Journal of Water and Health | 04.Suppl | 2006

Aesthetic issues for drinking water

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ABSTRACT

Although many people expect their drinking water to be “flavorless”, natural and processed drinking waters have flavors due to minerals and organics in the natural water, inputs from any step of water processing or transport, and interaction of these chemicals with an individuals’ nose and mouth. Since people can detect the flavor of water, the idea has been proposed that drinking water consumers be considered as sentinels who monitor water quality. This paper explores specific sensory components of drinking water, how humans perceive their drinking water, and future directions for aesthetic research that can better explain causes of and treatments for tastes and odors in drinking water and the human factors that make water a desirable beverage.

Key words | flavor, odor, sensory perception, taste, water quality

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INTRODUCTION

To assess the future directions of aesthetic research for drinking water, a brief historical perspective is appropriate. In the late 19th century, water professionals and consumers throughout the world used tastes and odors to assess water quality. “Stinky” water containing septic odors and algal-by-products were driving forces for the formation of the American Water Works Association in the 1890s. Advances in microbiology, microscopes and public health in the early 20th century, caused sanitation and disinfection to become drivers for water quality. In the mid and late 20th century, scientific advances in chemistry and analytical instrumentation enabled monitoring of inorganic and organic chemicals in drinking water. Upon discovering that some of these chemicals were toxicants, regulations of chemical species became another focus for water quality (Federal Register 1979). In the late 20th century, the drinking water industry rediscovered aesthetics and began to adapt sensory-assessment methods from the food and beverage industry so that a microbe-safe, chemical-safe, and palatable product could be delivered to consumers (Cairncross & Sjóstróm 1950; Krasner *et al.* 1985; Bruvold 1989; APHA 1995; Dietrich *et al.* 2003). At the beginning of the 21st century, all three of these factors – microbiology, chemicals, and aesthetics – are foci for consumers, water producers, and regulatory agencies related to the delivery of safe drinking water.

doi: 10.2166/wh.2005.034

Issues

How do people evaluate and perceive their drinking water?

Consumers bring the same preference and discrimination techniques to drinking water as they bring to other foods. Consumers smell, taste, and look at their water. They feel it in their mouths, and occasionally they listen to it as it is poured or spews from the tap. Then, they make a judgment on the quality of the water, one that may be different from that made by water industry professionals, who treat and distribute water according to regulated criteria (Figure 1).

The sensory properties of water are a combination of its chemical content and responses of a person’s senses. Personal preferences for drinking water are based on both psychological and physiological factors. Psychological

Figure 1 | Consumers use their senses and personal opinions to assess drinking water, the quality of which is determined by the raw water source, the treatment, and distribution according to regulated standards.

factors include personal experience, memory, and external stimuli; physiological factors include biochemistry, physical body factors, health, and external factors such as humidity, temperature, etc. For many consumer products, people are looking for consistency - the product is of similar quality and quantity as when they previously used it. Inconsistency is a sign that the product is different, which could mean that the product is not good. Hence, consumers do not want variations in their drinking waters. Individuals acclimatize to their local water quality - whether treated tap water or a selected bottled water - and can notice changes (McGuire 1995; Lawless & Heymann 1998; Meilgaard *et al.* 1999). Consequently, the idea has been proposed that utilities consider using their consumers as sentinels for water quality monitoring because consumers are at all locations at all times and should be able to detect differences (Whelton 2003).

Flavor is composed of tastes (sour, sweet, salty, bitter, umami), mouthfeel, and odors that are either inhaled directly by the nose or are directed to nasal cavities through the back of the mouth. Although consumers generally expect their water to have little or no flavor, people can detect variations in pH, mineral, and organic content of drinking water. The perception of drinking water taste is relative to one's saliva. In consumer surveys, the taste of water is an important factor for consumers (note: consumers often interchange "taste" and "flavor" even though these terms have different technical definitions). A nationwide survey of 1,754 bottled water users found that 39% chose bottled water because it tasted better, while only 18% said it was because of safety (Kolodziej 2004). In a survey of consumers concerning home plumbing and drinking water, 34% said aesthetic factors (taste, odor, and color) were important (Kleczyk *et al.* 2005). Similarly, drinking water utilities find that the sensory properties of water are what consumers most notice and result in the most complaints due to tastes, odors, or particulates.

What provides water with its flavor?

Sources include: (1) the chemical and microbial content of the natural water, which is most influenced by geology and ecology; (2) chemicals added or removed during treatment and (3) inputs and reactions that occur during distribution and storage. These three factors contribute to water whether it is from the tap, treated on-site, or bottled and sold. Individual taste and odor compounds which result in sensory response can occur in concentrations from pg/l to mg/l. Although it is hard to generalize, certainly many nuisance organic odorants in water are present at ng/l concentrations, while many mineral species evoke a taste at mg/l concentrations (Mallevialle & Suffet 1987). The intensity and descriptors of odors can vary with concentration and temperature (Rashash *et al.* 1996; Lawless & Heymann 1998; Whelton & Dietrich 2004).

The mineral and natural organic matter contents vary geographically because of regional geology and are different between ground waters and surface waters. Thus, waters really do come in a lot of "natural" flavors, although the variations are not as great as food. Surface waters usually have higher dissolved oxygen, microbial, organic matter and particulate content as well as temperature variations from near freezing to warm. Ground waters tend to be at a constant, cool temperature with higher mineral content, fewer microbes and particulates, but can suffer from sulfide-like odors produced by sulfate reducing bacteria. Minerals can add a salty, sweet, bitter, or sour flavor to water, and certainly they are responsible for much of a waters' "mouthfeel".

Water can be an important source of nutrients, such as calcium, which are in higher concentrations in hard waters. Drinking water can be an important source for micronutrients such as copper, although when the copper concentration exceeds about 4 mg/l Cu, gastrointestinal upset, detectable bad taste, and toxicity can occur (Cohen *et al.* 1960; Pizzaro *et al.* 1999; Olivares *et al.* 2001; Dietrich *et al.* 2004). As with other situations in human health, "the dose makes the poison" and species in drinking water are not exceptions.

Natural waters are living ecosystems with plants, animals, and microbes, some of which contribute to the adverse aesthetic quality of water. Two well-known and studied, but still not well understood, examples of an ecology-related aesthetic problem are geosmin and 2-methylisoborneol, which are respectively responsible for earthy and musty odors. Cyanobacteria and actinomycetes produce these compounds, which are the main cause of ecology related taste and odor problems worldwide. Cyanobacteria can also produce toxic microcystins (Mallevialle & Suffet 1987; Suffet *et al.* 1995; Zaitlin *et al.* 2003). Humans detect these earthy and musty odors at concentrations of only a few ng/l and the ability to smell geosmin and 2-methylisoborneol is influenced by water quality factors, including the presence of chlorine, which masks, but does not remove, earthy and musty odors (Mallevialle & Suffet 1987; Rashash *et al.* 1996; Worley *et al.* 2003).

Chemicals added during treatment (certain disinfectants; such as chlorine, chloramines, ozone, and chlorine dioxide) are noted for impacting the sensory properties of drinking water either directly as odorants or indirectly through formation of odorous by products. Chlorine is the most noticed chemical flavor in drinking water, and interestingly, there are some individuals who do not think that the water is safe to drink unless there is a residual chlorine odor. The odor threshold for chlorine varies between North Americans and Europeans. The French, who normally drink water with no or low chlorine concentrations, have a lower threshold for detection than Americans (Mackey *et al.* 2004; Piriou *et al.* 2004). Ironically, all four of these disinfectants can both add and remove specific odors to and from drinking water (Hoehn *et al.* 1990; Dietrich *et al.* 1995). In spite of chlorine being an odorant, it can be applied to destroy fishy odors, while ozone, which is a powerful oxidant, will remove the earthy and musty odors of geosmin and 2-methylisoborneol but may produce fruity odors (Suffet *et al.* 1995). Physical treatment of water, such as filtration through activated carbon, is a well established technique for removing odorous compounds. Filtration through activated carbon does not remove all odors all the time, and may alter the mineral composition by removing nutrients like copper and calcium. Membrane filtration, particularly by reverse osmosis, is a technique for removing both minerals and organics that can produce water which is nearly pure H_2O. Such water can be highly corrosive to metal plumbing and not palatable to humans.

Utility personnel list the distribution system, which conveys water from the treatment plant into the home through pipes, valves, storage tanks, etc., as the main cause of taste and odor problems (Burlingame & Alselme 1995; Khiari *et al.* 2002; Marchesan & Morran 2004). Considering that there are hundreds of miles of pipe and many materials that contact most drinking waters, it is not surprising that the water distribution infrastructure results in water quality changes (Payment *et al.* 1997; Khiari *et al.* 2002; Edwards 2004). Similar issues impact the bottled water industry. Contaminants with sensory properties can both leach into the water from the bottle material, leach through the material into the water, such as gasoline through plastic pipe (Khiari *et al.* 2002) or support biofilms which allow microbes to grow and produce odorous metabolites (Block 1992; Kirmeyer & LeChevallier 2001; Camper *et al.* 2003).

An interesting example of microbes and odors in distribution systems is the biomethylation of chlorophenols and bromophenols to form haloanisoles which have earthy and musty odors at concentrations less than 1 ng/l (Burlingame & Anselme 1995; Bruchet 2001). Chemical reactions during storage and transport also produce undesirable odors, such as rancid odors from the reaction of chlorine and chloramines with oleate pipe lubricants (Burlingame *et al.* 1994). Chemical odors can also result from the leaching of petroleum chemicals used in liners for water towers and other parts of the water conveyance system (Rigal & Danjou 1999; van der Jagt 1999; Khiari *et al.* 2002; Tomboulian *et al.* 2004).

Recommendations for research

What is the future direction of aesthetic research, and how do aesthetics interrelate with human health and safe drinking water?

As this brief summary of taste-and-odor issues illustrates, aesthetic factors in drinking water are diverse, and they can be attributed to the natural water, inputs from any step of water processing or transport, or interactions with the mouth/nose.

Whether aesthetic problems are just nuisances or truly health threats (such as many septic odors or the almond like odor of cyanide), they are certainly the properties of drinking water which consumers first notice. From an evolutionary perspective, humans are hard-wired to notice differences and to proceed with caution when they are found. Water that is not palatable, although safe, will be avoided. Thus, addressing aesthetic issues is important, especially in the 21st century global economy where consumers are able to obtain consistent consumer products, such as name brand coffees or bottled beverages, 24 hours and 7 days a week, across the world at standardized retail outlets. It is not surprising that consumers are bringing the same demands to their drinking water as they do to other beverages. Future research into the aesthetic issues of drinking water will necessarily involve the hard sciences and social sciences, as well as engineering and medicine. Specific issues which need to be addressed are listed below.

(1) *Identify the chemicals which cause tastes and odors in drinking water*. Although the drinking water industry has made a good start through the taste and odor wheel (Khiari *et al.* 2002), the industry needs to expand this list and connect a specific chemical and concentration in water with defined sensory properties.

(2) *Identify the cause and source of a specific tastant or odorant (e.g. microbial produced, leached from materials, etc.) and, if necessary, develop mechanisms to control the sensory problem*. Although this task presents a great challenge in terms of the amount of time and effort needed for research, more information in this area would aid professionals and consumers in their desire to access palatable drinking water.

(3) *Determine population variations with respect to the ability to determine taste and odor compounds, e.g. thresholds, aguesias, and anosmias*. The concentration necessary for a single odorant or tastant to evoke a sensory response in humans readily can vary from 10 to 1000 fold, due to cultural, physiological, or even genetic based differences. Understanding how different human populations perceive aesthetics will be important in producing acceptable water.

(4) *Develop defined "odor" standards for the water industry*. Currently there are no odorants with accepted concentrations which represent specific odor intensities.

(5) The drinking water industry should undertake the challenge to understand the sensory behavior of compounds in mixtures. Similar challenges are being faced by toxicologists, food scientists, and the medical community as they develop individual and combination products to help consumers. A specific question for drinking water is: how do odorants and tastants interact and contribute to the overall perceived flavor?

(6) *Evaluate short and long term impacts of distribution and storage materials on water quality (aesthetic, chemical, and microbial), including leaching from, sorption to, and transmission through plastics, metals or concrete*. This should be done both in the laboratory and in the field.

(7) *Evaluate water quality changes from various treatments and devices used to improve aesthetic water quality*. When taste and odor compounds are removed, are desirable minerals and nutrients also removed and what is added? Does the consumer perceive the water as more aesthetically pleasing under all levels of treatment?

(8) *Determine preferences for different water qualities (e.g. chlorine content, mineral content, flavor components)*

and relate to demographic and geographic factors. Knowledge of what consumers desire as a palatable, potable water can be used to understand regional differences in water preferences or develop bottled waters which people want.

(9) *Develop the concept of consumers as sentinels of water quality and incorporate this into protocols that drinking water and health professionals use for "syndromic surveillance" efforts*. Syndromic surveillance refers to a methodology that relies on detecting health or water quality problems based on related behavior, such as reports of above normal cases of diarrhea, too many complaints about tastes and odors, excess bottled water purchases.

(10) *Explore the relationship between drinking water and health*, especially with respect to issues of nutrition (such as trace minerals) provided by drinking water and the daily quantity necessary for a healthy life.

(11) *Educate consumers about the value and reality of water and water quality*, particularly concerning issues of why waters from different regions are naturally different, the process and costs of water treatment, and that fresh water is a limited and valuable resource.

The challenge to the drinking water industry is to produce a beverage that is microbiologically and chemically safe, plus aesthetically pleasing. Professionals in all fields, physical sciences, biological sciences, social sciences, engineering, and medicine, are necessary to surmount this challenge. Safe drinking water is intimately tied to human health, as stated so elegantly by Lewis Thomas (speech, 1984), the renowned physician and author:

> *"There is no question that our health has improved spectacularly in the past century. One thing seems certain: It did not happen because of improvements in medicine, or medical science, or even the presence of doctors, much of the credit should go to the plumbers and sanitary engineers of the western world."*

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