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The Monell Connection… from the Monell Chemical Senses Center, a nonprofit scientific institute devoted to research on taste, smell, and chemosensory irritation.

The Monell Connection

Salt Seasons All Things

Love is the salt of life…
American

Business is the salt of life…
Old English

Whether love or business, these proverbs refer to sodium chloride (NaCl), the granular white mineral used in cooking and seasoning food, and to enhance its flavor. Actually, sodium chloride is just one example of a salt, which to chemists is any compound formed by the interaction of an acid and a base. However, to most people salt means sodium chloride.

For thousands of years, humans have valued salt. Its importance has been noted in many ways, from economic to literary. Early civilizations had sophisticated methods for obtaining salt: several techniques to extract and purify it are described in a pharmacology text from China, published around 2700 B.C. As is the case today, salt was appreciated for many reasons, ranging from usefulness as a food preservative to various medicinal qualities — some perhaps more valid than others.

Salt has even been used in some cultures as a type of currency. In ancient Greece, slaves were traded for salt. Since antiquity, governments have levied salt taxes, and the resulting anger and revolts have helped shape human history. Although salt has led to warfare, certain cultures have never used it. In fact, the Finnish language has no word for salt. Some Eskimo tribes are reported to actually dislike the taste of salt, a trait utilized by an explorer who added small amounts of salt to the food he served when he wanted his Eskimo visitors to leave!

Salt is essential to survival: without salt, a person will die. Sodium chloride is required for a variety of biological functions and, because the body does not produce minerals such as sodium or chloride, these nutrients must be consumed on a regular basis.

Once ingested, salt separates into sodium and chloride ions. Chloride has many roles. For example, it contributes to maintaining the balance between acids and bases in the body, which is crucial for normal bodily function.

Sodium, the other component of salt, also has multiple functions. It contributes to the maintenance of body fluid balance and blood pressure, and is a critical component in the series of bioelectrical events that results in conduction of nerve impulses. As with chloride, sodium plays a role in maintaining acid-base balance.

What makes salt so important to some?

And why does it seem so unimportant to others?

Because sodium is so essential, the amount in the body is tightly regulated through a sophisticated system of neural, hormonal, and behavioral controls that affect sodium intake and excretion. When there is too much sodium, the kidneys remove and eliminate the excess; when there is too little, hormones are released to signal the kidney to recycle and conserve sodium.

Behavior is an important component of the sodium regulatory system. An obvious

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Salt Seasons *continued from page 1*

The ***Shake*** On Salt

◆ ***Where does salt come from?*** *About 24-million tons are produced each year in the United States. Vast salt deposits lie underground in Louisiana, Texas, New York, Ohio, Michigan and Kansas. From some of these deposits, salt can be mined directly. In others, brine formed when water is introduced into the salt deposit is extracted and the salt is removed after evaporation. Less than 4 percent of the salt mined each year is used for dietary purposes; the majority (approximately 70 percent) is used in the chemical industry to produce chlorine, soda ash, and other products.*

◆ ***How does salty taste work?*** *Apparently, there are no specialized taste receptors for salt. Instead, taste cell membranes contain ion channels that allow sodium into the cell. Because only sodium (and lithium, which is rare in nature) can pass through these channels, it has been extremely difficult to develop a salt substitute that doesn't contain sodium.*

◆ ***Salt's preservative qualities*** *account for its use as a symbol of purity and incorruption. A covenant of salt, as referred to in the Bible and elsewhere, is one that lasts forever and cannot be broken.*

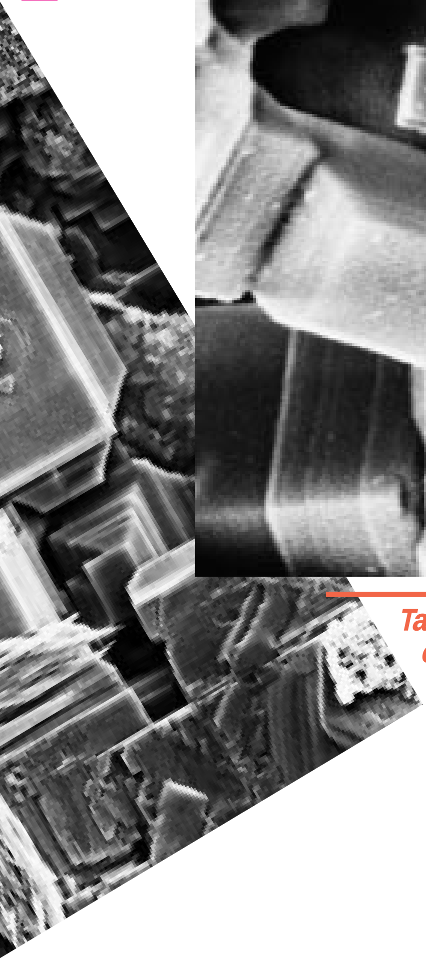
◆ ***In Westernized societies*** *people appear to obtain sufficient sodium for their biological needs without having to use additional salt. What, then, accounts for their high sodium preference and intake? One possibility is that they eat more salt because biological needs are higher than previously thought.*

way to correct sodium deficiency is to increase intake. When a laboratory rat experiences sodium deficiency for the first time, it becomes more active. The sodium-deficient rat sniffs about and nibbles objects in the environment, as if searching for something. When the rat finds a food source containing sodium chloride, its sense of taste innately enables it to recognize the nutrient it needs. The rat immediately proceeds to eat enough of that food — and therefore salt — to restore body sodium to normal levels.

In rodents and many other animals, this instinctive behavior — known as salt appetite — is specific for sodium. An animal deficient in sodium will immediately ingest large amounts of sodium salts, but not other salts, long before it has a chance to learn of sodium's restorative benefits. For reasons still not understood, calcium deficiency, in rodents at least, also triggers a salt appetite.

Salt appetite is seldom seen in humans. Perhaps this reflects the fact that modern man eats a wide variety of foods and, unlike creatures in the wild, rarely is in a situation where sodium is not available. For humans, therefore, sodium deficiency and salt appetite occur only under extreme circumstances.

Taste is an important factor in day-to-day salt consumption, even when the body has no actual need for sodium. Salty — along with sweet, sour, bitter, and savory — is a basic taste quality. Humans like the taste of salt and tend to consume much more than they apparently need. In fact, people in the United States consume 6 to 18 grams of salt every day, at least ten times more than the body is reported to require.



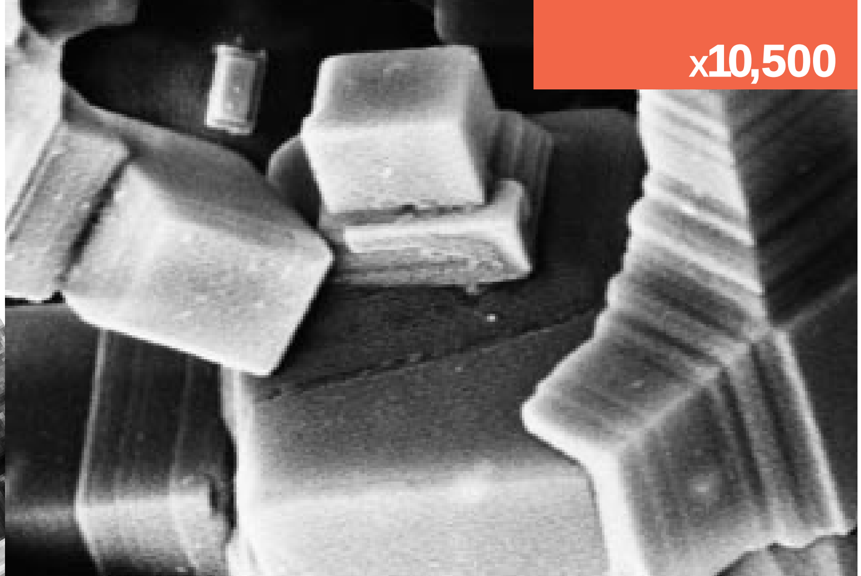


Table salt up close, closer, and even closer.

x40 Photomicrography by Linda M. Wysocki, Monell

x300 to x10,500 Scanning Electron Microscopy by Alicia K. Thompson, University of Southern California, Center for Electron Microscopy

In the United States, only five to ten percent of the salt that people eat is added in cooking or comes from the shaker. The remainder is either found naturally in food — for example, a tomato has about 14 milligrams of sodium and a cup of milk contains 122 milligrams — or is added during processing. Because salt enhances or improves the flavor of foods, and because of its properties as a preservative, it is added to almost all processed foods.

The means by which salt improves food flavor is still somewhat unclear. However, it has been found that the sodium ion is a potent suppressor of many bitter taste components. Therefore, one way that a food flavor may be enhanced by added salt is through suppression of unappealing bitterness and the apparent heightening of other, more pleasing, flavor components.

The reasons why humans like salty taste so much are not yet well understood. Studies at Monell and elsewhere are trying to determine to what extent salt preference is innate and to what extent it is learned or acquired. Questions being asked include: What are the relative contributions of taste and physiology to our liking for salt? And, do developmental events, such as excess sodium or a deficiency during infancy, affect subsequent salt preference?

In adults, how much salt people eat — and specifically, how much salt they ***taste*** — seems to influence how much they like it. In one study, individuals showed a decreased preference for salty foods after eating a reduced-sodium diet for 8 to 12 weeks. Interestingly, subjects learned to like lower-salt foods even when they swallowed a daily salt pill, indicating that reduced exposure to the ***taste*** of salt — rather than a change in salt intake — resulted in decreased salt preference.

Although fetuses swallow salty amniotic fluid in the womb, a preference for salt doesn't appear until sometime after birth. In research studies, newborn babies ingest salt solutions and water in equivalent amounts, or sometimes actually prefer water to the salt solutions. Apparently, at that young age the mechanisms necessary for detection of salty taste have not yet developed fully. Starting at about four-months-old, babies begin to show a preference for weak-to-moderate salty solutions.

At around 1 to 3 years of age, children reject solutions of salt water, but show a preference for the taste of salty foods, including liquids such as salted soup. Experience has taught the children which foods are appropriate for a salty taste — for example, salty ice cream probably would not be acceptable. However, there is little evidence that early exposure to high levels of dietary salt permanently influences salt preference later in life.

What's so great about salt? Our bodies need it. It has a distinctive and desired taste. These characteristics probably encouraged our ancestors to seek out salt in order to survive. Although conditions have changed since those early days, the preference for salt is still strong. ■

An Evolutionary Perspective...

► *The foods eaten are a major factor in determining whether additional sodium is needed in the diet.*

► *For example, carnivores can obtain sodium from their prey. But because plants contain very little sodium, herbivores are particularly vulnerable to a deficiency.*

► *Man's primate ancestors were almost completely vegetarian, and therefore often may not have obtained sufficient sodium in their daily diet. Through evolution, strategies developed to make sure adequate sodium was ingested, especially during times such as pregnancy and lactation when greater amounts are needed. It is possible that these mechanisms underlie both sodium appetite and the liking for salt seen today in humans and other species.*

► *Similarly, differences in foods eaten by various cultures might explain why some groups appear to be less attracted to salt. In most cultures in which added salt is neither eaten nor preferred, the primary diet consists of animal products such as meat or milk. Because these foods contain more than adequate amounts of sodium, it might be less necessary to eat salt. Over the course of time such people may learn to prefer diets without added sodium.*

Almost everyone has had the experience of a specific odor calling to mind a person or place…

The Nose Remembers When

Stephanie E. Jennings

Why would a cognitive psychologist interested in memory consider Monell a fertile place to carry out her research? One reason, according to Dr. Rachel Herz, is the intriguing possibility that smell — more than the other senses — can provide clues to the mystery of memory.

For centuries there have been anecdotes about odors triggering memories that are far more emotionally intense and evocative than those elicited by other sensory cues. Yet there has been little scientific discussion, and even less research, on the matter.

Using her background in cognitive psychology and the increasing knowledge about olfaction that she is acquiring at Monell, Herz hopes to explain why odor-evoked memories can bring about such powerful emotions.

Odor memories might have survival value. For example, if an animal becomes ill after eating a plant, the smell of that plant is likely to help the animal avoid ingesting it again.

Why does this phenomenon occur — and what is special about it? Herz explains that an odor-evoked memory is triggered by an odor that is linked to a meaningful personal event. Such memories, which do not occur frequently, are vivid and intense. Accounts from literature and personal reports attest, and Herz's own research confirms, that odor-evoked memories are notable for their emotional potency.

To illustrate, Herz describes the puzzling experience of a woman who suddenly became overwhelmed with emotion and started to cry uncontrollably while washing dishes in a home where she was a guest. She couldn't figure out what had aroused this flood of emotion until she realized that the smell of the dishwashing soap was making her remember her much-loved deceased grandmother, in whose home she had used that same soap to wash dishes.

According to Herz, there is anatomical and evolutionary support for the unique relationship between odors and emotion in memory. The olfactory system has more connections than the other senses to the brain's limbic system, an area involved in both emotion and memory. Further, the limbic system appears to have evolved from the olfactory bulb. "One way to think about this," she maintains, "is that we would not have emotion if we did not have the sense of smell."

Describing herself as both a memory psychologist and a biological scientist, Herz considers Monell the ideal environment for investigating how odor-evoked memories

Dr. Rachel S. Herz

▸ In one of Dr. Herz's studies, a subject assesses the visual cue for the odor of peppermint.

A subject sniffs while studying a painting, as part of Dr. Herz's research to evaluate the effects of different sensory cues on memory.

differ from memories evoked by other senses. She notes that coming to Monell "is a perfect way to bring together both of my worlds."

After starting out with an undergraduate major that combined biology and physiological psychology, Herz decided that she wanted to apply what she was learning "to the human side of things," and specifically to that very human characteristic: emotion.

During Ph.D. studies at the University of Toronto, she came across a paper on mood and memory that described a way to use odor to manipulate mood. The paper sparked Herz's interest in odor as a powerful emotional cue. "An undergraduate advisor once told me that odor is the key to memory," she recalls. "I had no idea that statement would become so important to me."

In order to learn about olfaction, Herz contacted researchers in industry and academia "to ask them to teach me how to do smell research." She assembled a team of supervisors — an animal researcher to help with the physiology, an expert in memory, and a scientist who studied emotion — "because each tied in with my work in some way." Herz explains, "Everything came together — biology and emotion and psychology," leading to a Ph.D. dissertation titled *The Relationship Between Odor and Emotional Memory*.

After additional training in cognitive psychology during a postdoctoral fellowship at the University of British Columbia, her next step was to learn more about olfaction. "When I first found out about Monell," she reports, "it was a bonanza! Because I was in a psychology department where there was no ongoing olfactory research, there was never much discussion about the sense of smell. Monell gives me the chance to be with people who really want to talk about olfaction."

One aspect of Herz's current work focuses on describing the differences between odor-evoked memories and memories evoked by the other senses. She wants to determine the specific aspects of odor that separate it from the other senses as a memory cue. Her research has already shown that memories evoked by odors have more emotional impact than memories elicited by verbal cues, and she is now exploring why this is so. Is it because odor is a more primitive sense, or are there other characteristics that set it apart?

A specialized memory system involving odor might have evolved to make sure that significant events, like those involving food, kin, or places, would be approached or avoided.

Emotion itself can increase the effectiveness of odor as a memory cue. In a recent experiment, Herz showed that if an emotional state, such as anxiety, is experienced in the presence of an odor while learning, the odor will later act as a better memory cue than if emotion had not been present.

Herz also wants to learn more about how odor-evoked memories are formed. She explains that critical variables determine how effective an odor will be in evoking a memory. One such factor is context. In the example of the woman who found herself crying over a sink of soapy dishes, the context and perception of the soapy odor were similar to the original incident. The woman most likely would not have had the same emotional experience if she had smelled that soap in an elevator or a department store.

In addition, Herz's research has shown that the distinctiveness of an odor within a certain context — how well it does or does not "fit" into a specific environment — influences how effective that odor will be as a cue to remembering information learned in that setting. Thus, the smell of gasoline might serve as an effective memory cue in a library, where it is out of context, but not in a garage. In future studies, Herz plans to examine how other aspects of odor quality, such as familiarity and pleasantness, relate to odor memory.

"I believe that nothing can survive or revive the past with the same immediacy or emotional potency as can an odor," notes Herz. She hopes that by identifying the unique properties of odor memory and then comparing it with other sensory memory systems, she will be able to achieve a more comprehensive and improved understanding of memory as a whole. ■

A Perspective…

Opportunities to Collaborate

It has been said before and needs repeating: collaboration at Monell is easy. The multidisciplinary research interests of our scientists and the fact that we are all situated within a single building facilitate interactions among colleagues who otherwise might have a hard time connecting.

A senior scientist at Monell — trained in psychology — was discussing how one of his projects was going. His interest is in control of appetite, focusing on the liver. Until recently, he was using behavioral and pharmacological approaches. Now, along with other Monell scientists, he has begun work on imaging calcium influx into single liver cells, and is exploring techniques of molecular biology in order to understand control of the channels that mediate the influx. This should provide new insights into hunger and satiety, and even perhaps aid in control of eating disorders. (No, the fat genes are not the final answer!)

What amazed him, even after many years at Monell, was how this collaborative work seemed to happen so easily. Just down the hall or upstairs were people who were experts at calcium imaging and molecular biology. Although nothing is ideal, I believe that circumstances such as this help make Monell's research environment outstanding.

The trick is to keep it outstanding and, if possible, even improve it. This goal is now significantly threatened by current and anticipated cutbacks in federal support for scientific research. For certain agencies that provide support for Monell's research activities, the crunch has already begun. At the National Institutes of Health, our major source of federal support, the budget situation remains murky but I think it is safe to say that funding levels are not likely to get better and probably will become worse. The main question is how *much* worse.

What is to be done? There are several levels on which we all must work. First, as a national issue, we should encourage Congress not to cut biomedical research. Although clearly self-serving, I strongly believe that this is an area where the United States is extremely strong and we must not lose any ground. Savings obtained by severely strangling biomedical, agricultural, and environmental research programs are trivial overall, but such cuts could be deadly — not only to Monell, but also to hospitals, medical centers, universities, and other basic research institutes nationwide. The problem here, of course, is that in the current situation every dollar we successfully encourage Congress to devote to basic and applied research means a dollar less for other, often worthy, causes. If only I could be the one to decide where cuts would be made!

Second, at the local level, Monell has opportunities with the private sector that most other institutions lack. We have a long and successful history of partnership with companies in the flavor, fragrance, food, beverage, pharmaceutical and chemical industries. Over the past few years the number of collaborative research projects supported by our corporate sponsors has risen dramatically.

The most encouraging aspect of this increase is the realization that these projects offer great basic research opportunities — which they must if Monell is to undertake them — while still having important practical implications. It often (in fact, almost always) requires our friends in industry to tell us about the practical side of what we do. Yet it is surprising how many of Monell's scientists find this melding of the basic and practical to be fascinating and fulfilling. For some, it opens avenues of research that they might never have known existed.

We encourage more such collaborations. They make good financial sense given the budgetary issues discussed previously — and they make research sense. Although we are not planning to test new products or do market research on current ones, we are eager to work together with sponsors on projects that combine our basic interests in the mechanism and functions of the chemical senses with real world issues. Certainly, our new human research laboratories, due to be completed in 1996, should facilitate this.

In our changing environment, can Monell maintain those qualities that make it such an attractive place to do research? I hope so and I expect so. An excellent group of scientists, a supportive group of corporate sponsors, and a strong, active and committed Board of Directors make me confident that Monell will prosper, even in these difficult times. ■

Q&A

What is the function of saliva in taste?

Saliva is the medium in which taste stimuli are dissolved and through which they reach taste receptor cells.

The very acts of tasting and chewing increase the rate of salivary flow. Individuals with impaired flow sometimes experience taste abnormalities because stimuli have difficulty reaching the receptor cells.

Saliva contains a low concentration of sodium ion, which is the principal stimulus for salty taste. Because the taste cells are always in contact with this low concentration of salivary sodium, the level of sodium required to stimulate salty taste must be higher than this baseline level. Anything causing a change in flow rate, or a disease of one of the salivary glands, may alter sensitivity to salty stimuli.

Pungent food flavorings and acids, as well as other stimuli that produce sensations of irritation, can have a potent effect on salivary flow. In individuals with a high flow rate, sour stimuli often become less sour. This is because the increase in the flow rate induced by a sour stimulus increases the secretion of one of saliva's many components — bicarbonate — which further diminishes, or buffers, the sour taste.

The effect of dilution that occurs when taste stimuli from foods or beverages are dissolved in saliva is probably of minor importance in normal eating. However, dilution might be important in laboratory taste tests that use low concentrations and small amounts of a stimulus.

Where in the brain does taste information go?

When a stimulant reaches tastebuds on the tongue, it activates sense cells that respond to the primary tastes: sweet, sour, salty, bitter, or savory.

Information about the stimulant is then transmitted through the chorda tympani and other nerves to a small cluster of cells in the brain known as the nucleus tractus solitarius (NTS).

The NTS is a major information-sorting center for automated control of the body's functions. It receives information from the sensory nerves throughout the digestive tract, and sends commands back to the body to regulate feeding and digestion. When food first enters the mouth, taste signals passing through the NTS tap into this command flow and prepare the body for incoming nutrients even before food reaches the stomach.

From the NTS, taste information travels to the thalamus, where it joins multiple streams of information from other sensory modalities that are being relayed to the outer surface of the brain, the neocortex.

In the neocortex, higher cognitive functions — such as the conscious decision to eat or not eat a certain food — are performed. In humans, the decision to consume a good-tasting food might be modified by knowledge of its nutritive value.

What's the effect of having no sense of smell?

The impact of *anosmia*, which is the complete loss of the ability to smell, is often minimized. But because smell serves a protective function and contributes appreciably to enjoying life, its absence can be devastating.

At the Monell-Jefferson Taste and Smell Center, where individuals who have chemosensory problems are evaluated, about 25 percent of the referred patients are anosmic. Typically, their loss is due to nasal/sinus disease or head trauma, but also might be a result of upper respiratory infection or exposure to toxins.

Since smell is the major contributor to flavor perception, anosmia results in a marked decrease in ability to appreciate foods and beverages. Without a variety of flavors, anosmics often find meals bland, uninviting, and unsatisfying.

Further, individuals without the sense of smell lose the protection that olfaction provides, because they are unable to detect smoke, natural gas leaks, or spoiled foods. Anosmics, lacking the early warning system that others rely upon, are understandably concerned about these dangers.

Finally, anosmics lose out on the many joys that odors provide — the allure of perfume, the welcoming aroma of a cozy fire, the fragrance of flowers, and the evocative recall of memories.

Fortunately, cases of total anosmia are relatively rare, and there is often some degree of recovery. ■

Contributors: *Joseph G. Brand, Ph.D.; Graeme Lowe, Ph.D.; John D. Pierce, Jr., Ph.D.*

Must the Neuron Meet the Bulb?

Olfactory neurons, which contain the olfactory receptors, connect with olfactory bulbs in the brains of healthy individuals. It had been thought that this contact must occur before the neuron itself is able to function normally and respond to odors in a specific and selective fashion.

The contact between olfactory neuron and olfactory bulb is not present in patients with Kallman syndrome (KS), a rare inherited disorder characterized by hypogonadism and anosmia, because olfactory bulbs of KS patients are either missing or reduced in size.

To determine whether contact with the olfactory bulb is necessary for olfactory neurons to develop and function, Dr. Rawson and colleagues isolated olfactory neurons from two KS patients. By measuring changes in calcium concentrations inside the neurons after stimulation with odorants, the researchers demonstrated that the neurons responded in a way typical of mature neurons from normal healthy adults.

The data demonstrate that olfactory neurons do not have to connect with the olfactory bulbs in the brain in order to function appropriately. Further, the inability of KS patients to perceive odorants cannot be explained by a total absence of functional olfactory neurons.

This was the first study to look at the functionality of olfactory neurons from human anosmics. The findings may provide insight regarding the possibility of restoring olfactory perception to KS and other anosmic patients.

Functionally mature olfactory neurons from two anosmic patients with Kallman syndrome. Nancy E. Rawson, Joseph G. Brand, Beverly J. Cowart, Louis D. Lowry (Thomas Jefferson University), Edmund A. Pribitkin (Thomas Jefferson University), Vijay A. Rao (Thomas Jefferson University), and Diego Restrepo. *Brain Research, 1995, 681, 58-64.*

Impact of Taste and Smell Disorders on Diet

Although one of the principal functions of the chemical senses is to guide food consumption, little is known about the impact of chemosensory disorders on dietary consumption and nutritional status. To help identify afflicted individuals who might be at nutritional risk, Dr. Mattes and Dr. Cowart studied food habits, nutrient intake, and changes in body weight of 310 patients at the Monell-Jefferson Taste and Smell Clinic.

Overall, dietary responses to chemosensory disorders were varied. Most patients reported changes in eating patterns and decreased enjoyment of their food. Other complaints included decreased appetite and formation of food aversions.

About one third of the patients indicated that their body weight had increased or decreased by at least 5 percent, suggesting that the chemosensory disorder had affected their nutritional status. Two factors in particular were associated with weight change. First, of the various chemosensory diagnoses, patients suffering from multiple chemosensory dysfunctions were at highest risk for body weight change, with approximately one third of these individuals losing or gaining at least 10 percent of their predisorder body weight. Second, approximately 74 percent of all patients with notable weight change also reported a change in eating patterns.

Accordingly, the authors suggest that a report of change in eating patterns is a useful indicator to help identify which patients with chemosensory disorders might need nutritional counseling. Due to the wide variability of dietary responses to chemosensory disorders, patients will benefit most from individualized assessment and advice.

Dietary assessment of patients with chemosensory disorders. Richard D. Mattes and Beverly J. Cowart. *Journal of the American Dietetic Association, 1994, 94, 50-56.*