cooking a dish. We try to determine whether it was made this time with too much or too little salt, or enough curry, or was cooked too long or not enough, or any of the dozens of variables possible. Smell has the property of being, in general, "synthetic"; that is, a mixture of several smells makes a new unified smell. It is not "analytic," the way taste is: sweet and sour tastes sweet and sour rather than being a new unified taste.

The synthetic quality of smell challenges us to explain how the smell pathway discriminates its stimulus molecules, so that we can understand its contribution to flavor. I start with an introduction to the basic types of flavor molecules in the foods we eat that activate the sense of retronasal smell.