The "Gray Line" Between Odor Nuisance and Health Effects

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ABSTRACT

Ambient air in the community holds a mixture of chemicals from the everyday activities of it's citizens and the commercial enterprises that make up modern day society. Exposure to chemicals in the ambient air is a part of life and a part of a community. However, from time to time citizens find the odors of these chemicals objectionable and at some point declare them a nuisance. Additionally, citizens frequently report adverse health effects from these chemicals.

An odor nuisance can be a result of a series of odor episodes experienced by a citizen. The frequency of these episodes, the duration of each odor episode, the intensity of the odors, and the character of the odors all contribute to the nuisance experience and the resulting citizen complaint.

Citizens sometimes experience adverse health effects that are attributed to odors or odorants (chemicals) in the ambient air. Often these health effects are non-specific symptoms (headaches, nausea, reflex nausea, GI distress, fatigue, eye irritation, throat irritation, shortness of breath, runny nose, sleep disturbance, inability to concentrate, classical stress response, etc.) which cannot be directly linked to a specific chemical or exposure event. These health effects were discussed at an EPA workshop held at Duke University Medical School in April 1998, entitled "Health Effects of Odors." Elements from the discussions at this workshop will be addressed in this paper.

A "gray line" exists between odor nuisance and health effect experiences. The odor perception and not the chemical odorant may in fact cause symptoms otherwise attributed to chemical exposures in the community. Furthermore, effects that are not always considered symptoms (i.e. anxiety, depression, etc.) of chemical exposure have been sufficient for citizens to claim an odor nuisance.

This paper will discuss the distinction between odors and odorants and the distinction between nuisance non-specific symptoms and health effects as defined by the medical community. The "gray line" refers to the overlap of health effects caused by odorants and those caused by odors, as well as, the overlap of some health effects that may contribute to a nuisance.

INTRODUCTION

Community odors remain one of the top three complaints to air quality regulators and government bodies around the country. More than 70% of all air pollution complaints to the EPA are odor related.

As odor nuisance lawsuits continue to arise in the United States, there is a subset of citizens from this population who are experiencing non-specific symptoms such as headaches, nausea, reflex nausea, G.I. distress, fatigue, eye irritation, throat irritation, shortness of breath, runny nose, sleep disturbance, inability to concentrate, classical stress response, etc. Nuisance lawsuits which describe citizens' general decline in their neighborhood quality of life, include legal terminology such as: 1.) personal discomfort, inconvenience and annoyance…, 2.) loss of enjoyment of personal property, and/or 3.) diminished property value or rental value.

These claims rarely include the health effect component to the citizens' discomfort and annoyance. While these health concerns play some role in the citizens' complaint, it is still unknown whether these non-specific symptoms are a direct or indirect result of the odor. For example, is a headache due to a physiological change caused by the presence of a chemical odorant, or is it because the citizen is "simply annoyed."

This paper will discuss the topics of olfactory anatomy, citizen annoyance, the current knowledge of the health effects of odors, and current theories of these health effect mechanisms. Through this presentation and discussion, our goal is to help the reader understand the current knowledge and leading issues of odors and related health effects.

OLFACTORY ANATOMY

Of the five senses, the sense of smell is the most complex and unique in structure and organization. While human olfaction supplies 80% of flavor sensations during eating, the olfactory system plays a major role as a defense mechanism by creating an aversion response to malodors and irritants. This is accomplished with two main nerves. The olfactory nerve (first cranial nerve) processes the perception of chemical odorants. The trigeminal nerve (fifth cranial nerve) processes the irritation or pungency of a chemical odorant.

During normal nose breathing only 10% of inhaled air passes up and under the olfactory receptors in the top, back of the nasal cavity. When a sniffing action is produced, either an involuntary sniff reflex or a voluntary sniff, more than 20% of inhaled air is carried to the area near the olfactory receptors due to turbulent action in front of the turbinates.[1] These receptors are ten to twenty-five million olfactory cells making up the olfactory epithelium. Cilia on the surface of this epithelium have a receptor contact surface area of approximately five square centimeters due to the presence of many microvilli on their surface. Supporting cells surrounding these cilia secrete a mucus which acts as a trap for chemical odorants.

In 1991, researchers Dr. Linda Buck and Dr. Richard Axel at Columbia University discovered that over 1000 genes in the human body encode the olfactory receptors. This vast number of genes, almost one percent of all human genes, allows humans to perceive over 10,000 different odors.

Chemical odorants pass by the olfactory epithelium and are dissolved (transferred) into the mucus at a rate dependent on their water solubility and other mass transfer factors. The more water-soluble the chemical, the more easily it is dissolved into the mucus layer. A "matching" site on the olfactory cells then receives the chemical odorant. The response created by the reception of a chemical odorant depends on the mass concentration or the number of molecules present. Each reception creates an electrical response in the olfactory nerves. A summation of these electrical signals leads to an "action potential." If this action potential has a high enough amplitude (a threshold potential), then the signal is propagated along the nerve, through the ethmoidal bone between the nasal cavity and the brain compartment where it synapses with the olfactory bulb.

All olfactory signals meet in the olfactory bulb where the information is distributed to two different parts of the brain. One major pathway of information is to the limbic system which processes emotion and memory response of the body. This area also influences the signals of the hypothalamus and the pituitary gland, the two main hormone control centers of the human body. The second major information pathway is to the frontal cortex. This is where conscious sensations take place as the information is processed with other sensations and is compared with cumulated life experiences for the individual to possibly recognize the odor and make some decisions about the experience. The entire trip from nostril to the signal in the brain takes as little as 500 milliseconds.

The location of the olfactory system and the direct connection of the nerves with the brain create a unique pathway for environmental pollutants to potentially cause adverse health effects.

ODOR vs. ODORANT

Frequently the terms odor and odorant are used interchangeably and incorrectly. There is a distinct difference between these two terms, which is fundamental to the discussion of odor nuisance and health effects.

The term "odor" refers to the perception experienced when one or more chemicals come in contact with receptors on the olfactory nerves.

The term "odorant" refers to any chemical in the air that is part of the perception of odor.

The best analogy to understand what is happening in odor perception in the olfactory system is that the receptor nerves are like keys on a piano. As a chemical odorant "hits" the piano keyboard a key is played. When multiple chemical odorants are present the result is a cord or specific perception. For example, if keys 1, 3, and 7 are "hit", then the brain perceives "banana." Likewise, if keys 4, 6, and 12 are "hit", then the brain perceives "sewer." The greater the numbers of odorant molecules present (higher concentration), the louder the cord is played. The loudness of the chord is analogous to the intensity of the odor perception.

CITIZEN COMPLAINT PYRAMID

A conceptual model for what makes an odor episode lead to a citizen complaint is the "Citizen Complaint Pyramid" (see Figure 1). Four parameters make up the hierarchy in this pyramid: 1) Character, 2.) Intensity, 3.) Duration, and 4.) Frequency. This assumes an odor episode exists when an odorant is present above the detection threshold.

The "character" of the odor is the actual description of what the odor "smells like." This parameter is sometimes called the "quality" or "offensiveness" of the odor. More offense odors will be more annoying.

"Intensity" of the odor refers to the overall strength or power of the odor. The more intense the odor, the more likely a citizen is to be annoyed. Even very pleasant odors such as perfumes can be very annoying at high intensities.

"Duration" is the elapsed time of each individual odor episode. Longer duration odor episodes can lead to more drastic changes in plans around a citizen's home or community. Episodes of very short duration may be over before the citizen even thinks about adjusting his or her plans.

Finally, "frequency" refers to how often the citizen experiences odor episodes. The more frequent the intrusion into the citizen's life, the more annoying each experience becomes.

This model is sometimes given the acronym "F-I-D-O" (frequency, intensity, duration, and offensiveness) with the "offensiveness" term used instead of the "character" term. The cumulative effect of these four parameters creates the nuisance experience and the resulting citizen's complaint.

HEALTH EFFECTS OF ODORS

Non-specific, multi-system symptoms have been experienced in communities near industrial sites, waste water treatment plants, agricultural sites, and hazardous waste sites.[1] Citizens frequently report that chemical odors are making them sick. These symptoms include: headaches, nausea, reflex nausea, G.I. distress, fatigue, eye irritation, throat irritation, shortness of breath, runny nose, sleep disturbance, inability to concentrate, and classical stress response.

In a survey near a waste treatment plant in 1983, one in nine respondents reported that odors had made them sick.[2] A 1991 study of health effects from pesticides used on a potato field showed that while health effects were not related to proximity of citizens to the fields, odor perception was strongly related to the number of symptoms reported, the length of occurrence of the symptoms, and the severity of the symptoms.[3] More recently these odor related symptoms are being reported by large groups of citizens near agribusiness feedlots (concentrated animal confinement facilities) around the country.

A study in 1997 conducted at the University of Iowa assessed both the physical and mental health of residents near a large-scale swine operation. This pilot scale study consisted of interviewing 18 residents within two miles of the 4,000 sow facility and 18 comparable residents living near smaller swine facilities. The results indicated that the neighbors of the large swine facility reported higher rates of a variety of symptoms including respiratory problems, nausea, headaches, and irritated eyes, nose and throat.[4]

THE ODOR CONCENTRATION GRADIENT

Consider one individual's exposure to an odor consisting of specific odorants. This presentation follows two models. Each specific chemical odorant follows traditional toxicological paradigms where different health outcomes are based on the concentration of the chemicals and the time factors of exposure (frequency and duration). Secondly, the odor perception follows it's own paradigm not yet fully understood.

The concentration gradient of any odor begins at sub-threshold (see Figure 2). At some increased concentration the individual can detect the presence of the odor (the air is no longer the same). This is the detection threshold (DT).[5] At some higher concentration the individual will then recognize a character to the odor. This is the recognition threshold (RT).[5]

At some point, moving up the concentration gradient, the individual will reach some point where they are annoyed by the odor. This we will call the "annoyance threshold" (AT). This annoyance threshold may be below or above the recognition threshold. From the "Complaint Pyramid" model, the position on the concentration gradient will depend on the character and the intensity of the odor at different concentrations. For the individual, the annoyance threshold depends on their memories, their socioeconomic background, their health history, and their general well being. The degree of annoyance will lie somewhere on an "annoyance index" (see Figure 2).

Another threshold on this odor concentration gradient is the "health threshold" (HT). This is the point at which the individual begins to elicit some adverse health response such as headache, nausea, itchy eyes, running nose, etc. This threshold is a toxicological limit for this individual to this specific odor perception of the odorants. It is based on the individual's health history, their body mass, and the condition of their immune system. The degree of health effects will lie somewhere on a "health index" for this individual. Future research may bring to light other factors that influence this threshold.

One example of where these thresholds come into play is with people affected by Multiple Chemical Sensitivity (MCS). These individuals report detecting odors at extremely low concentrations and that these observations lead to symptoms such as headaches, nausea, irritated eyes, ears, and throat. This condition may be due to an, as yet, unexplained shift in these thresholds.

THE TIME FACTOR

The odor concentration gradient described above becomes more complex when the last two levels in the "citizen complaint pyramid" hierarchy are considered. The duration and frequency of the odor episode could affect the position of the annoyance and health thresholds. For example, while an odor may be present at an intensity that would normally be annoying, if it is only present for three seconds the annoyance may not exist. Likewise, a very light odor that is present on and off for a week may become very annoying.

It is unknown how duration and frequency would effect the health threshold. Traditional toxicology would say that the longer the duration, the more severe the response. However, research has shown that chemicals at low concentrations do not necessarily follow traditional toxicology. Additional research is needed to better understand when and why health effects appear at certain concentrations for certain odors and odorants.

ODORS IN THE COMMUNITY

Through accepted olfactometry standards the detection and recognition threshold of a specific odor can be found.[5] A group of trained assessors' perceptions can be used to calculate an average for each of these thresholds.

However, at some point along the odorant gradient (increasing odor concentration) it is unclear when the odorant becomes a health effect for the community at large, because each individual in the community has a different point at which an adverse health effect appears. Current medical science and practice do not provide tools for identifying starting points of these health effects.

Furthermore, it is unclear whether the odor perception or specific odorants cause the health effect. For example, when an individual gets a headache when an odor is present, is that headache:

1.) due to the odor perception causing a physiological change?;

2.) due to the face reaction while the odor is present, such as a grimace?;

3.) due to a change in breathing patterns?; or

4.) due to chemical toxicology?

ODORS AND TOXICOLOGY

The world of odors and how humans react to them has to this date been basically ignored by toxicology. Those who assume that health symptoms from odors could not be caused by toxicological mechanisms are assuming that currently accepted standards and guidelines are sound and robust. However, there is little scientific research surrounding long term, low level exposure to chemicals or short term exposures with the olfactory area as a key route of exposure.

One example of the potential benefits to a greater understanding of this area of the human body exists at the University of Minnesota where researchers in the school of medicine are seeing effective results in preliminary clinical trials for the presentation of Parkinson's disease and Alzheimer's disease drugs to the brain through the olfactory area. They are using this route because skin injection and swallowed pills do not deliver enough drug to the affected area of the brain since a significant amount is metabolized before it reaches the brain. Increasing the concentration of the key ingredients presented through these routes makes the drugs toxic to other parts of the body. However, introduction of the drugs directly to the olfactory area allows the drugs to quickly pass the blood brain barrier without significant losses of dose.[6]

Furthermore, The California EPA summarizes the health effects of odors issue by stating that their investigations have led them to believe that the apparent health effects of chemical odors defy explanation by classical toxicological terms.[1] It is believed that non-traditional, olfactory related toxicological mechanisms likely prevail. It is commonly believed that odors alone cannot make you sick, however, no one disputes the ability of a summer barbecue odor to cause the stomach to growl and the mouth to salivate. It is the mechanisms of this example and aversion responses that is not yet fully understood.

RESPONSE MECHANISMS

There are three main theories of why adverse health effects are experienced with the presence of certain odors and odorants. These can be remembered as the "SAP", "SLAP", and "SPIN" theories of odor aversion.

The first theory ("SAP") is known as the "total body burden" theory. At some point a person's exposure to physical, chemical, antigenic, and psychological stresses exceeds a limit.[7] The individual's energy is "sapped" out of their body during challenges of these different stresses. When these stresses occur one way the body can react is with the immune system eliciting a response. These changes in the immune system lead to the various symptoms. Other research has shown that moods are negatively affected by unpleasant odors.[8,9] Furthermore, negative moods have been shown to affect the immune system function. Those who "oppose" the immune system theories feel the immune system is often blamed because of its complexity and unknowns related to mechanisms and how functional changes manifest themselves.[10]

The second theory ("SLAP") is known as the "conditioning" theory. After an initial exposure or after a certain duration of exposure, the body becomes conditioned to respond to stimuli through symptoms.[11] This could be solely an effect or it could be the body's way of warning of possible unknown future effects. It is thought that this conditioning is rooted in the powerful relationship of the olfactory system and memory. If a person is repeatedly tapped on the right shoulder and then slapped on the cheek as they turn to look, this person will begin to show a conditioned response of flinching whenever they are tapped on the shoulder. This person would show anxiety to being tapped on the shoulder which could lead to other symptoms such as sleeplessness, upset stomach, headaches, etc. caused by the fear of when they will be tapped on the shoulder next and then slapped or not slapped.

The third theory ("SPIN") is known as the "electrochemical response" theory. This theory is related to transmission pathways of the nerve signals or to the action of different neurotransmitters. One researcher has termed this electrochemical response "olfactory dementia",[12] which relates this theory to the large number of patients who report symptoms related to decreased cognitive function.[8] The olfactory system sends signals to the brain where they are processed and sent throughout the body. These signals may be "incorrectly" sent. For example, incorrect signals sent to the hypothalamus and pituitary may adversely effect the endocrine system and thus hormone balance. These adverse effects are then thought to cause the immune system to elicit a response, thus leading to further adverse symptoms. These incorrect signals put the body's physiology into a spin of confusion.

These three major physiological theories, 1.) total body burden ("SAP"), 2.) conditioning ("SLAP"), and 3.) electrochemical confusion or dementia ("SPIN"), have many similarities and cross over concepts. It is possible that each theory plays a role in the health effects. Conversely, future research may find other mechanisms that explain the symptoms of adverse health effects.

FUTURE RESEARCH

Currently, the amount of olfactory research being conducted is increasing. Measurement of odors and research in olfactometry, field observation, and electronic nose technologies are being conducted at commercial laboratories and university laboratories around the world (e.g. Univ. Of Minnesota, Iowa State Univ., Purdue Univ., Duke Univ., North Carolina State, Texas A&M, Univ. of Alberta, Univ. of Manitoba). These same universities are also conducting important research in methods of odor control and odor regulation.

Health based research is also being conducted at a variety of universities in many disciplines. At the University of Iowa, researchers in the Dept. of Agricultural Engineering are teamed up with public health researchers to look at the health effects experienced by workers in concentrated animal feedlot operations as well as the citizens in the surrounding communities.[4] Research at Duke University is looking at mood and other psychological characteristics of citizens near these feedlot facilities.[8,9] Furthermore, Universities such as Yale and Carnegie Mellon are conducting odor research involving functional MRI and other brain imaging techniques.

The success of future research will depend heavily on three main topics:

1.) who will conduct the research;

2.) what methods will be accepted; and

3.) who will fund the research.

It will be imperative for input between many disciplines and fields of study including, but not exclusively, neurologists, toxicologists, physiologists, psychologists, physicians, immunologists, microbiologists, and environmental specialists.

CONCLUSIONS

The medical community acknowledges that certain non-specific symptoms have causes (pathways) that cannot be presently explained using conventional medical or toxicological theories.

Citizens that perceive odors and report non-specific symptoms deserve to be heard and must be included in health based studies.

Current multidisciplinary research that is studying animal and human physiological and neurological responses to odorants will lead to new understanding of the ‘gray line’ between odor nuisance and health effects.

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Figure 1. Citizen Complaint Pyramid.

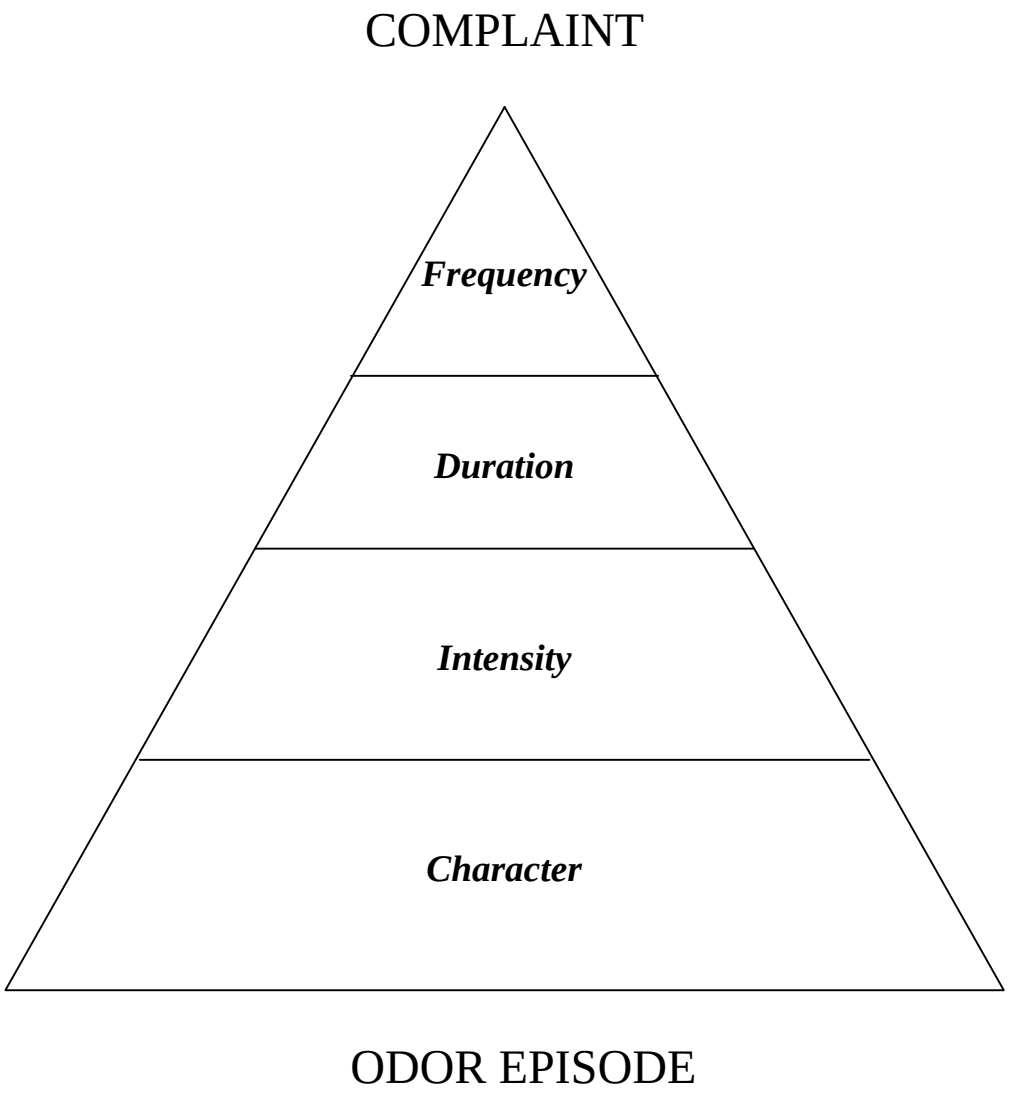

Figure 2. Individual Dose-Response Odor Concentration Gradient. DT = Odor Detection Threshold, RT = Odor Recognition Threshold, AT = Annoyance Threshold (beginning of Annoyance Index), and HT = Health Threshold (beginning of Health Index). All thresholds will vary from individual to individual as well as from odorant to odorant.