THE SENSES

They delight, heal, define the boundaries of our world. And they are helping unlock the brain's secrets

To the 19th-century French poet Charles Baudelaire, there was no such thing as a bad smell. What a squeamish, oversensitive bunch he would have deemed the denizens of 20th-century America, where body odors are taboo, strong aromas are immediately suppressed with air freshener, and perfume—long celebrated for its seductive and healing powers—is banned in some places to protect those with multiple chemical sensitivities.

Indeed, in the years since Baudelaire set pen to paper, civilization has played havoc with the natural state of all the human senses, technology providing the ability not only to tame and to mute but also to tease and overstimulate. Artificial fragrances and flavors trick the nose and tongue. Advertisers dazzle the eyes with rapid-fire images. Wailing sirens vie with the beeping of pagers to challenge the ears' ability to cope.

Yet even as we fiddle with the texture and scope of our sensibilities, science is indicating it might behoove us to show them a bit more respect. Growing evidence documents the surprising consequences of depriving or overwhelming the senses. And failing to nurture our natural capabilities, researchers are discovering, can affect health, emotions, even intelligence. Hearing, for example, is intimately connected to emotional circuits: When a nursing infant looks up from the breast, muscles in the middle ear reflexively tighten, readying the child for the pitch of a human voice. The touch of massage can relieve pain and improve concentration. And no matter how we spritz or scrub, every human body produces a natural odor as distinctive as the whorls on the fingertips—an aroma that research is showing to be a critical factor in choosing a sexual partner.

Beyond their capacity to heal and delight, the senses have also opened a window on the workings of the human brain. A flood of studies on smell, sight, hearing, touch and taste in the last two decades have upended most of the theories about how the brain functions. Scientists once believed, for example, that the brain was hard-wired at birth, the trillions of connections that made up its neural circuits genetically predetermined. But a huge proportion of neurons in a newborn infant's brain, it turns out, require input from the senses in order to hook up to one another properly.

Similarly, scientific theory until recently held that the sense organs did the lion's share of processing information about the world: The eye detected movement; the nose recognized smells. But researchers now know that ears, eyes and fingers are only way stations, transmitting signals that are then processed centrally. "The nose doesn't smell—the brain does," says Richard Axel, a molecular biologist at Columbia University. Each of our senses shatters experience into fragments, parsing the world like so many nouns and verbs, then leaving the brain to put the pieces back together and make sense of it all.

In labs across the country, researchers are drafting a picture of the senses that promises not only to unravel the mysterious tangle of nerves in the brain but also to offer reasons to revel in sensuous experience. Cradling a baby not only feels marvelous, scientists are finding, but is absolutely vital to a newborn's emotional and cognitive development. And the results of this research are beginning to translate into practical help for people whose senses are impaired: Researchers in Boston last year unveiled a tiny electronic device called a retinal chip that one day may restore sight to people blinded after childhood. Gradually, this new science of the senses is redefining what it means to be a feeling and thinking human being. One day it may lead to an understanding of consciousness itself.

SIGHT

Seeing is believing, because vision is the body's top intelligence gatherer, at least by the brain's reckoning. A full quarter of the cerebral cortex, the brain's crinkled top layer, is devoted to sight, according to a new estimate by neuroscientist David Van Essen of Washington University in St. Louis—almost certainly more than is devoted to any other sense.

SIGHT

Cells in the retina of the eye are so sensitive they can respond to a single photon, or particle of light.

It seems fitting, then, that vision has offered scientists their most powerful insights on the brain's structure and operations. Research on sight "has been absolutely fundamental" for understanding the brain, says neurobiologist Semir Zeki of University College in London, in part because the visual system is easier to study than the other senses. The first clues to the workings of the visual system emerged in the 1950s, when Johns Hopkins neurobiologists David Hubel and Torsten Wiesel conducted a series of Nobel Prize–winning experiments. Using hair-thin electrodes implanted in a cat's brain, they recorded the firing of single neurons in the area where vision is processed. When the animal was looking at a diagonal bar of light, one neuron fired. When the bar was at a slightly different angle, a different nerve cell responded.

Hubel and Wiesel's discovery led to a revolutionary idea: While we are perceiving a unified scene, the brain is dissecting the view into many parts, each of which triggers a different set of neurons, called a visual map. One map responds to color and form, another only to motion. There are at least five such maps in the visual system alone, and recent work is showing that other senses are similarly encoded in the brain. In an auditory map, for example, the two sets of neurons that respond to two similar sounds, such as "go" and "ko," are located near each other, while those resonating with the sound "mo" lie at a distance.

Though we think of sensory abilities as independent, researchers are finding that each sense receives help from the others in apprehending the world. In 1995, psycholinguist Michael Tanenhaus of the University of Rochester videotaped people as they listened to sentences about nearby objects. As they listened, the subjects' eyes flicked to the objects. Those movements—so fast the subjects did not realize they'd shifted their gaze—helped them understand the grammar of the sentences, Tanenhaus found. Obviously, vision isn't required to comprehend grammar. But given the chance, the brain integrates visual cues while processing language.

The brain also does much of the heavy lifting for color vision, so much so that some people with brain damage see the world in shades of gray. But the ability to see colors begins with cells in the back of the eyeball called cones. For decades, scientists thought everyone with normal color vision had the same three types of cone cell—for red, green and blue light—and saw the same hues. New research shows, however, that everybody sees a different palette. Last year, Medical College of Wisconsin researchers Maureen Neitz and her husband, Jay, discovered that people have up to nine genes for cones, indicating there may be many kinds of cones. Already, two red cone subtypes have been found. People with one type see red differently from those with the second. Says Maureen Neitz: "That's why people argue about adjusting the color on the TV set."

HEARING

Hearing is the gateway to language, a uniquely human skill. In a normal child, the ears tune themselves to human sounds soon after birth, cementing the neural connections between language, emotions and intelligence. Even a tiny glitch in the way a child processes sound can unhinge development.

About 7 million American children who have normal hearing and intelligence develop intractable problems with language, reading and writing because they cannot decipher certain parcels of language. Research by Paula Tallal, a Rutgers University neurobiologist, has shown that children with language learning disabilities (LLD) fail to distinguish between the "plosive" consonants, such as *b, t* and *p*. To them, "bug" sounds like "tug" sounds like "pug." The problem, Tallal has long argued, is that for such kids the sounds come too fast. Vowels resonate for 100 milliseconds or more, but plosive consonants last for a mere 40 milliseconds—not long enough for some children to process them. "These children hear the sound. It just isn't transmitted to the brain normally," she says.

Two years ago, Tallal teamed up with Michael Merzenich, a neurobiologist at the University of California–San Francisco, to create a set of computer games that have produced stunning gains in 29 children with LLD. With William Jenkins and Steve Miller, the neurobiologists wrote computer programs that elongated the plosive consonants, making them louder—"like making a yellow highlighter for the brain," says Tallal. After a month of daily three-hour sessions, children who were one to three years behind their peers in language and reading had leaped forward a full two years. The researchers have formed a company, Scientific Learning Corp., that could make their system available to teachers and professionals within a few years. (See their Web site: *http://www.scilearn.com* or call 415-296-1470.)

An inability to hear the sounds of human speech properly also may contribute to autism, a disorder that leaves children unable to relate emotionally to other people. According to University of Maryland psychophysiologist Stephen Porges, many autistic children are listening not to the sounds of human speech but instead to frightening noises. He blames the children's fear on a section of the nervous system that controls facial expressions, speech, visceral feelings and the muscles in the middle ear.

HEARING

At six months, a baby's brain tunes in to the sounds of its native tongue and tunes out other languages.

These muscles, the tiniest in the body, allow the ear to filter sounds, much the way muscles in the eye focus the eyeball on near or distant objects. In autistic children, the neural system that includes the middle ear is lazy. As a result, these children attend not to the pitch of the human voice but instead to sounds that are much lower: the rumble of traffic, the growl of a vacuum cleaner. In the deep evolutionary past, such noises signaled danger. Porges contends that autistic children feel too anxious to interact emotionally, and the neural

system controlling many emotional responses fails to develop.

Porges says that exercising the neural system may help autistic kids gain language and emotional skills. He and his colleagues have begun an experimental treatment consisting of tones and songs altered by computer to filter out low sounds, forcing the middle ear to focus on the pitches of human speech. After five 90-minute sessions, most of the 16 children have made strides that surprised even Porges. Third grader Tomlin Clark, for example, who once spoke only rarely, recently delighted his parents by getting in trouble for talking out of turn in school. And for the first time, he shows a sense of humor. "Listening to sounds seems so simple, doesn't it?" says Porges. "But so does jogging."

TOUCH

The skin, writes pathologist Marc Lappé, "is both literally and metaphorically 'the body's edge'... a boundary against an inimical world." Yet the skin also is the organ that speaks the language of love most clearly—and not just in the erogenous zones. The caress of another person releases hormones that can ease pain and clear the mind. Deprive a child of touch, and his brain and body will stop growing.

This new view of the most intimate sense was sparked a decade ago, when child psychologist Tiffany Field showed that premature infants who were massaged for 15 minutes three times a day gained weight 47 percent faster than preemies given standard intensive care nursery treatment: as little touching as possible. The preemies who were massaged weren't eating more; they just processed food more efficiently, says Field, now director of the University of Miami's Touch Research Institute. Field found that massaged preemies were more alert and aware of their surroundings when awake, while their sleep was deeper and more restorative. Eight months later, the massaged infants scored better on mental and motor tests.

Being touched has healing powers throughout life. Massage, researchers have found, can ease the pain of severely burned children and boost the immune systems of AIDS patients. Field recently showed that office workers who received a 15-minute massage began emitting higher levels of brain waves associated with alertness. After their massage, the workers executed a math test in half their previous time with half the errors.

SIXTH SENSES

Wish you had that nose?

Folklore abounds with tales of animals possessing exceptional sensory powers, from pigs predicting earthquakes to pets telepathically anticipating their owners' arrival home. In some cases, myth and reality are not so far apart. Nature is full of creatures with superhuman senses, built-in compasses, highly accurate sonar, infrared vision. "Our worldview is limited by our senses," says Dartmouth College psychologist Howard Hughes, "so we are both reluctant to believe that animals can have capabilities beyond ours, and we attribute to them supernatural powers. The truth is somewhere between the two."

In the case of Watson, a Labrador retriever, reality is more impressive than any fiction. For over a year, Watson has reliably pawed his owner, Emily Ramsey, 45 minutes before her epileptic seizures begin, giving her time to move to a safe place. Placed by Canine Partners for Life, Watson has a 97 percent success rate, according to the Ramsey family. No one has formally studied how such dogs can predict seizure onset consistently. But they may smell the chemical changes known to precede epileptic attacks. "Whatever it is," says Harvard University neurologist Steven Schachter, "I think there's something to it."

Scientists have scrutinized other animals for decades, trying to decipher their sensory secrets. Birds, bees, moles and some 80 other creatures are known to sense magnetic fields. But new studies indicate birds have two magnetic detection systems. One seems to translate polarized light into visual patterns that act as a compass; the other is an internal magnet birds use to further orient themselves.

Dolphin sonar so intrigued government researchers that they launched the U.S. Navy Marine Mammal Program in 1960, hoping it would lead to more sophisticated tracking equipment. But the animals still beat the machines, says spokesman Tom LaPuzza. In a murky sea, dolphins can pinpoint a softball two football fields away. A lobe in their forehead focuses their biosonar as a flashlight channels light, beaming 200-decibel clicks.

It took night-vision goggles for humans to replicate the infrared vision snakes come by naturally. A cameralike device in organs lining their lips lets them see heat patterns made by mammals. And humans can only envy the ability of sharks, skates and rays to feel electric fields through pores in their snouts—perhaps a primordial skill used by Earth's earliest creatures to scout out the new world.

BY ANNA MULRINE

TOUCH

People with "synesthesia" feel colors, see sounds and taste shapes.

While such findings may sound touchy-feely, an increasing volume of physiological evidence backs them up. In a recent series of experiments, Swedish physiologist Kerstin Uvnas-Moberg found that gentle stroking can stimulate the body to release oxytocin, sometimes called the love hormone because it helps cement the bond between mothers and their young in many species. "There are deep, deep, physiological connections between touching and love," Uvnas-Moberg says. Oxytocin also blunts pain and dampens the hormones release when a person feels anxious or stressed.

For the babies of any species, touch signals that mother—the source of food, warmth and safety—is near. When she is gone, many young animals show physiological signs of stress and shut down their metabolism—an innate response designed to conserve energy until she returns. Without mother, rat pups do not grow, says Saul Schanberg, a Duke University pharmacologist, even when they are fed and kept warm. Stroking them with a brush in a manner that mimics their mother licking them restores the pups to robust health. "You need the right kind of touch in order to grow," says Schanberg, "even more than vitamins."

SMELL

Long ago in human evolution, smell played a prominent role, signaling who was ready to mate and who was ready to fight. But after a while, smell fell into disrepute. Aristotle disparaged it as the most animalistic of the senses, and Immanuel Kant dreamed of losing it. Recent research has restored the nose to some of its former glory. "Odor plays a far more important role in human behavior and physiology than we realize," says Gary Beauchamp, director of Philadelphia's Monell Chemical Senses Center.

SMELL

A woman's sense of smell is keener than a man's. And smell plays a larger role in sexual attraction for women.

A baby recognizes its mother by her odor soon after birth, and studies show that adults can identify clothing worn by their children or spouses by smell alone. In 1995, Beauchamp and colleagues at Monell reported that a woman's scent—genetically determined—changes in pregnancy to reflect a combination of her odor and that of her fetus.

The sense of smell's most celebrated capacity is its power to stir memory. "Hit a tripwire of smell, and memories explode all at once," writes poet Diane Ackerman. The reason, says Monell psychologist Rachel Herz, is that "smells carry an emotional quality." In her latest experiment, Herz showed people a series of evocative paintings. At the same time, the subjects were exposed to another sensory cue—an orange, for example—in different ways. Some saw an orange. Others were given an orange to touch, heard the word "orange" or smelled the fruit. Two days later, when subjects were given the same cue and were asked to recall the painting that matched it, those exposed to the smell of the orange recalled the painting and produced a flood of emotional responses to it.

Herz and others suspect that an aroma's capacity to spark such vivid remembrances arises out of anatomy. An odor's first way station in the brain is the olfactory bulb, two blueberry-sized lumps of cortex from which neurons extend through the skull into the nose. Smell molecules, those wafting off a cinnamon bun, for example, bind to these olfactory neurons, which fire off their signals first to the olfactory bulb and then to the limbic system—the seat of sexual drive, emotions and memory. Connections between the olfactory bulb and the neocortex, or thinking part of the brain, are secondary roads compared to the highways leading to emotional centers.

Scientists once thought all smells were made up of combinations of seven basic odors. But in an elegant series of experiments, research teams led by Columbia's Axel and Linda Buck of Harvard have shown the mechanics of smell to be much more complicated. In 1991, the scientists discovered a family of at least 1,000 genes corresponding to about 1,000 types of olfactory neurons in the nose. Each of these neuronal types responds to one—and only one—type of odor molecule.

ARE YOU A SUPERTASTER?

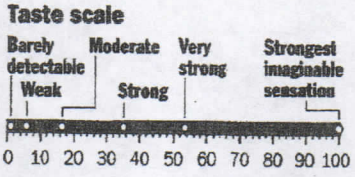
All tongues are not created equal. How intense flavors seem is determined by heredity. In this test, devised by Yale University taste experts Linda Bartoshuk and Laurie Lucchina, find out if you are a **nontaster**, an **average taster** or a **supertaster**. Answers on next page.

TASTE BUDS. Punch a hole with a standard hole punch in a square of wax paper. Paint the front of your tongue with a cotton swab dipped in blue food coloring. Put wax paper on the tip of your tongue, just to the right of center. With a flashlight and magnifying glass, count the number of pink, unstained circles. They contain taste buds.

SWEET. Rinse your mouth with water before tasting each sample. Put ½ cup of sugar in a measuring cup, and then add enough water to make 1 cup. Mix. Coat front half of your tongue, including the tip, with a cotton swab dipped in the solution. Wait a few moments. Rate the sweetness according to the scale shown below.

SALT. Put 2 teaspoons of salt in a measuring cup and add enough water to make 1 cup. Repeat the steps listed above, rating how salty the solution is.

SPICY. Add 1 teaspoon of Tabasco sauce to 1 cup of water. Apply with a cotton swab to first half inch of the tongue, including the tip. Keep your tongue out of your mouth until the burn reaches a peak, then rate the pain according to the scale.



The average person, of course, can detect far more than 1,000 odors. That's because a single scent is made up of more than one type of molecule, perhaps even dozens. A rose might stimulate neurons A, B and C, while jasmine sets off neurons B, C and F. "Theoretically, we can detect an astronomical number of smells." says Axel—the equivalent of 10 to the 23rd power. The brain, however, doesn't have the space to keep track of all those possible combinations of molecules, and so it focuses on smells that were relevant in evolution, like the scent of ripe fruit or a sexually receptive mate—about 10,000 odors in all.

Axel and Buck have now discovered that the olfactory bulb contains a "map," similar to those the brain employs for vision and hearing. By implanting a gene into mice, the researchers dyed blue the nerves leading from the animals' olfactory bulbs to their noses. Tracing the path of these neurons, the researchers discovered that those responsible for detecting a single type of odor molecule all led back to a single point in the olfactory bulb. In other words, the jumble of neurons that exists in the nose is reduced to regimental order in the brain.

Smell maps may one day help anosmics, people who cannot smell. Susan Killorn of Richmond, Va., lost her sense of smell three years ago when she landed on her head while in-line skating and damaged the nerves leading from her nose to her brain. A gourmet cook, Killorn was devastated. "I can remember sitting at the dinner table and begging my husband to describe the meal I'd just cooked," she says. Killorn's ability to detect odors has gradually returned, but nothing smells quite right. One possibility, says Richard Costanzo, a neurophysiologist at Virginia Commonwealth University, is that some of the nerves from her nose have recovered or regenerated but now are hooked up to the wrong spot in her smell map.

Though imperfect, recoveries like Killorn's give researchers hope they may one day be able to stimulate other neurons to regenerate—after a spinal cord injury, for example. Costanzo and others are searching for chemicals made by the body that can act as traffic cops, telling neurons exactly where to grow. In the meantime, Killorn is grateful for every morsel of odor. "I dream at night about onions and garlic," she says, "and they smell like they are supposed to."

TASTE

Human beings will put almost anything into their mouths and consider it food,

from stinging nettles to grubs. Fortunately, evolution armed the human tongue with a set of sensors to keep venturesome members of the species from dying of malnutrition or poison. The four simple flavors—sweet, salty, bitter and sour—tell human beings what's healthy and what's harmful. But as researchers are finding, the sense of taste does far more than keep us from killing ourselves. Each person tastes food differently, a genetically determined sensitivity that can affect diet, weight and health.

TASTE

Human beings are genetically hard-wired to crave sweetness; sugar on the lips of a newborn baby will bring a smile.

In a quest for novelty, people around the world have developed an affinity for foods that cause a modicum of pain. "Humans have the ability to say, 'Oh, that didn't really hurt me—let me try it again,'" says Barry Green, a psychologist at the John B. Pierce Laboratory in New Haven, Conn. Spicy food, Green has found, gives the impression of being painfully hot by stimulating the nerves in the mouth that sense temperature extremes. The bubbles in soda and champagne feel as if they are popping inside the mouth; in reality, carbon dioxide inside the bubbles irritates nerves that sense pain.

One person's spicy meatball, however, is another's bland and tasteless meal. Researchers have long known that certain people have an inherited inability to taste a mildly bitter substance with a tongue-twisting name: propylthiouracil, or PROP, for short. About a quarter of Caucasians are "nontasters," utterly insensitive to PROP, while the vast majority of Asians and Africans can taste it. Now, researchers at Yale University led by psychologist Linda Bartoshuk have discovered a third group of people called "supertasters." So sensitive are supertasters' tongues that they gag on PROP and can detect the merest hint of other bitter compounds in a host of foods, from chocolate and saccharin to vegetables such as broccoli, "which could explain why George Bush hates it," Bartoshuk says. She has recently discovered that supertasters have twice as many taste buds as nontasters and more of the nerve endings that detect the feel of foods. As a consequence, sweets taste sweeter to supertasters, and cream feels creamier. A spicy dish can send a supertaster through the roof.

RESULTS OF TASTE TEST ON PREVIOUS PAGE

	SUPER-TASTERS	NON-TASTERS
No. of taste buds	25 on average	10
Sweet rating	56 on average	32
Tabasco rating	64 on average	31

Average tasters lie in between. Bartoshuk and Lucchina lack the data to rate salt.

In an ongoing study, Bartoshuk's group has found that older women who are nontasters tend to prefer sweets and fatty foods—dishes that some of the supertasters find cloying. Not surprisingly, supertasters also tend to be thinner and have lower cholesterol. In their study, the researchers ask subjects to taste cream mixed with oil, a combination Bartoshuk confesses she finds delicious. "I'm a nontaster, and I'm heavy," she says. "I gobble up the test." But tasting ability is not only a matter of cuisine preference and body weight. Monell's Marcia Pelchat and a graduate student recently completed a study indicating that nontasters also may be predisposed to alcoholism.

The human senses detect only a fraction of reality: We can't see the ultraviolet markers that guide a honeybee to nectar; we can't hear most of the noises emitted by a dolphin. In this way, the senses define the boundaries of mental awareness. But the brain also defines the limits of what we perceive. Human beings see, feel, taste, touch and smell not the world around them but a version of the world, one their brains have concocted. "People imagine that they're seeing what's really there, but they're not," says neuroscientist John Maunsell of Baylor College of Medicine in Houston. The eyes take in the light reflecting off objects around us, but the brain only pays attention to part of the scene. Looking for a pen on a messy desk, for example, you can scan the surface without noticing the papers scattered across it.

The word "sentience" derives from the Latin verb *sentire*, meaning "to feel." And research on the senses, especially the discovery of sensory mapping, has taken scientists one step further in understanding the state we call consciousness. Yet even this dramatic advance is only a beginning. "In a way, these sexy maps have seduced us," says Michael Shipley, director of neurosciences at the University of Maryland–Baltimore. "We still haven't answered the question of how do you go from visual maps to recognizing faces, or from an auditory map to recognizing a Mozart sonata played by two different pianists." The challenge for the 21st century will be figuring out how the brain, once it has broken the sensory landscape into pieces, puts them together again.

BY SHANNON BROWNLEE
WITH TRACI WATSON

From *U.S. News & World Report*, January 13, 1997, pp. 51-56, 58-59.

http://fleen.psych.udel.edu/articles/AEP04.3.7.PDF

"*Coming to Our Senses,*"
by Shannon Brownlee
(U.S. News and World Report, Jan.13, 1997)

I. SIGHT

1. Anatomically speaking, where does vision rank in the hierarchy of the senses? Explain.
2. What 'tool,' or approach, does the brain use to process a visual stimulus?
3. What has psycholinguist Michael Tanenhaus discovered concerning the interrelatedness of the senses? Explain his study.
4. Using the research Jay and Maureen Neitz explain the following statement: Red is not green, it may not be red either.

II. HEARING

1. What is LLD and how does it affect a child?
2. What technology has been created for these children? How does it work?
3. According to recent research, what disorder may be closely tied to hearing? Explain the problem in processing that may explain this notion.
4. What experimental therapy technique is employed to help these children based on the above assumption?

III. TOUCH

1. According to the research on prematurely born infants, how does the sensation of touch affect the development of children? Be thorough.
2. What are some of the measurable benefits of a massage?
3. What is oxytocin and what does it do for the human body?
4. Explain the role touch (or the lack of touch) plays in the infant-mother relationship.

IV. SMELL

1. What is remarkable about the scent of a woman (genetically determined) during pregnancy?
2. How are memory and smell linked through anatomy?
3. According to Axel and Linda Buck (Harvard), how many smells does the nose/brain potentially detect? How much of this does the brain actually store and "use?" Why only this fraction?
4. How is olfactory sensation similar to that of vision with respect to the brain's approach to the stimulus?
5. People who cannot smell are known as _____ ?

V. TASTE

1. What are the four basic flavors?
2. What are supertasters? How might this explain why George Bush hates broccoli? What are some of the physical characteristics of supertasters?
3. What is a nontaster? To what -ism may nontasters be predisposed?

CHECK FOR UNDERSTANDING (You need to have read the entire article to answer these questions)

* Explain the following statement: *You do not see with your eyes, and you do not smell with your nose.*
* Name the sense(s) that best describes each statement below:
  a. "skin is the organ that speaks the language of love most clearly"
  b. "gateway to language"
  c. "is the body's top intelligence gatherer"
  d. "sweet, salty, bitter, and sour--- tell human beings what is healthy and what is harmful"
  e. "has power to stir memory"
* What is the etymology of the word "sentience?"
* According to Michael Shipley, director of neuroscience at UMB, what is the challenge for the 21st century?
* Human beings are hardwired to crave which basic flavor?
* How much more sensitive is a dog's nose than a human's?