

AN ABSTRACT OF THE THESIS OF

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Title: Carbonation and Its Interaction with Other Sensory Modalities

Abstract approved: Signature redacted for privacy.

Prof. Mina R. McDaniel

The study of carbonation perception is limited, even though carbonated beverages are very popular. A series of experiments were conducted to determine the sensory properties of carbonation itself and its interaction with other sensory modalities.

First, the power functions of carbonation in carbonated spring water were developed by a trained panel using two assessing conditions, swallowing and expectoration. Five carbonation levels, 1.2, 2.0, 2.5, 3.0, and 3.9 volumes CO₂, were employed. The size of the exponents, 2.79 (swallowing) and 2.65 (expectoration), suggested a sharp increase of perceived carbonation magnitude with increasing concentration. There was no significant difference between exponents resulting from the two assessing conditions.

Second, the effects of temperature on carbonation perception in carbonated spring water were determined by use of both a trained panel and a naive panel. Two carbonation levels, 2.4 and 3.0 volumes, and four temperature levels, 3°, 10°, 16° and 22°C, were employed. Carbonation intensity was perceived to be higher at lower

temperatures than at higher temperatures. This effect held true for both trained and naive panels. The temperature effect on carbonation perception, however, was carbonation level dependent. Differences were more evident at the higher carbonation level.

Thirdly, the mutual effects of carbonation and tastants (sweetener and acidulant) were determined by a trained panel. How CO₂ affects sweetness and how sweetener level affects carbonation perception were measured in both sucrose and aspartame sweetened systems. How CO₂ level affects sourness and how acid level affects carbonation perception were measured in both citric acid and phosphoric acid acidulated systems. The effects were measured at concentrations of 2-16% (w/v) for sucrose, 0.015-0.12% (w/v) for aspartame, 0.02-0.29% (w/v) for citric acid, and 0.015-0.06% (v/v) for phosphoric acid. Higher carbonation reduced sweetness ratings in aspartame-sweetened samples but had no effect on sweetness in sucrose-sweetened samples. Only the highest concentration of sucrose (16% w/v) reduced carbonation perception. Carbonation enhanced sourness ratings at the lower acid levels and had no effect at higher acid levels for both acid systems. No effect of acid level on carbonation perception was found.

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**Carbonation and Its Interaction with
Other Sensory Modalities**

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Carbonation and Its Interaction with other Sensory Modalities

INTRODUCTION

The consumption of carbonated beverages in the U.S. has increased dramatically since 1960 (Shanken, 1979). The history of carbonated beverages goes back to the seventeenth century when they were developed in Britain; they became popular in the 1880's in the U.S.A. (Jacobs, 1959a). They are currently the most popular drinks in the beverage market.

The popularity of carbonated beverages has resulted from their zest and unique taste, and the "refreshing" aftertaste which contributes positively to their acceptance. The effervescence in carbonated beverages such as soda pop, beer and sparkling wines, is due to the carbon dioxide they contain. The sensation results from the impingement of bubbles of escaping CO₂ gas against the wall and roof of the mouth and the tongue. This sensation is called "carbonation perception" in this study.

Although carbonated beverages have been popular for several decades, little has been published about carbonation perception. Carbonation perception is different from the classical perception of olfaction and gustation since it is actually a "mouthfeeling". Garcia-Medina and Cain (1982) categorized this sensation as a common chemical sense (CCS), which is a sensory modality responsive to chemical stimuli but is, in respect, a skin sense.

Information on carbonation perception is limited. The sensory properties of carbonation are critical to the carbonated beverage industry. For example, how carbonation perception changes with concentration, how carbonation perception is affected by temperature and viscosity, or how it is affected by sweeteners, acidulants and other additives in the beverage are all unknown. On the other hand, how carbonation will affect the sweetness, sourness, flavor and perceptual viscosity in a beverage are also of interest. Information such as this is very useful and practical to the industry in terms of product production, formula modification and new product development. Furthermore, the assessing conditions, like swallowing vs expectoration, or drinking from a cup vs sipping from a straw, may affect perception. This information refers to consumption behavior and may be useful to the marketing department. Research into carbonation perception could take many directions.

This dissertation represents the first steps of ongoing research at Oregon State University to answer questions regarding carbonation perception. The research goals are to determine the sensory properties involved with carbonation perception and to establish the basic models to describe these properties. Secondly, the interactions between carbonation and other sensory qualities were investigated. The objectives chosen to meet these goals include:

- (1) To determine the power function of oral carbonation perception in carbonated water.
- (2) To determine how the power function of carbonation perception is affected by swallowing and expectoration.

- (3) To determine the effect of temperature on carbonation perception in carbonated water within a reasonable temperature range.
- (4) To determine how the effect of temperature on carbonation perception is affected by panel training (trained panel vs naive panel).
- (5) To determine the interaction between carbonation and sweeteners for the systems sweetened with sucrose and aspartame.
- (6) To determine the interaction between carbonation and acidulants for the systems acidulated with citric acid and phosphoric acid.

LITERATURE REVIEW

CARBONATION

Solubility of carbon dioxide

Carbonated beverages are manufactured by the process of carbonation. The basic principle of carbonation is related to the solubility of carbon dioxide under certain conditions. Theoretically, the dissolution of a gas in a liquid follows Henry's Law. A state of equilibrium is reached when the liquid is saturated with gas. The solubility of gas depends on the temperature and pressure, as well as on the nature of gas and the liquid solvent (Glasstone and Lewis, 1960). The solubility decreases as the pressure decreases or temperature increases. The dissolution of carbon dioxide into an aqueous system obeys Henry's Law very closely at moderate temperatures and low pressure. As the pressure is increased or the temperature decreased, marked departure from ideal behavior (Henry's Law) becomes apparent. The influence of temperature on the solubility of carbon dioxide is greater than that on the solubilities of other gases (Glasstone and Lewis, 1960). This is related to the chemical reaction between carbon dioxide and water. According to Henry's Law, the solubility of carbon dioxide in a solution is proportional to its partial pressure above the solution.

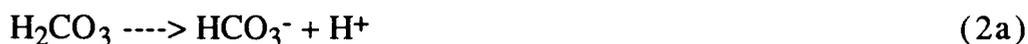
Quinn and Jones (1936^a) reported that most inorganic compounds decreased the solubility of carbon dioxide in the solution at a fixed temperature. Certain carbon compounds like citric acid,

glycerol and sucrose also could decrease the solubility of carbon dioxide at fixed temperatures. This similar effect of sugar content in solution is also observed by Jacobs (1959b). The concentration of alcohol (% v/v) in solution affected the solubility of carbon dioxide, even though the effects were mixed (Quinn and Jones, 1936a). It is of special interest to note that the minimum solubility of carbon dioxide was observed at 28% (v/v) of alcohol in the solution at 20°C.

There is no universally accepted unit for the solubility of gas. The most common two units were discussed by Quinn and Jones (1939a): (1) Bunsen absorption coefficient is defined as "the volume of gas reduced to standard conditions which at the temperature of the experiment is dissolved by one volume of solvent, the partial pressure of the gas being 760 mm". (2) Ostwald solubility is defined as "the ratio of the concentration of the gas in the liquid to its concentration in the gas phase". The difference between the two is that the volume of dissolved gas in the second definition is not reduced to a standard condition. Based on the definition of the Bunsen absorption coefficient, the unit of measurement that has been adopted by the beverage industry as a standard is "volume". This is defined as "the amount of gas in ml that a given volume of water will absorb at 760 mm and 15.6°C" (Jacobs, 1959b). This condition registers as zero on the scale of gauges. For example, at 0°C and 0 psi, one vol. of water can dissolve 1.7 vol. of CO₂. If the pressure increases 1 atm (14.7 psi) at the same temperature, the solubility increases an additional 1.7 vol. of carbon dioxide.

Mechanism of carbon dioxide dissolution

As gaseous carbon dioxide is pumped through water, the carbon dioxide disperses or dissolves into the water system, and becomes aqueous carbon dioxide. Carbon dioxide molecules are surrounded or absorbed by water molecules. Then the chemical reaction between water and carbon dioxide, the hydration of carbon dioxide, occurs. Daniels et al. (1985) reviewed the mechanism of the hydration of carbon dioxide. The three major reactions of carbon dioxide in aqueous solution are:



Step (2a), the dissociation of carbonic acid to the bicarbonate ion and hydrogen ion occurs very quickly, though step (1a) occurs very slowly. The overall dissociation of carbonic acid to the various ions depends on the pH of the solution. At $\text{pH} < 6$, the predominant form is $\text{CO}_{2(\text{dis})}$; at $\text{pH} 7-10$, the predominant form is HCO_3^- while the predominant form is CO_3^{2-} at $\text{pH} > 11$. They also found that the average estimation of the proportion of carbonic acid to be about 2% of total aqueous carbon dioxide. This hydration mechanism was also discussed in detail by Kern (1960), who reported that only a small fraction of aqueous CO_2 exists in the hydrated form, H_2CO_3 , and that is due to the slowness of the interconversion of carbon dioxide to hydrated carbonate species, which is an important concept to the industry. At $\text{pH} < 8$, the predominant pathways are:



The (2b) reaction occurs instantaneously as (1b) occurs. At pH > 10, the predominant pathways are:



The (2c) reaction occurs instantaneously as (1c) occurs. In the pH 8-10 range, all pathways are important. Quinn and Jones (1936^b) stated that when carbon dioxide dissolves in water an equilibrium is set up between the various molecules (CO₂, H₂O and H₂CO₃) and the ions (HCO₃⁻, CO₃⁻²). The carbon dioxide in solution is also in equilibrium with the undissolved carbon dioxide in the gaseous phase of the system. Approximately 0.2-0.5% of the total aqueous carbon dioxide is in the form of carbonic acid.

pH of carbonated solutions

The acidity of a solution containing dissolved carbon dioxide increases because of the formation of carbonic acid. Larsen et al. (1918) first reported that the degree of the acidity of a carbon dioxide solution under pressure lies between pH 3 and 4 when CO₂ pressure ranged from 1-50 atmospheres. Valley and Rettger (1927) also found that the pH of carbonated agar dropped to 4.3 and that of carbonated water dropped to 3.8 at 95% CO₂ by volumes. They also reported that a large amount of carbon dioxide is necessary to cause any appreciable change in pH of ice cream since ice cream is highly buffered. Prucha et al. (1931) made a similar observation in their study on carbonation of cream. The percentage of acidity (computed as lactic acid) of cream was increased from 0.12 to 0.28 at 4.4°C. A review of systematic studies in the dissociation of H₂CO₃ under high

pressures was conducted by Quinn and Jones (1936b). They stated that the pH of a water solution of carbon dioxide could be calculated from the partial pressure of carbon dioxide and dissociation constants. But the dissociation constant depends on the CO₂ concentration and is not constant as assumed in the calculations. They found the pH of a solution decreased when the pressure increased at a fixed temperature. At 0°C and 1 atm CO₂ pressure, the pH of a solution is 3.5. The pH could reach 3.2-3.3 at 20-30 atm or reach 2.9 at 50 atm. The significant drop in pH (to 3.8-4.4) in carbonic acid solutions was also reported by Becker (1936), and Koser and Skinner (1922) in their research. However, Jenness and Patton (1983) reported the pH of carbonated milk (240 ml/l) decreased only from 6.6 to 6.3. This observation was attributed to the strong buffer system in milk. This is in agreement with the results from Yau et al. (1989).

Evolution of carbon dioxide

Most carbonated beverages are bottled through supersaturation with carbon dioxide. The supersaturation of carbon dioxide in beverages is of special importance to the beverage and bottling industry. The loss of carbonation is a serious problem in the manufacture and consumption of carbonated beverages. Sudden or rapid loss of carbonation is termed "boiling" when it occurs at the filler and "gushing" when it occurs as the bottle cap is removed (Jacobs, 1959b).

The phenomenon of the evolution of carbon dioxide from supersaturated solutions was studied by Findlay and King (1913).

They found that the rate of desaturation was proportional to the concentration of the gas in the solution. They discussed evolution in both unagitated and agitated situations. In unagitated supersaturated solutions, the escape of gas on reduction of the pressure to atmospheric was succeeded quite sharply by a period of quiescence. During this period, no gas was evolved from the supersaturated solution. This quiescence was obtained only if the solution was allowed to maintain undisturbed after saturation. This period, however, did not persist indefinitely. After a certain time, a rapid evolution of gas set in. In this metastable condition, the solution is exceedingly sensitive. A very slight mechanical shock is sufficient to cause a considerable evolution of gas. The evolution is also caused by other small dirt particles or grease on the walls of the vessel, or small particles of solid in the solution. When gaseous nuclei are formed, they will grow due to the diffusion of gas from the surrounding supersaturated solution into them. They become bubbles which increase in size, so evolution occurs. The rate of evolution of gas diminishes gradually as the solution becomes desaturated. However, the decrease in this rate was not continued but periodic. As the solution becomes less concentrated and the process of diffusion becomes slower, the length of the periods between the rapid evolutions of gas becomes longer. The ratio of the volume of gas which passes into solution through a unit area in a unit time (invasion coefficient) to the volume of gas which similarly passes out of solution (evasion coefficient) is constant, and equal to the absorption coefficient. The cause of gas release with agitation is not entirely clear; it is probably due to increased contact with nuclei.

The rate of gas evolution in an agitated supersaturated solution is proportional to the degree of supersaturation.

Findlay and King (1914) also studied the factors that affect the rate of evolution. They reported that the solutions of gelatin, agar, peptone and ferric hydroxide cause more rapid evolution of gas initially than in the case of water, as do the solutions of dextrin and starch. They also found these phenomena depend on the concentration of those colloids and aging periods. Furthermore, Findlay and Howell (1922) discussed the effect of those colloids on the rate of carbon dioxide evolution. They believed that it is not surface tension nor "blocking action" that determines the rate of escape, which was assumed before, but rather the inner pressure of solution which relates to diffusion.

Jacobs (1959b) summarized that rapid loss of carbonation is due to (1) presence of discharge nuclei (2) excess air in the drink (3) unnecessary agitation (4) improper storage. The nuclei effect depends on the shape and size of the particles. More rough, irregular-shaped particles are more likely to act as nuclei. Sometimes heavy metals contaminated in the system act as nuclei, or even the scratches in the interior bottle walls as well as the microorganisms and oil droplets could be the nuclei. Improper storage, such as at high temperatures, could also cause a problem.

Foam formation

During gas evolution, foam is formed if the surface tension of the system is proper. Foam is an emulsion of gas dispersed in liquid. In other words, foams are agglomerations of bubbles. Bikerman

(1973) discussed the principle of foam formation. There are two types of foams: (1) the dispersion type, defined as "when air is injected into solution, a large volume of gas is comminuted and mixed with the dispersion medium (liquid)", and (2) the condensation type, defined as "when pressure in the liquid saturated with compressed gas is released, the excess dissolved gas combines to large aggregates to form bubbles". When bubbles reach the upper surface of the liquid, the surface tension of the liquid determines the foam formation. If the liquid has no foaming tendency (improper surface tension), bubbles burst at once. If the liquid provides a film which has significant persistence, bubbles lift a dome and foam is formed. Walstra and Jenness (1984) stated that the surface tension depends on the composition of the two phases and the substance absorbed. Surfactants usually are amphiphilic molecules and could be either antifoaming or foaming agents. Proteins usually are surface active macromolecules. Yau (1987) reviewed some aspects of foam formation.

Carbonation procedures

Carbonation in the beverage industry is defined as "the process of saturating the beverage with carbon dioxide" (Phillips and Woodroof, 1981). This is a practical application of the solubility of carbon dioxide. Phillips and Woodroof (1981) discussed the conditions encountered in industry. The equilibrium pressure for the gas-liquid system will vary with temperature and the amount of gas and liquid present. The time required to reach equilibrium depends on the relative area of the liquid surface exposed to the carbon

dioxide gas. Agitation may be employed to increase the contact area and then hasten the establishment of the equilibrium pressure. This helpful shaking (agitation) was reported 50 years ago (Prucha et al., 1931). Cooling the water is necessary to enhance the absorption. The combination of a large contact surface and high pressure enables cold water to absorb the gas quickly.

Air, in varying amounts, will accumulate in the carbonator during processing. The pressure gage on the carbonator indicates the sum of the pressures of all the gases present in the carbonator. The actual CO₂ pressure in the carbonator is always somewhat less than the pressure read on the gage and varies with the amount of air in the system. This is one of the reasons why the estimation of carbonation in the finished product is not totally accurate if it relies on the temperature and pressure of the carbonator alone. Air in carbonated beverages causes other troubles such as: (1) air may be a nuclei for facilitating the gas escape at the filler or as the cap is opened, (2) oxygen may encourage the growth of certain types of microorganisms, (3) air may affect the flavor and color loss due to oxidation, and (4) air may assist in the darkening of the crown disc. An additional amount of air may be entrapped in a bottle from the time the bottle is filled until the bottle is capped. Also the greater the volume in the headspace, the greater the amount of air. Higher pressure filling caused higher bottling speed which tends towards higher air content in the headspace of containers.

Carbonation level testing

Uniform carbonation at the required gas level is one of the critical items in quality control for the carbonated beverage industry. The carbonation level test for individual finished products is important. Based on the principle of the solubility of carbon dioxide, Zahm and Nagel Co. developed a method to test carbonation, which has been widely accepted in the beverage industry. It employs a Zahm piercing device (Zahm and Nagel Co., 1964) which makes possible the measurement of pressure of headspace and temperature; the accurate gas content in the system can then be calculated.

In order to avoid or remove the bias reading from excess air mixed with CO₂ in headspace, Phillips and Woodroof (1981) suggested two ways to revise the error: (1) After the pressure measurement, the headspace gases are released into a burette filled with a sodium hydroxide solution. This solution absorbs all of the CO₂, leaving only air in the burette. Nearly all the air present in system can be transferred to the burette by repeated shaking and release of gas into the burette. The air content of the burette is then measured and the total pressure value is corrected for the amount of air present; (2) Before the pressure measurement, "sniffing" of the headspace will be used. Sniffing is a procedure that employs shaking the container to fill the headspace of the container with gas (CO₂ and air) and then releasing the gas from the headspace. The purpose of sniffing is to expel the air present. This is possible because air is only slightly soluble in water and most of it is present in the headspace of the container.

Due to the decreased sensitivity of piercing devices to the lower pressure of headspace, some other methods have been considered for lightly carbonated beverages. Morrison (1962) suggested an enzymatic determination of carbon dioxide. The author used carbonic anhydrase to catalyze the hydration of CO_2 . This can facilitate the slow reaction during the titration measurement. Furthermore, Caputi et al. (1970) developed a titrimetric method which combined the enzymatic and volumetric methods. They used carbonic anhydrase to facilitate the reaction. However, they conducted titration measurements within a certain pH range. The hydration of carbon dioxide is affected by the pH level in the system. Based on this principle, they found the amount of hydrogen ion used for titration between pH 4 and 8.6 is equivalent to the amount of CO_2 initially present in system. Although a number of methods are available for carbon dioxide determination, many are time consuming (like the manometric method in AOAC) while others do not provide the required precision.

An increase in temperature may be necessary to get a reading in the accurate range when using a piercing device for low carbonation levels. A corrected CO_2 volume reading may also be necessary to remove the variation in volume of the headspace of the container.

Effect of carbon dioxide on bacteria

Van Slyke and Bosworth (1907) first reported fresh milk can be kept in good condition for several weeks by treatment with carbon dioxide under a pressure of 70 pounds or more. Koser and

Skinner (1922) also found a very high pressure of carbon dioxide is necessary to achieve inhibitory action on microorganisms. Prucha et al. (1931) studied the effect of carbon dioxide on bacterial growth in several different dairy products and found that carbonation tended to inhibit the multiplication of some bacterial species but not others. In general, carbonation did not prevent, nor in most cases did it retard, the deterioration of dairy products. The effect of carbonation on bacteria depends on the nature of the bacterial contamination. It is also affected by storage conditions such as temperature.

Tomkins (1932) found that the retarding effect of CO₂ on growth of fungi was not due to pH decrease and was independent of oxygen concentration within wide limits. The author also reported that the latent period of germination for certain fungi increased markedly in the presence of CO₂. King and Nagel (1967) found that CO₂ inhibited the metabolism of Pseudomonas and also concluded that this inhibition is due to gaseous CO₂, not a pH decrease, since other environmental factors were controlled. Daniels et al. (1985) reviewed the effect of CO₂ on the growth of microorganisms. They found carbon dioxide to be effective for foods whose spoilage flora is dominated by gram-negative, aerobic and psychrotrophic bacteria. The overall effect of carbon dioxide is to increase both the lag phase and the generation time of spoilage microorganisms. The mechanism could be (1) displacement of oxygen (2) intracellular acidification (pH decreasing) (3) rapid cellular penetration (4) alteration of cell permeability (5) negative effect on enzymatic and biochemical pathways.

Carbonation effect on sensory properties

Published research on the effect of carbonation on sensory properties is limited. Van Slyke and Bosworth (1907) reported that the carbonated milk in their study has a "slightly acid, pleasant flavor" and "somewhat more saline than ordinary milk". They also found the cream separated in the bottle and remixed after a little shaking without appearance of separate particles of cream. Baranowski and Park (1984) studied the effects of titratable acidity and carbonation level on preference of pineapple juice. Juices were carbonated at three levels, 2.5, 3.0 and 3.5 vol. CO₂. Eighteen untrained panelists ranked the samples based on preference. They found that the lower level of carbonation (2.5-3.0 vol.) was preferred and concluded that carbonated pineapple juice could be an acceptable and popular drink. At the same time, McLellan et al. (1984) reported on the descriptive analysis of apple juice carbonated at 0.6, 2, 3.5 and 4 vol. CO₂. Perceived sourness increases with increasing carbonation and perceived mouthfeel (body) decreases with increasing carbonation. On interpretation of the response surface, a specific optimum level of carbonation existed for each level of soluble solids in the carbonated apple juice. A maximum acceptability on the surface was obtained by calculation at 15.06 °Brix and 1.3 vol. CO₂. They proposed an equation for optimum levels of carbonation, based on soluble solids, as "vol. CO₂ = 5.79 - 0.29 (°Brix)".

Choi and Kosikowski (1985) carbonated sweetened and flavored yogurt beverages under 0.5 kg/cm² CO₂ at 4°C (approximately at 2.0 vol. CO₂) and measured consumer acceptance.

To avoid bias, the panel was divided into those who liked commercial yogurt and soft drinks, and those who disliked either or both of them. They reported that sweetened strawberry flavored carbonated yogurt beverages displayed a clean and high quality yogurt flavor, balanced between acidity, sweetness and fruit flavor. A tingling effect of carbon dioxide was described by many panelists as thirst-quenching and refreshing. They concluded that carbonation apparently enhances sensory qualities through its effect on mouthfeel. Yau et al. (1989) studied sweetened, blueberry-flavored carbonated milk beverages carbonated to 1.7-1.8 vol. CO₂. Carbonation enhanced the trained panel sensory ratings of overall flavor intensity, sweetness and blueberry flavor but not that of viscosity. Approximately 50% of potential consumers indicated they liked the products. Carbonation and sweetness level were near their optimum. However, King et al. (1988) carbonated Muscadine grape juice under 2 kg/cm² CO₂ at 2°C (approximately at 3.0 vol. CO₂) and reported that carbonated juices were preferred equally to non-carbonated juices, except for color. The color was lighter in the carbonated samples.

INNERVATIONS

Chorda tympani

The classic tastes, sweet, sour, salty and bitter, are perceived at the taste cell level in papillae which are located predominantly on the tongue. When chemical stimuli contact the microvilli of the taste

cell, they activate the nerve fiber which creates a change in the electrical potential of the nerve fiber (depolarization); the signals are transmitted via the chorda tympani (Cranial nerve VII) to the brain (Zotterman, 1971; Sekular and Blake, 1985).

Each taste bud is innervated by more than one nerve fiber. A single chorda tympani nerve fiber innervates several taste cells and therefore the response of a single fiber represents collective properties of several taste cells (Sato, 1971). Usually, a single cell possesses multiple sensitivities to more than one stimuli. Thus the multiple sensitivities of a single chorda tympani nerve fiber results from the multiple sensitivities of a single cell and the collective properties of several cells (Sato, 1971). Though a single chorda tympani fiber is not specifically sensitive to a particular chemical, there is a difference in the activity pattern produced by stimuli. They respond relatively selectively to different chemicals at varying degrees and rarely respond to only one stimuli. This relative specificity depends on the concentration of stimuli (Sato, 1971).

Although a fiber responds to more than one stimuli, it usually does not respond equally well to all stimuli. The fibers which respond to two of the four basic stimuli are the most common, followed by those that respond to one and three of the four taste stimuli and those that respond to all four stimuli are the least common (Pfaffmann, 1969). Pfaffmann (1969) also reported that 60% of the fibers are sensitive to NaCl, 60% are sensitive to HCl, 40% are sensitive to quinine and 40% are sensitive to sucrose. However, the sensory quality does not depend on the all-or-none activation of some particular fibers alone, but on the pattern of the active fibers

(Sato, 1971). The afferent neural message for quality is probably expressed in terms of the relative amounts of neural activity across many neurons. Stimuli which give similar patterns should taste somewhat alike, while stimuli producing highly dissimilar patterns should taste considerably different.

Trigeminal nerve

The trigeminal nerve, Cranial nerve V, innervates the mucosa of the eyes, nose and mouth. The distal afferents of this nerve are not regular neurons, but free nerve endings. Although trigeminal nerve endings can be stimulated by chemicals, they are usually considered as primary mediators of the sensations of pain, touch, temperature and proprioception (Silver, 1990). The trigeminal nerve endings are relatively specific. For example, some endings only respond to thermal stimuli while others only respond to mechanical stimuli. For chemical stimuli, they may stimulate either thermal or mechanical nerve endings (receptors), but are mediated by some much smaller and slower conducting fibers than those fibers for thermal or mechanical stimuli (Silver, 1990).

Carstens (1990) postulated that thermal and mechanical stimuli could cause some kind of decomposition of the tissue and release some biochemical compounds. These compounds could depolarize the nerve ending, then the signal is transformed to an electrical potential and transmitted via trigeminal nerves to the brain (or central nervous system). Chemical stimuli may act on the nerve endings directly to start the depolarizations. Cain (1981) found that the reaction time to nasal pungency fell markedly behind the reaction

time to odor in human subjects. The trigeminal system generally seems to react to chemical stimulation slower than to thermal or mechanical stimulation (Cain and Murphy, 1980).

Common Chemical Senses (CCS)

The CCS, different from the classical modalities of olfaction and gustation, is a sensory modality which is responsive to chemical stimuli but is a skin sense. It has been defined as "the sense of irritation aroused by the action of noxious chemicals on mucous membranes" (Silver, 1990). The receptors of the CCS are more widely distributed than those of olfaction and gustation (Silver and Maruniak, 1981). The CCS refers not only to chemical, but also to tactile or thermal perceptual qualities such as stinging, cooling, irritating, burning, prickling, and tingling (Cometto-Muñiz and Noriega, 1985). Examples of CCS perceived in food systems are chemical heat from capsaicin or pepperine, pungency from spices or herbs, ethanol in alcoholic beverages, and carbonation perception in champagne or soda. These sensations are mediated by free nerve endings that comprise the distal afferents of the trigeminal nerve.

The mechanism of carbonation perception is unknown. Carbonic anhydrase has been suggested to play a role in trigeminal sensitivity to CO₂ (Bryant et al. 1991). This enzyme catalyzes the hydration of CO₂ and therefore facilitates the diffusion (or transportation) of CO₂ stimuli in the receptor and nerve system.

Pain

Aristotle classified pain, not among the five primary senses, but as a passion of the soul that resulted from sensation. Carstens (1990) defined pain as a complex experience consisting of a variety of sensory, reflex, autonomic and emotional responses normally elicited by a potentially damaging noxious stimulus. Pain also can exist in the absence of overt damage. Pain is not a fixed response to a stimulus; it can be modified by past expectation and psychological conditions. The stimulus can be mechanical, chemical, electrical and thermal. Rachlin (1985) classified pain into two categories. First, fundamental "sensory" pain, which refers to a response to a given stimulus and is relieved by the removal of the stimulus. The intensity of response is a direct function of the intensity of various stimuli. The intensity of pain increases as the stimulus intensity increases up to intolerable levels. There is also spatial summation and temporal summation in the intensity of pain perception. For example, pain intensity increases with increasing stimulus area and with increasing stimulus frequency (or time). Second, "psychological" pain, which refers to a response that may not be relieved by the removal of the stimulus. The intensity is highly modifiable by various psychological factors (ex: hypnotism) or by external contextual events, but not normally eliminated by those factors. Sensory pain is more respondent and usually involved in a peripheral process. Psychological pain is more operant and usually involved in a central (integrated) process.

Pain is a three-dimensional perception (Rachlin, 1985). Usually, people can identify the quality of pain (ex: stinging, grinding, cutting)

first. The second dimension refers to the intensity (degree) of the pain (ex: mild, strong, severe) and the third dimension refers to the reaction to the pain (ex: bearable, uncomfortable, intolerable). The intensity dimension seems to measure the sensory component of pain while the reaction dimension seems to measure the psychological component of pain.

Pain adaptation is expected as pain sensation decreases as a function of the repetition of the nociceptive (harmful and/or destructive) stimulus (Ernst et al., 1986). The adaptation depends on the strength and rate of stimuli, on the general reactivity of the nervous system, and on the transient changes in mental states. Ernst et al. (1986) reported that the adaptation was of two types. "Primary adaptation" refers to the decrease of pain perception on repetition. "Secondary adaptation" refers to the decrease in pain sensitivity as measured at the conclusion of sequences of repeated stimuli. A similar primary adaptation has also been found at the central level. Such central adaptation evidenced the existence of a mechanism at the central level which is different from the sensory adaptation at the receptor level.

Recent studies have revealed that the thinnest myelinated (A-delta) and unmyelinated (C) nerve fibers have cutaneous receptors responsive only to noxious stimuli (Carstens, 1990). These receptors are called nociceptors. Nociceptors can encode noxious stimulation and are different from other mechano- or thermoreceptors which can not encode noxious stimulation. The major nociceptors on the A-delta fiber are mechanical nociceptors. The major ones on the C-fiber are polymodal nociceptors which can respond to noxious thermal,

mechanical and chemical stimuli on the skin. The nociceptors are specific to noxious stimuli and dictate pain sensation. However, the response of nociceptor starts to decline during the period when the intensity of perceived pain is increasing. This suggests that there is a central process involved. Carstens (1990) also postulated a common biochemical transduction process for all the chemical, thermal and mechanical stimuli on polymodal nociceptors. The stimuli evoke the release of intermediary biochemical substances, then these substances depolarize the receptors. The projection of nociceptors is through the spinal cord (spinothalamic tract).

INTERACTIONS

Although taste is probably the most specific sensory modality associated with the mouth, the sensations of the common chemical senses, pain, temperature, texture and touch can also arise in the mouth. Therefore, a large number of perceptual interactions occur among the different modalities in addition to the interactions among the tastes (gustations).

Gustatory interactions

The study of interaction is important because most sensory stimuli are in a complex system. A stimulus comprised of only one sensory quality is rare. Different sensory modalities are functionally independent. They do not combine together and produce a new modality in stimuli mixtures.

Most research has concentrated on interactions between the tastes. Fabian and Blum (1943) measured the effect of a subthreshold concentration of one substance upon the perceived intensity of a suprathreshold concentration of another. They proposed the competitive and compensatory actions for two tastes mixed together. "Compensatory" action occurs when a second substance influences the taste quality of the first one after mixing. The term "competitive" action is used when the second substance did not influence the quality of the original taste.

Pangborn (1961), in the study of the depression of sucrose sweetness by citric acid, compared the single stimulus and paired stimuli method. The paired stimuli method was slightly more sensitive than the single stimuli method, especially when one member of the pair within a set was kept constant. The author also reported that citric acid depressed the sweetness of sucrose. The masking of sweetness by acid was greater at lower than at higher sucrose concentrations. However, Kamen et al. (1961) conducted a series of similar experiments using a single-stimulus method. They concluded that citric acid generally increases the sweetness of sucrose while sucrose reduces the sourness of citric acid. This result was contradictory to Pangborn's (1961) results. Gregson and McCowen (1963) studied the relative perception of sucrose-citric acid mixtures at near threshold intensities. They reported that some subjects found citric acid increased the sweetness of sucrose, whereas the other subjects found the opposite. Gregson and McCowen (1963) stated that both concordant and contrasting response can occur as types of response behavior. Either theory is excluded as an

adequate general description of responses over the near-threshold range. The two types of change appear to be associated with two separate groups of judges. This can not lead to consistent changes in acceptability. They concluded that it is misleading to treat all judges as equivalent. Amerine et al. (1965) criticized the experimental design in Kamen's et al. (1961) study as it did not permit complete replication of all comparisons. This led to rather large error terms in some cases. They also agreed with Gregson and McCowen's argument. Individual differences might influence responses. The individual judge variation could account for lack of agreement among laboratories. Perceptual processes may affect the response, too. Therefore, controls and measures of the taster's prior relevant behavior are necessary.

Moskowitz (1972, 1973) provided a summary of studies on mixtures of substances. He suggested that suppression results when substances are mixed with different tastes, the more different the tastes the greater the suppression, while the simple additivity or synergism occurs when substances with similar tastes are mixed. Bartoshuk (1975) worked on the relationships between the perceived behavior of a mixture and the power function of each component in the mixture. She suggested that the psychophysical functions relating taste intensity to stimulus concentration of the unmixed components is a better predictor of mixture interactions than are the qualities of the components. When substances are mixed, their taste qualities can usually be recognized but intensities may be decreased (suppression) or increased (enhancement or synergism). There are three hypothetical psychophysical functions

that relate taste intensity to stimulus concentration. They are (1) compression where the slope of the function is less than one, (2) simple additivity where the slope is equal to one and (3) expansion where the slope is greater than one (Bartoshuk, 1975). Substances which show the least compression when unmixed also show the least suppression when other substances are added to them. The author hypothesized antidromic inhibition as a possible mechanism for suppression. This inhibition occurs as substances hyperpolarize the receptor membrane. The synergism in a mixture only occurs when one or both components show expansion.

Bartoshuk (1975) also studied more than two components in mixtures because she believed that the study of interactions in higher order mixtures offer a bridge between the simple stimuli of the laboratory and the complex mixtures actually encountered in the real world. In general, the more taste components in the mixture the more suppression exists. She concluded that mixture suppression encodes a potentially very large concentration range into a fairly small psychological range. Bartoshuk and Cleveland (1977) confirmed these results. They reported that suppression results from mixtures of substances with compressed psychophysical functions, and synergism results from mixtures of substances with expanded functions. The mixture suppression evident in these results contradicts the conclusion that substances that taste similar show simple additivity or synergism. However, Meiselman (1971) has reported that the shape of these psychophysical functions could vary from compression to expansion by changing the way in which a stimulus was tasted. Bartoshuk (1977) also reported the method of

presentation could result in different responses. The procedure where the stimuli were flowed across the subject's tongue tended to produce compressed functions, while the sip-and-spit procedure can produce expanded functions for sugars. The investigator concluded that whether or not all operations that change the shapes of psychophysical functions will change mixture interactions as well is not known. However, the results of these studies show that mixture laws can not be stated simply in terms of the qualities of substances to be mixed.

Kuznicki and McCutcheon (1979) provided another view point for the interactions among the taste qualities. They found that the intensity of one taste quality can be increased by prior exposure to another taste quality stimulus. This phenomenon is called "cross-enhancement". They proposed three possible explanations. First, this may be the result of interactions among the physiological mechanisms that code taste quality. The second possibility is the water solvent of the second stimulus produced a taste after exposure of the tongue to the first stimulus and added to the taste of solute in the second stimulus. A third possibility is that taste receptors on the tongue may be sensitized by exposure to a taste stimulus. Their research showed that the third explanation is the most acceptable. They found that sugars could act as proton acceptors and thus can make the receptor surface more receptive to protons in the acid stimulus. The proton acceptor NaOH could also enhance the sourness of citric acid. In the mixtures of sugars and acids, sourness was reduced even when the sweet taste system was blocked with *Gymnema sylvestre* extract. This outcome could result from

competition between sucrose molecules and receptor sites for hydrogen ions. They concluded that a taste stimulus may affect other taste receptor sites that are unrelated to itself, because of its physicochemical properties.

The mechanisms of the interactions between the tastes may also be applied to the interactions between the modalities.

Thermal interaction

Thermal sensations pervade the experience of eating and drinking. Thermal sensitivity has been reported to not vary with the rate of temperature change (Molinari et al., 1977). But Kenshalo (1970) reported that the thermal threshold is influenced by skin temperature, rate of temperature change and stimulated area of skin. Green (1984) reported that responsiveness to cooling was more homogeneous across oral locations compared to warming. In further research, Green (1986) concluded that the mouth is more sensitive to warming than cooling at both threshold and suprathreshold levels. The thermal sensations, both warm and cold, refer to certain sensory modalities.

Sato (1963) reported that the chorda tympani contains fibers mediating warm and cold sensations and classified the fibers into four categories. The first group, 50% of the fibers, responds to cooling, warming and taste stimuli; 30% responds to cooling and taste; 10% responds to taste only and the last 10% respond to thermal change only. This finding agrees with that of Oakley (1985), who found that the chorda tympani shows vigorous responses to mechanical touch and cooling of the tongue. Furthermore, Sato (1971)

found that the fibers which respond to cooling tend to be sensitive to HCl and quinine in rats, while those which respond to warming tend to respond to sucrose. So the thermal impulses play a very important role in discrimination of qualities of tastes.

The interaction of taste response and thermal perception is expected since most of the chorda tympani fibers respond to both taste and thermal stimuli. The effect of temperature on basic tastes has been extensively studied (Beidler, 1954; Sato, 1963 and 1967; Moncrieff, 1967; Pangborn et al., 1970; McBurney et al., 1973; Paulus and Reisch, 1980; Bartoshuk et al., 1982; Calvino, 1984; Calvino, 1986), though the results were not consistent. Moncrieff (1967) summarized that the sensitiveness of taste sensation was greatest when the stimulus was at a temperature in the range of 20-30°C, and decreased with increase or decrease of temperature. Sato (1963) also found the maximum sensitivity to NaCl and sucrose at 30-40°C, and to quinine and tartaric acid at 35°C, in a study of thresholds for NaCl, caffeine, quinine hydrochloride, citric acid and tartaric acid at temperatures of 10-60°C. The authors confirmed that the stimulus recognition thresholds were lowest at 20-40°C and increased with increasing temperature. Sekular and Blake (1985) summarized the temperature effect on the four basic tastes. The sensitivities to salty and bitter stimuli decrease as temperature increases, while that to sweet compounds increases with the increase of temperature. Sourness is relatively unaffected by temperature.

Thermal stimuli beyond certain ranges will cause a pain sensation which is mediated by trigeminal nerves. Stevens and Green (1978) studied the effect of temperature on the human touch

modality and verified that cooling intensified touch magnitude as perceived via the forehead and forearm. In further research, Stevens (1979 and 1982) and Stevens and Hooper (1982) confirmed that cooling and warming enhanced the touch sensation. Green (1990) also found the burn intensity from capsaicin was greater when the temperature was increased. The thermal sensation is mediated by trigeminal nerves as is carbonation perception. The interaction of thermal perception and carbonation perception is therefore expected.

SENSORY METHODS

Magnitude estimation

Magnitude estimation (ME), developed by Stevens (1957), is a ratio scaling method which yields a direct quantitative measure of the subjective intensity of an attribute. It has been used widely (Stone and Oliver, 1969; Moskowitz, 1970a, 1970b; Moskowitz and Sidel, 1971; McDaniel and Sawyer, 1981; Shand et al., 1985) In his study, Stevens (1961) found that ME is the sensory scale most directly related to the physical measurements of samples. Stone and Oliver (1969) used ME to measure relative sweetness and stated that it is a rapid, reliable and effort saving method. Moskowitz (1970^a, 1970^b) stated that the ratio of magnitude estimates of a single observer is kept during rescaling by the geometric mean normalization procedure. Moskowitz and Sidel (1971) also stated that ME can produce reliable and meaningful ratio scales of sensory magnitude that may be correlated with the measure of physical

intensity. Further, McDaniel and Sawyer (1981), and McDaniel (1985) found that ME results tend to show more differences when the differences among the samples are very small than do other methods. Lawless (1989) reported that the ME method was less efficient than the category scale or line scale in the hands of untrained consumers. Yau (1987) also reviewed the ME method.

Category scale

Category scales (CS) have long been used by psychologists to measure attitudes. They were introduced extensively in concept, principle and application by Guilford (1954). CS is a method used to rate the intensity of a stimulus by assigning it a category on a limited scale (Meilgaard et al., 1987). CS data are generally considered to be ordinal but not numerical. The CS method has limitations and disadvantages. Moskowitz and Sidel (1971) reviewed the limitations including (1) the CS lacks a true zero and interval or ratio properties, (2) judges tend to avoid using the extreme categories at both ends of the scale (central tendency error) and (3) the intervals between categories may be psychologically unequal. McDaniel and Sawyer (1981) concluded that the CS method resulted in more variability due to panelist and replication than the ME method. At the same time, Pangborn (1981) reported CS data to be less reproducible than ME data. However, Shand et al. (1985) reported that the CS method was as sensitive as the ME method to most treatment differences and the CS was preferred over the ME by panelists. The panelists thought CS was easier than ME to learn and required less effort in evaluation, especially as the evaluation involved several attributes

simultaneously. The CS may not provide enough information about treatment difference but is a useful tool in the general description of products and with untrained consumers.

THE POWER FUNCTION OF CARBONATION

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ABSTRACT

The relationship between the physical carbonation level of carbonated spring water and the magnitude of carbonation perception was determined by a trained panel using two assessing conditions - swallowing and expectoration. Spring water was carbonated to 5 carbonation levels. Panelists were asked to rate their perception of carbonation intensity by using magnitude estimation. The power function equations were established with high correlation coefficients for both assessing conditions. The exponents, 2.79 (swallowing) and 2.65 (expectoration), suggested a sharp increase of perceived CO₂ magnitude with increasing concentration. There was no significant difference between exponents resulting from the two assessing conditions. Therefore, the response should not be affected if samples are expectorated in studies of carbonation perception.

INTRODUCTION

The effervescence in carbonated beverages, due to the carbon dioxide they contain, makes a positive sensory contribution to the acceptability of soda pop, beer and sparkling wines. Little has been published about carbonation perception, which is different from the classical perception of olfaction and taste since it is a "mouth feeling". This tingling sensation is caused by impingement of bubbles of escaping CO₂ gas against the wall and roof of the mouth and tongue (Jacobs, 1959). Szczesniak (1979) stated that this sensation, which results from a very dynamic system in a state of disequilibrium, is due to the pressure differentials of CO₂ bubbles on the tongue. Pressure differentials caused by CO₂ bubbles are highly localized events and involve an element of pain. Garcia-Medina and Cain (1982) categorized this sensation as a common chemical sense (CCS), a sensory modality which is responsive to chemical stimuli but is, in respect, a skin sense. The sensations mediated by the CCS refer not only to chemical, but also to tactile or thermal perceptual qualities, such as stinging, cooling, irritating, burning, tingling, etc. (Cometto-Muniz and Noriega, 1985). The receptors of the CCS are more widely distributed than those for olfaction and gustation, since they are responsible for the chemical sensitivity of oral and nasal mucosae (Silver and Maruniak, 1981). Recently, this carbonation sensation has been described as "CO₂ oral pungency" (Cometto-Muniz et al., 1987). It is well-known that this sensation is associated with the stimulation of free nerve endings which belong primarily to the trigeminal nerve (cranial nerve V).

Magnitude estimation (Stevens, 1957) has been widely accepted as a scaling tool for use when studying the relationship between stimulus magnitude and response magnitude (Stevens, 1969; Anderson, 1970). The relationship between a stimulus and its perceived response has been established in a variety of sensory modalities (Moskowitz and Arabie, 1970; Moskowitz, 1970; Moskowitz, 1971; Meiselman, 1968; Sauvageot, 1987; Krajewska and Powers, 1988). Little work has been published on the relationship between physical carbonation level and magnitude of carbonation perception, although carbonated beverages have been popular for decades. Cometto-Muniz and Noriega (1985) studied the psychophysical function of CO₂ pungency and found the exponents of CO₂ nasal pungency were 1.6 for males and 2.2 for females while those of CO₂ buccal pungency were 1.1 for both males and females. However, the authors did not measure the exact carbonation level in their solutions. Instead, they prepared an oversaturated solution by pumping in CO₂ gas until 4.7 volumes of carbonation were reached and then diluted this solution to different percentages to obtain the various pungency levels.

Perception of carbonation may be influenced by a number of factors both in the carbonated product and in the testing procedures utilized. For example, the effect of swallowing should be investigated prior to extensive research on carbonated products. Expectoration has been employed widely in sensory testing in order to avoid fatigue, even though some scientists have criticized this practice because swallowing occurs during the normal consumption of foods and beverages (Lucas and Bellisle, 1987). Perception of carbonation

during swallowing may affect overall perception since carbonation is probably perceived by free endings of the trigeminal nerve in the throat area. The effect of swallowing or expectoration on carbonation has not been reported. In other flavored products, it has been hypothesized that swallowing would produce greater olfactory effects by increasing retronasal olfactory stimulation (Mozell et al., 1969). This hypothesis was partially supported by Frank et al. (1989) but not by Burdach et al. (1984). Kelly and Heymann (1989) contrasted the effects of ingestion and expectoration with paired comparisons and triangle tests in two systems : kidney beans with varying salt levels and nonfat milk with varying milkfat levels. They reported that there was no significant difference between ingestion and expectoration for either threshold or fatigue effect determinations.

The objectives of this study are to determine the power function, or growth of perception with increase in concentration, of oral carbonation perception in carbonated spring water and to determine how it is affected by swallowing and expectoration. The power function model will be very useful to further research on carbonated beverages and has practical applications in the carbonated beverage industry.

MATERIALS AND METHODS

Experiment 1

Sample production

Commercial spring water (Water-boy, Corvallis, OR) was carbonated with commercial carbon dioxide (Industrial Welding, Albany, OR) in a Zahm and Nagel 18.9-liter stainless steel carbonator (Zahm and Nagel Co., Buffalo, NY). Batches (7.5 liters per batch) of spring water were carbonated to 5 suprathreshold carbonation levels (Table 1), which covered the range of carbonation levels of commercial carbonated drinks, by controlling different pressures and carbonation times. Levels 1, 2 and 3 were carbonated at 0.35 kg/cm² (headspace) for 40 - 50 sec, 1 - 2 min and 5 min, respectively, and all bottled at 0.35 kg/cm². Level 4 was carbonated at 1.4 kg/cm² for 5 min and bottled at 1.4 kg/cm², while level 5 was carbonated at 2.8 kg/cm² for 5 min and bottled at 2.8 kg/cm². The carbonation unit was in an ice bath in order to hold the temperature at 00 - 10C. The samples were bottled in 355 ml clear bottles and stored at 10C. Twenty two bottles were prepared for each batch. Storage time before testing was 1 - 3 weeks. Carbonated water was produced twice for each level.

Carbonation measurement

A Zahm and Nagel piercing device (Zahm and Nagel Co., Buffalo, NY) was used to measure carbonation levels. Sample temperatures and the headspace pressures were taken for each of six bottles from each batch. Temperature and pressure readings were converted into "volumes CO₂ per volume water" by using a conversion table (Zahm and Nagel Co. Inc., 1964). The means and standard deviations of the 5 carbonation levels are shown in Table 1.1.

Table 1.1 Means and standard deviations (in parentheses) of the 5 physical carbonation levels* in both experiments.

Levels	Expt. 1	Expt. 2
1	1.3 (.100)	1.2 (.173)
2	2.0 (.198)	2.0 (.113)
3	2.4 (.156)	2.5 (.095)
4	3.0 (.265)	3.1 (.129)
5	3.7 (.224)	3.9 (.287)

* expressed as volumes CO₂ per volume water

Sensory measurement

Eleven panelists (3 males and 8 females), all students of the Department of Food Science and Technology at Oregon State University were recruited to form the panel. They were familiarized with different levels of carbonation and with magnitude estimation during 5 training sessions.

Swallowing was expected to affect carbonation perception even though, upon continued sampling, it might cause satiation and fatigue. Therefore, the power function determination was conducted for the same samples when expectorated and swallowed. Panelists were asked to hold the sample in the mouth for 3 sec before swallowing or expectorating.

Three panel replications were conducted for the first production replication and two for the second production replication. Two sample sets were prepared for each panelist for each session, one for the swallowing procedure and the other for the expectoration procedure. The presentation order of the two assessing conditions was randomized as were the samples on each tray. Magnitude estimation (Stevens, 1957) was employed for rating the samples. One reference, level 3, and four samples, levels 1, 2, 4 and 5, coded with three digit random numbers were presented on each tray. The carbonation perception intensity of the reference was assigned a value of 100. The reference was expectorated in the expectoration procedure and was swallowed in the swallowing procedure. Spring water was used as a warm-up or mouth-conditioning sample and was available for panelists throughout testing.

Samples were served at 9 - 120C in 60 ml plastic cups. Special steps were taken to minimize the escape of CO₂ : no pre-pouring of the sample was allowed; each bottle was opened and stoppered with a rubber stopper; any bottle opened for 15 min or contained less than 5 cm of remaining sample was discarded.

Data Analysis

Magnitude estimates were normalized for each panelist across all 5 replications (McDaniel and Sawyer, 1981; Stone and Oliver, 1969). The normalized data were then averaged across replications for each panelist. The geometric mean of the whole panel was calculated for each carbonation level. Power functions were established by regressing the log of the response (sensory) on the log of the stimuli (physical). Exponents between the two groups of replications (replications 1,2,3 and replications 4,5) were compared by using multiple regression analysis (Neter et al., 1983) in order to evaluate any possible learned or time effect.

Experiment 2

In order to quantify any difference in the carbonation power function when samples are expectorated and swallowed, a second experiment was conducted. Sample production procedures and physical measurement were the same as those in experiment 1. The means and standard deviations of the carbonation levels are shown in Table 1. Ten panelists (2 males and 8 females) were recruited to evaluate samples. Six of the panelists were the same as in experiment 1. The two assessing conditions were compared by

employing a common reference which was expectorated for both assessing conditions. Then samples to be rated were either expectorated or swallowed as required. There were 3 panel replications. All other procedures and conditions for sensory measurement were the same as those in experiment 1. The data for the two assessing conditions and three replications were normalized together for each panelist. Exponents between the two assessing conditions were compared by multiple regression analysis (Neter et al., 1983). The normalized data were analyzed by ANOVA using SAS (SAS Institute Inc., Cary, NC) to measure the main effects and their interactions. A compound F-test was used to calculate F values for treatment effects (Anderson and Bancroft, 1952).

RESULTS AND DISCUSSION

Experiment 1

The power law exponents for each replication and groups of replications are shown in Table 2. It was noted that, in general, the size of the power function increased across replications. Therefore, the difference in exponents between the first group of replications (1,2,3) and the second group of replications (4,5) was tested. There was no significant difference ($p > .05$) in exponents between the two groups, though the exponents for replications 4 and 5 were higher than those for replications 1, 2 and 3 for both procedures (Table 1.2). The exponents of the two assessing conditions were not compared

Table 1.2 Power law exponents of each replication and groups of replications for both assessing conditions in experiment 1.

Individual replications	Swallowing	Expectoration
1	2.59	2.27
2	2.33	2.48
3	2.75	2.81
4	2.94	3.25
5	3.29	3.30
Group replication means		
1,2,3	2.59	2.47
4,5	3.28	3.14
1,2,3,4,5	2.79	2.65

directly, because the references were treated differently in the two conditions.

The power function is normally expressed as (Stevens, 1970):

$$\log \psi = n \log \phi + \log k$$

In this equation, ψ represents the magnitude of response; ϕ represents the magnitude of stimuli; n represents the exponent which implies the rate of the change of response with the change of stimuli; and k represents a constant. The power functions for carbonation were then expressed as:

$$1) \log (\text{response}) = 2.79 \log (\text{concentration}) + \log (.103) \quad (\text{Eq.1})$$

($p \leq .01$)

$$2) \log (\text{response}) = 2.65 \log (\text{concentration}) + \log (.118) \quad (\text{Eq.2})$$

($p \leq .01$)

for the swallowing and the expectoration procedures, respectively. The correlation coefficients (r^2) were .970 for equation 1 and .965 for equation 2, suggesting a strong linear relationship.

The exponents reported here are higher than those reported by Cometto-Muniz and Noriega (1985). In their study they found a CO_2 nasal pungency exponent of 1.6 for males and 2.2 for females, and a buccal pungency exponent of 1.1 for both males and females. In the latter study the stimuli were dilutions from different percentages of an oversaturated CO_2 solution of distilled water, in contrast the samples in this study were produced in a pilot-scale carbonator. In the earlier study the actual CO_2 concentration was not measured. It is therefore difficult to compare their results with the ones found in this study. Rigorous comparison of the Cometto-Muniz and Noriega's results with the present study are further complicated due to the

lack of information on the extent of training of the panelists and the lack of information on serving temperature and method of sample presentation used in the previous study.

The sharp increase of perceived CO₂ magnitude with concentration is in agreement with work on nasal pungency by Garcia-Medina and Cain(1982), and Cain and Murphy (1980). Garcia-Medina and Cain reported that a two-fold change in concentration led to an almost three-fold increase in perceived magnitude. The exponents of carbonation perception in spring water obtained in the present study were also much higher than those of the basic tastes, 1.3 - 1.4 approximately for sweetness and saltiness, and 1.0 approximately for sourness and bitterness (Moskowitz and Arabie, 1970). This may be due to the two different perception systems involved. Carbonation perception is mediated by trigeminal nerves, as is electrical current intensity. The power law exponents of electric shock have been reported to be 2.26 (Cross et al., 1975), 3.5 (Stevens et al., 1958; Stevens, 1970; Hawkes, 1960a), and 3.7 (Hawkes, 1960b), although Algom et al. (1986) reported the exponent to be only 1.1. These results are in agreement with the high exponents reported here.

The sensitivities of individual panelists responding to stimuli vary. Therefore, it was of interest in this study to examine individual responses in carbonation perception. The exponents for each panelist over replications for both assessing conditions are given in Table 1.3. There was quite a variation among panelists within one assessing condition. The exponents ranged from 2.17 to 4.16 for swallowing and from 1.49 to 3.82 for expectoration. This kind of variation was

Table 1.3 The power law exponents of carbonation perception for each panelist for both assessing conditions in experiment 1.

Panelist #	Swallowing	Expectoration
1	2.17	2.13
2	2.62	2.80
3	2.30	2.19
4	2.49	2.67
5	2.38	2.35
6	3.63	3.81
7	3.29	2.39
8	2.31	2.69
9	2.84	2.81
10	4.16	3.82
11	2.52	1.49

also found by Adair et al.(1968) and Algom et al. (1986). Adair et al. reported the exponents of the perception from thermal irradiance for individual subjects were 0.53 - 1.95; Algom et al. reported the exponents for individual subjects ranged from 0.70 to 2.48 in the study of the power function of electrocutaneous stimulation.

Individual power functions may be influenced by individual preference or pain thresholds. In the present study, some panelists described pain as one part of carbonation perception while others did not. Cain (1981) stated that the preference for controlled common chemical stimulation varies markedly. For example, some people love hot spicy food, whereas others avoid it. The difference is postulated to be due to personal criteria used for judging and interpreting pain. This statement is in agreement with the results reported here.

Experiment 2

The power functions for swallowing and expectoration, respectively, were expressed as follows:

$$1) \log (\text{response}) = 2.37 \log (\text{concentration}) + \log (.140) \quad (\text{Eq.1})$$

(p ≤ .05)

$$2) \log (\text{response}) = 2.46 \log (\text{concentration}) + \log (.133) \quad (\text{Eq.2})$$

(p ≤ .05)

The correlation coefficients were .974 for equation 1 and .970 for equation 2. There was no significant difference (p >.05) between the exponents of the two assessing conditions (Fig. 1.1). This is in agreement with results reported by Burdach et al. (1984) and Kelly and Heymann (1989).

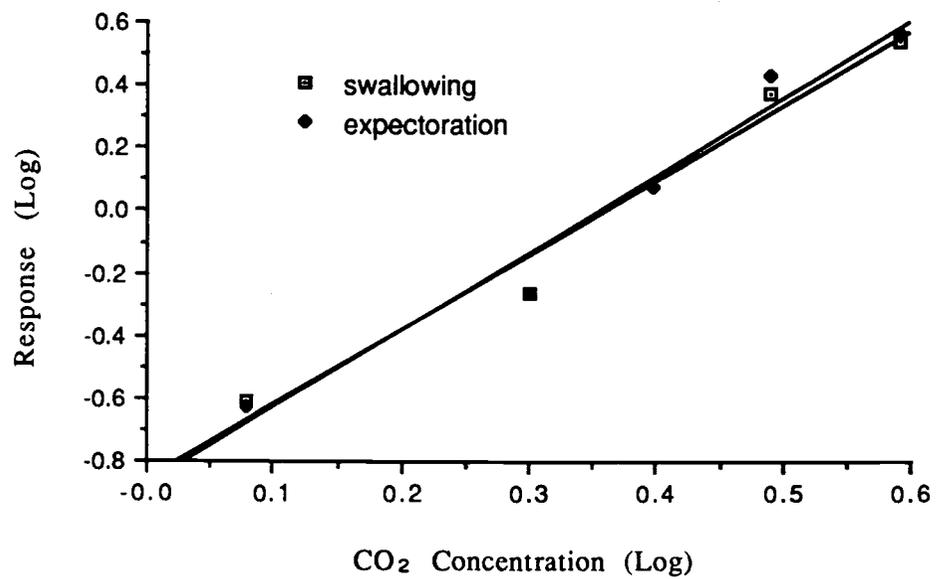


Fig. 1.1 The power functions of carbonation for swallowing and expectoration in experiment 2

Inspection of the fit of the regression line (Fig. 1.1) reveals that the rate of increase varied between carbonation levels. The rate of increase was slow between levels 1 and 2, more rapid between levels 2 and 4 and then slow again between levels 4 and 5. Polynomial regression tests showed that the models with the best fit were the third-order models (correlation coefficients were 1.0) for both swallowing and expectoration. This particular shape of the function held true among all replications and across both experiments. In several of the individual replications, a plateau occurred between levels 4 and 5. Carbonation perception at levels 4 and 5 may approach the terminal threshold. Therefore, the exact exponent resulting from an experiment of this type will be dependent upon the range of the carbonation levels tested.

ANOVA results, including the main effects of panelist, assessing condition and carbonation level, and their interactions are shown in Table 4. Although the interaction between panelist and assessing condition was not found to be statistically significant ($p > .05$), there were some panelists who perceived carbonation intensity differently in the two assessing conditions according to their comments. Some of them perceived swallowed samples to be higher in carbonation due to the augmentation of the perception in the throat (stinging perception). Other panelists rated the expectorated sample higher because they felt more bubbles on their lips during expectoration. There was a significant interaction ($p \leq .01$) between the panelist effect and the carbonation level effect (Table 1.4). Panelist 4 appeared to contribute to the interaction (Fig. 1.2). Panelist 4's data was removed, the remaining data was reanalyzed, and the

Table 1.4 The ANOVA table of carbonation perception across assessing conditions and carbonation levels in experiment 2.

Source	Degrees of freedom	Mean square	F
Panelist (Pan)	9	.38	3.46**
Assessing Condition (AC)	1	.40	1.50
Pan by AC	9	.22	1.99
Level (Lev)	3	53.58	174.23***
Pan by Lev	27	.38	2.79**
AC by Lev	3	.12	1.13
Error	27	.11	

** , *** refers to significance at $P \leq .01$ and $P \leq .001$, respectively

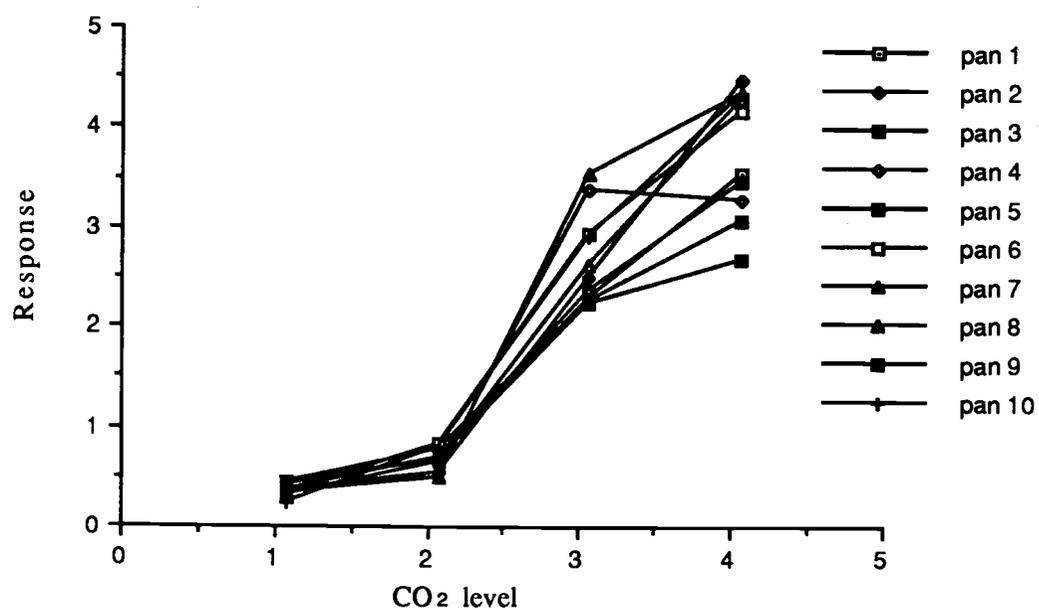


Fig. 1.2 The carbonation responses of individual panelists (averaged) over two assessing conditions) in experiment 2

interaction remained significant. Although all panelists perceived carbonation intensity increasing with concentration, their rates of increase were different which contributed to the interaction significance (Fig. 2). This may be due to the different sensitivities, personalities and backgrounds of the panelists. They may have different criteria for pain perception and therefore interpret the perception differently.

CONCLUSIONS

The power law exponents of carbonation perception in spring water were much higher than those for the basic tastes. They were also much higher than those previously reported for CO₂ nasal and buccal pungency. Therefore, a small CO₂ concentration change could cause a large change in carbonation perception in a carbonated beverage system. There was no significant difference between the power functions resulting from the samples having been expectorated or swallowed. Therefore, the data should not be affected if samples are expectorated in future studies of carbonation perception.

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**THE EFFECT OF TEMPERATURE ON
CARBONATION PERCEPTION**

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ABSTRACT

The objective of this study was to determine the effect of temperature on carbonation perception in carbonated spring water and to determine the influence of the degree of panel training on this effect. Spring water was carbonated to two carbonation levels, 2.4 and 3.0 volumes CO₂. The samples were served at 3°, 10°, 16° and 22° C, and evaluated by both trained and naive panels. Two assessing conditions, swallowing and expectoration, were employed to rate samples. Carbonation intensity was perceived to be higher at lower temperatures than at higher temperatures, even after having taken into account the fact that there was less CO₂ in the samples at higher temperatures. This effect held true for both naive and trained panels. The temperature effect on carbonation perception was carbonation level dependent; differences were more evident at the higher carbonation level.

INTRODUCTION

Carbonation perception is an important part of the total sensory experience associated with drinking carbonated beverages. The effect of temperature on perception of carbonation in such beverages is of interest. Fluids are consumed at temperatures anywhere from 0° to 75°C. For carbonated beverages the most common range of serving would be 0°-10°C, however under certain circumstances they could be consumed at room temperature or above. Serving at room temperature is rarely seen in the U.S. but may be more prevalent in other countries. The carbonation levels of commercial beers and most carbonated beverages range from 2.5 to 3.0 volumes of CO₂, while those of cola products are 3.5 volumes or above (Phillips and Woodroof, 1981). When a liquid is carbonated, both chemical and physical changes take place. Chemically, carbonation produces carbonic acid in the liquid. Physically, carbonation introduces dissolved gaseous CO₂ into the liquid. Both effects may contribute to the carbonation perception.

The sensory responses to carbonated stimuli may include sourness perception from the formed carbonic acid and carbonation perception from the dissolved CO₂. Sourness perception is mediated by the chorda tympani while carbonation perception is believed to be mediated by trigeminal nerves. The chorda tympani also contains fibers mediating warm and cold sensations (Sato, 1963). Since most of the chorda tympani fibers respond to both taste and thermal stimuli, an interaction between taste response and thermal perception might be expected. The receptors that respond to

mechanical stimulation may also respond to thermal stimulation (Stevens and Green, 1978) and to stimulation by CO₂. An interaction between carbonation perception and thermal perception is consequently expected as well. The effect of temperature on basic tastes has been extensively studied, although the results were not consistent (Beidler, 1954; Sato, 1963 and 1967; Pangborn et al., 1970; McBurney et al., 1973; Paulus and Reisch, 1980; Bartoshuk et al., 1982; Calvino, 1984 and 1986; Green and Frankmann, 1987). Sekular and Blake (1985) concluded that sensitivities to salty and bitter stimuli decrease as temperature increases, sensitivities to sweet compounds increase with temperature and sourness is relatively unaffected by temperature. No reports have been found describing the effect of temperature on the perception of carbonation.

Hilgard (1969) found that pain perception on the hand increased as the temperature of water decreased from 15° to 0°C in a study using the cold pressor test. Stevens and Green (1978) studied the effect of temperature on the human touch modality and verified that cooling intensified touch magnitude as perceived on the forehead and forearm. Stevens (1979 and 1982) and Stevens and Hooper (1982) confirmed in later research that cooling enhances the touch sensation. Green (1990) reported that burn intensity from capsaicin in the oral cavity increased with increasing temperature in the range of 12°-46°C.

The objective of the present research is to determine the effect of temperature on carbonation perception in carbonated spring water within a temperature range of 3°-22°C. Individual differences in response patterns will also be examined. Since the comparison

between trained panel and naive panel results was also of interest, a trained panel was used in the first experiment and a naive panel was used in the second experiment.

MATERIALS AND METHODS

Experiment 1

Sample production

Batches of commercial spring water (Aqua Cool, Portland, OR) were carbonated with commercial carbon dioxide (Industrial Welding, Albany, OR) in a Zahm and Nagel 18.9 liter stainless steel carbonator (Zahm and Nagel Co., Buffalo, NY). Seven and a half liters of spring water were carbonated for each batch. Two carbonation levels, 2.4 volumes CO₂ (C1) and 3.0 volumes CO₂ (C2), were employed. The carbonation unit was held in an ice bath to keep the temperature between 0° to 1°C for carbonation and bottling. The samples were bottled in 355 ml clear glass bottles and stored at 1°C for 1-2 weeks before testing. Carbonation levels were measured with a Zahm and Nagel piercing device (Zahm and Nagel Co., Buffalo, NY) as described by Yau and McDaniel (1990). Four temperature levels, 3°C (T1), 10°C (T2), 16°C (T3) and 22°C (T4), were chosen to cover a reasonable temperature range for consumption of carbonated beverages. Since it was not possible to avoid CO₂ escape during serving, a physical measurement of the CO₂ amount remaining after a simulated pouring procedure was conducted for each thermal level.

Each sample bottle was opened and poured into an empty bottle. After 2 min the sample was recapped and cooled to 3°C prior to carbonation measurement.

Sensory measurement

Eleven panelists (3 males and 8 females), all students of the Department of Food Science and Technology at Oregon State University volunteered to form the panel. They were familiarized with carbonation perception and magnitude estimation during 5 training sessions. During the training sessions, some panelists thought that a bubbling feeling was the major part of carbonation perception while others thought that pain was the major part of carbonation perception. The final definition of carbonation perception, "overall perception in the whole mouth including both bubbling feeling and pain perception", was decided through discussion.

Two assessing conditions, swallowing and expectoration, as described by Yau and McDaniel (1990), were employed. No fixed interval between samples for panelists was set. After rating one sample, the panelists were asked to rinse and then rest until any sensation ceased before taking the next sample. The approximate interval ranged from 40 sec to 2 min. The test was replicated three times for each carbonation level. Two sample sets were prepared for each panelist for each session, one for swallowing and the other for expectoration. The presentation order of the two assessing conditions was randomized, as were the samples on each tray. Magnitude estimation (Stevens, 1957) was the scaling technique used. The intensity of carbonation perception of the reference was assigned a

value of 100. Each sample was assigned a number reflecting perceived intensity as compared to the reference. One reference (C1T2) and 3 samples (C1T1, C1T3 and C1T4) were on each tray for the low carbonation level. The same reference and 4 samples (C2T1, C2T2, C2T3 and C2T4) were on each tray for the high carbonation level. The reference was expectorated in the expectoration procedure and swallowed in the swallowing procedure. Samples were served in 60 ml plastic opaque cups.

Data analysis

The geometric mean of magnitude estimates across replications for each panelist was calculated. The reference was included in the calculation of each geometric mean (McDaniel and Sawyer, 1981). The magnitude estimates of each panelist were subsequently rescaled by dividing by the individual geometric mean. The rescaled data were then analyzed through ANOVA using Statistical Analysis System (SAS Institute Inc., Cary, NY) for each carbonation level and for both swallowing and expectoration. A compound F test (Anderson and Bancroft, 1952) was used to test for the treatment effect. The Least Significant Difference (LSD) test (O'Mahony, 1986) was used to distinguish differences among the samples.

Panelists who were not reproducible were identified by using coefficient of variation (CV) values (Snedecor and Cochran, 1980) as an index. If the individual CV was greater than the panel CV, then the data of that panelist were excluded from analysis and the remaining data were reanalyzed to determine whether or not the mean square of the panelist by treatment interaction (P*T) was

decreased (Calvin, 1990). If the decrease was obvious, the data of the inconsistent panelist, who contributed to the P*T interaction, was excluded. For this experiment, data from panelists 5 & 10, who had the highest CVs and who contributed to the P*T interaction (mean square of P*T was reduced from 1.099 to 0.261 for the swallowed samples, and from 0.529 to 0.336 for the expectorated samples), were excluded for the carbonation level of 2.4. The comparison of the two carbonation levels at all temperatures was conducted by using a paired t-test (Meilgaard et al. 1987), as was the comparison between the trained and naive panels for the 2.4 vol. samples at all temperatures assessed by swallowing.

Experiment 2

Sensory measurement

Forty naive panelists (21 males and 19 females), all faculty, staff and students of the Department of Food Science and Technology at Oregon State University, were asked to evaluate the samples. One carbonation level (2.4 volume CO₂) was used. The panelists were asked to swallow the samples C1T1, C1T2, C1T3 and C1T4, and to rate carbonation perception using magnitude estimation. Panelists received no prior training in magnitude estimation and were instructed in the procedure only before testing. The C1T2 was chosen as the reference and its intensity of carbonation perception was assigned a value of 100. Samples were served in black opaque wine glasses in order to impede observation of any bubbles.

Data analysis

The data were rescaled using the geometric mean of the magnitude estimates for each panelist as described in experiment 1. The rescaled data were then analyzed through ANOVA using SAS (SAS Institute Inc., Cary, NY). The LSD test was used to distinguish differences among the treatment means.

RESULTS AND DISCUSSION

Experiment 1

Physical measurement

Means of CO₂ volumes measured after the samples had undergone the simulated pouring-procedure are plotted as a function of temperature in Figure 2.1. Although carbonation loss was 15% larger in the sample at 22°C compared to the sample at 3°C, there was no significant difference ($p > 0.05$) among samples at the 2.4 vol. level. However, there was a significant difference ($p \leq 0.05$) in CO₂ retention among samples at the 3.0 vol. level (Figure 2.1). Compared to the sample at 3°C, there was a 9% larger loss in the sample at 16°C and a 21% larger loss in the sample at 22°C. The evolution of CO₂ was more rapid at the higher temperature. Evolution of CO₂ from supersaturated solutions was studied by Findlay and King (1913). They found that the rate of CO₂ desaturation was proportional to the logarithm of the gas concentration in the solution. This is consistent

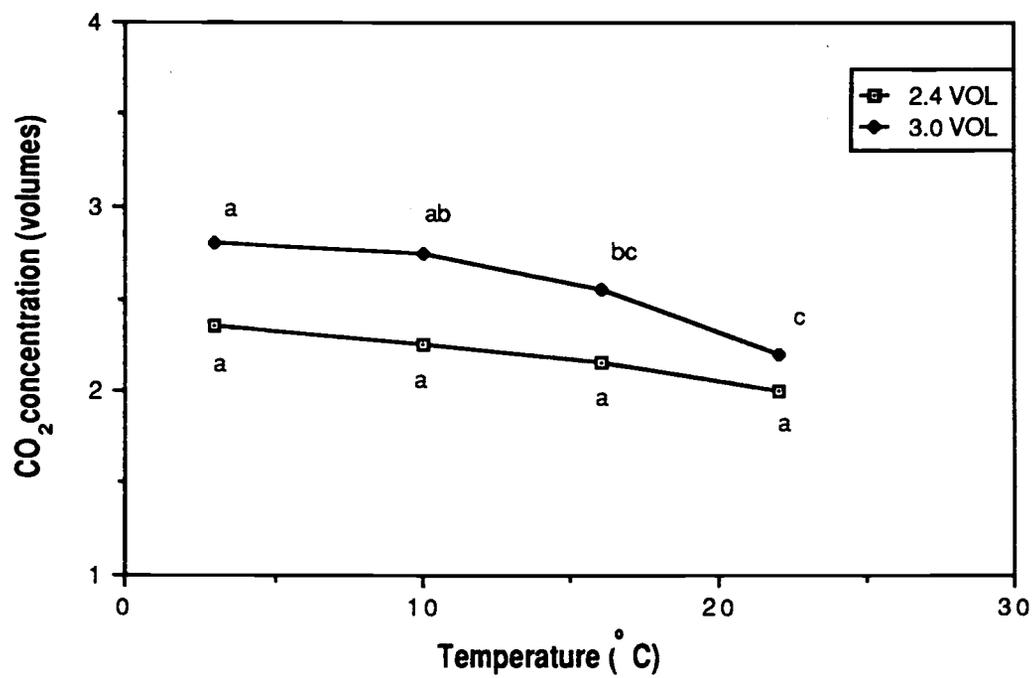


Fig. 2.1 The CO₂ levels of the four samples after the simulated pouring-procedure at both carbonation levels (Y axis: CO₂ concentration in volumes CO₂ per volume water, abc- points with common letters are not significantly different)

Table 2.1 ANOVA results of normalized magnitude estimates of carbonation perception for two assessing conditions and two carbonation levels from the trained panel

	Source	DF	Swallowing F-value	Expectoration F-value
2.4 vol.	Panelist(P)	8	0.51	0.41
	Temperature(T)	3	1.62	3.49*
	PxT	24	3.15***	4.69***
	Replication(R)	2	0.01	0.19
	PxR	16	0.08	0.19
	TxR	6	1.29	1.09
	Error	48		
3.0 vol.	Panelist(P)	10	1.39	1.18
	Temperature(T)	3	6.10***	9.62***
	PxT	30	2.13**	1.84*
	Replication(R)	2	0.14	0.05
	PxR	20	0.13	0.31
	TxR	6	0.37	1.48
	Error	60		

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

with the findings in the present study as more CO₂ was lost in the samples at 3.0 vol, correspond to a carbonation level of 2.4.

ANOVA results

The ANOVA results for the tests with the two assessing conditions at the two carbonation levels are shown in Table 2.1. Though there was not a significant temperature effect for the swallowed samples at the 2.4 vol. level, there were significant temperature effects on carbonation perception for the expectorated sample at the 2.4 vol. level ($p \leq 0.05$), and for both the swallowed and expectorated samples at the 3.0 vol. level ($p \leq 0.001$).

Temperature effects

In order to observe the effect of increasing temperature on carbonation perception over and above the loss of CO₂ in samples, CO₂ level and resultant carbonation perception were plotted on a log-log basis (Figures 2.2 and 2.3). On the same figures are the power functions of carbonation perception determined for both expectoration and swallowing in a previous study (Yau and McDaniel, 1990). If a low temperature enhances carbonation perception, but a high temperature does not, a graph of these data would result in a steeper slope than if no enhancement had occurred. For the 2.4 vol. level, the relationship followed a linear function for both assessing conditions. For expectoration, the slope of the function (2.87) was similar to that of the power function (2.46) obtained previously (Figure 2.2). For swallowing, however, the slope of the function (1.88) was lower than that of the power function (2.79) obtained previously

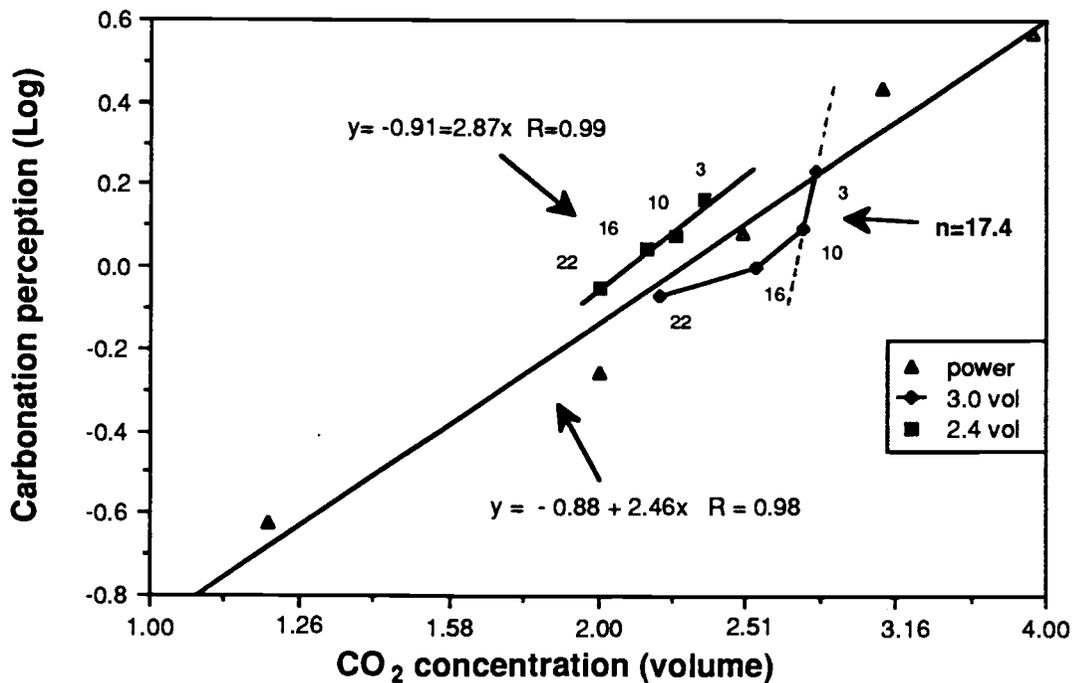


Fig. 2.2 The relationship between the CO₂ level and carbonation perception at the four thermal levels (3, 10, 16 and 22 refer to data from samples at 3°, 10°, 16° and 22°C) and at both carbonation levels for samples expectorated (Y axis: rescaled magnitude estimates of response, n: the decreasing rate, Δ: data from the previous power function study)

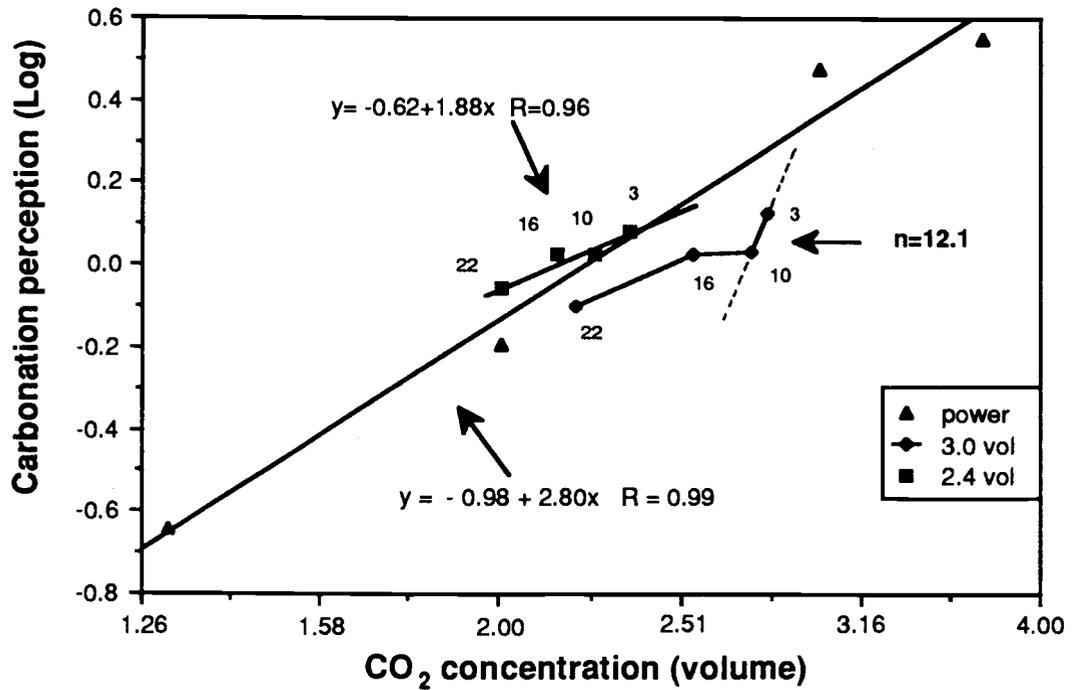


Fig. 2.3 The relationship between the CO₂ level and carbonation perception at the four thermal levels (3, 10, 16 and 22 refer to data from samples at 3°, 10°, 16° and 22°C) and at both carbonation levels for samples swallowed (Y axis: rescaled magnitude estimates of response, n: the decreasing rate, Δ: data from the previous power function study)

(Figure 2.3). This may be due to the smaller range of CO₂ concentration used in the present study. There was no temperature effect on carbonation perception from the point of view that the relationship followed a function which is similar to the power function. On the other hand, there was no significant difference in the CO₂ level of the samples for the 2.4 vol. level.

The effect of temperature was more noticeable for the samples at the 3.0 vol. level (Figures 2.2 and 2.3). The relationship among carbonation ratings across temperatures was not linear at the higher carbonation level, which suggests different effects occurring at different temperatures. There was a sharp decline in carbonation perception between the samples at 3°C and 10°C for both assessing conditions. A dotted line was used to indicate a "possible" decreasing rate which describes this decline (Figs. 2.2 and 2.3). The rates of these dotted lines were 17.38 for samples expectorated (Figure 2.2) and 12.13 for samples swallowed (Figure 2.3). The relationship among 10°, 16° and 22°C samples level out for both swallowing (slope=1.46) and expectoration (slope=1.60). There was more sensitivity between temperature levels at lower temperatures. Even after having taken into account the fact that there was less CO₂ in the samples at higher temperatures, carbonation perception was dramatically reduced by increasing the temperature from 3° to 10°C.

Comparison of the two carbonation levels

The comparison between the samples at 2.4 and 3.0 vol. levels is also shown in Table 2. There was no significant difference for the swallowed samples at 2.4 vol. level. For the expectorated sample at

the 2.4 vol. level, a significant difference could be detected only between the temperature extremes. Carbonation perception at 3°C was 1.7 times higher than that at 22°C. Differences were more obvious for the samples at the 3.0 vol. level, since a significant difference could be detected between the samples at 3°C and 10°C. For the swallowed samples, carbonation perception at 3°C was 1.2 times higher than that at 10°C and 1.6 times higher than that at 22°C. Similarly for the expectorated samples, carbonation perception at 3°C was 1.4 times higher than that at 10°C and 2 times higher than that at 22°C.

Panelists were more sensitive to the difference at the 3.0 vol. level than that at the 2.4 vol. level, which suggests that the effect of temperature on carbonation perception maybe dependent on the level of carbonation. Green (1990), in the study of the effect of temperature on irritation from an NaCl solution, also noted that the thermal effect depends to some extent on the intensity of irritation which was related to NaCl concentrations. The dependence in this study may be that as the intensity of stimulation increased, the interaction of coldness and carbonation was additive or synergistic. Green (1984) noted that the exponent of the power function for the sensation of cold perceived to arise from the teeth was 1.6 and that for the sensation of cold perceived to arise from the rest of the mouth was 1.2. The exponents of the power functions for carbonation perception perception were between 2.46 to 2.79 (Yau and McDaniel, 1990). Since both exponents of the functions for coldness and carbonation were greater than 1 (expansion), the additivity or synergism of the two may be expected (Bartoshuk, 1977).

Theory of interaction

This enhancement of carbonation perception with decreasing temperature is in agreement with the findings reported by Stevens and Green (1978) that cooling intensified touch magnitude, and by Hilgard (1969) that a decrease in temperature enhanced pain perception on the hand. Stevens and Green (1978) hypothesized that thermal stimulation can also arouse activity in receptors that respond primarily to mechanical stimulation, the total activity then becomes a joint function of thermal and tactile stimulation. The mechanism of the enhancement observed in this study is not clear. It may be due to the interaction between coldness and carbonation perception. Carbonation stimulation could arouse activity in receptors that primarily respond to mechanical stimulation (e.g. CO₂ bubbles impinging on the surface of the mouth cavity) and could be mediated by the trigeminal nerves (Szczesniak, 1979). Two effects can be expected as the low temperature stimulation (coldness) and stimulation by CO₂ exist simultaneously. First, thermal stimulation could arouse activity in receptors that primarily respond to mechanical stimulation, as could the stimulation by CO₂, thus causing an integration of response effects. Second, cold stimulation beyond certain ranges causes pain as does the stimulation by CO₂. The total activity of the trigeminal nerves should be a joint function of thermal and tactile sensations as proposed by Stevens and Green (1978). In addition to carbonation perception, sourness perception is another component of the sensory responses to carbonated spring water. Temperature usually does not affect sourness perception (Sekula and Blake, 1985).

Table 2.2 The means¹ of carbonation intensity for the two assessing conditions at the two carbonation levels from the trained panel

Carbonation level	Treatment (°C)	Swallowing	Expectoration
2.4 vol.	3	1.21 ^a	1.35 ^a
	10	1.07 ^a	1.08 ^{ab}
	16	1.07 ^a	1.06 ^{ab}
	22	0.87 ^a	0.79 ^b
3.0 vol.	3	1.45 ^a	1.71 ^a
	10	1.19 ^b	1.24 ^b
	16	1.10 ^{bc}	1.00 ^{bc}
	22	0.90 ^c	0.85 ^c

1 - from rescaled magnitude estimates

abc - means with common superscriptors within each group are not significantly different ($p > .05$)

Patterns of response

There were significant panelist by treatment (P*T) interactions for both carbonation levels and both assessing conditions (Table 2.2), showing that panelists responded differently to the samples in this study. Therefore, individual differences were examined in detail. The patterns of P*T interaction for the two carbonation levels and two assessing conditions can be seen in Figure 2.4. There were two groups of responses. One group (e.g. panelists 2 and 6 for the swallowed sample at the 2.4 vol. level) perceived that the 3°C sample was highest in carbonation while the other group (e.g. panelists 4 and 8 for the swallowed sample at the 2.4 vol. level) thought the 10°C and the 16°C samples were highest. The panelists may have concentrated on different parts of the definition for carbonation, including both the perception of pain and bubbling feeling; the colder samples may induce more pain and the warmer ones may induce more bubbling feeling. Inspection of Figure 2.4 reveals that there was higher variation (less agreement on intensity) among panelists at 3°C than at any other thermal level regardless of assessing condition or carbonation level.

Since the reference samples were treated differently in the two assessing conditions, the conditions cannot be compared directly. The expectoration assessing condition appears to be more sensitive in detecting differences in this study, even though a previous study (Yau and McDaniel, 1990) found there was no significant difference between the power functions resulting from two assessing conditions. The difference between the results from the two assessing conditions in this study may be due to panelists' attention to different parts of

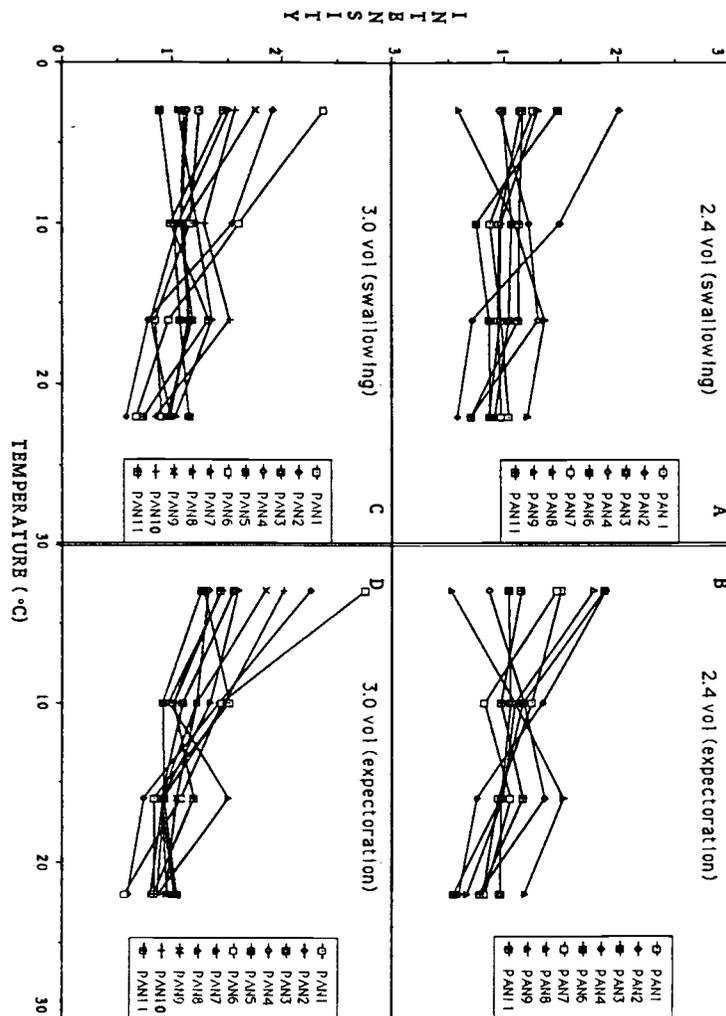


Fig. 2.4. The panelist by treatment interaction from tests with two assessing conditions at two carbonation levels from the trained panel. (Y axis: rescaled magnitude estimates of response)

the definition for carbonation. Again, swallowing might draw more attention to painful stimulation in the throat and expectoration might draw more attention to the bubbling feeling in the mouth.

Experiment 2

ANOVA results

The ANOVA from the naive panel data resulted in a significant temperature effect ($p \leq 0.001$). The mean intensity estimates of carbonation at 3°C (1.56) was significantly higher, 1.5-1.8 times, than the means of the 10°C (1.01), 16°C (0.88), and the 22°C (0.97) samples. The relationship between carbonation perception and CO₂ concentration was found not to be linear (Figure 2.5). The slope for the sharp decline (between 3°-10°C) was 9.95.

Patterns of response

Inspection of the plots of panelists' treatment means (Figure 2.6) reveals that panelists rated the samples differently. In general, there were four typical patterns of response. The first and second groups of responses followed the direction of the panel as a whole; the carbonation perception was highest at 3°C and decreased as temperature increased. The first group of panelists, however, perceived carbonation much higher at 3°C than those at the other thermal levels while the panelists in the second group did not. This result supports the possibility that cold stimulation enhances the perception of carbonation. The third group of panelists generally perceived the 3°C and 22°C samples to be higher in carbonation than

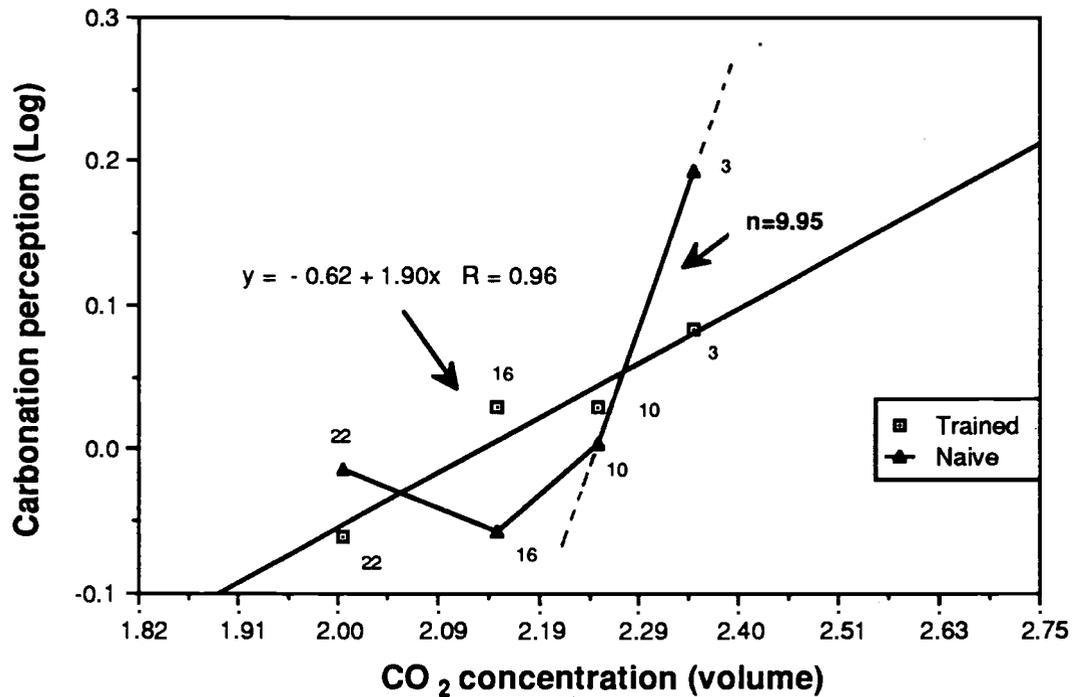


Fig. 2.5 The relationship between the CO₂ level and carbonation perception of the four samples at 2.4 vol. level for swallowing for the trained and naive panels (Y axis: rescaled magnitude estimates of response, n: the decreasing rate)

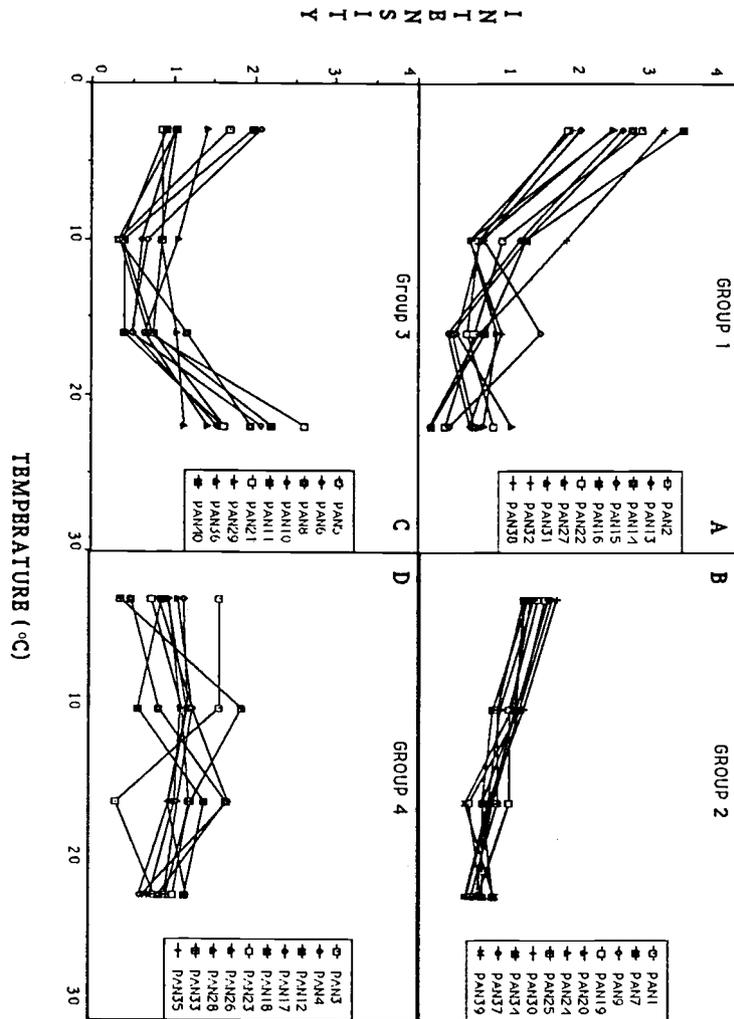


Fig. 2.6. The four typical patterns of the interaction of panelists and treatments for 2.4 vol. for swallowing from the naive panel. (Y axis: rescaled magnitude estimates of response)

the 10°C and 16°C samples. Considering that the response to carbonation perception may be made up of pain and/or bubbling feeling, the pain component may have out-weighed the bubbling feeling component at 3°C, while at 22°C the opposite may have occurred. The fourth group of panelists generally rated the 10°C and 16°C samples higher in carbonation than the 3°C and 22°C samples. Ten panelists fell in the first group, eleven were in the second group, nine were in the third group and ten were in the fourth group.

Trained vs Naive

The results of trained and naive panels were compared with respect to the individual response patterns and overall temperature effect on carbonation. Basically, the patterns of responses from the trained panel can also be divided into the four groups described above. Therefore, panelists rated the samples differently while rating carbonation perception regardless of the degree of panel training. Overall, there was no significant difference ($p > 0.05$) between the means from the trained and naive panels for the samples at the 2.4 vol. level with swallowing (Figure 2.7). There was a sharp decline in carbonation perception between the samples from 3° to 10°C for the naive panel, which was not the case for the trained panel (Figure 5). A similar sharp decline was observed for the samples at the 3.0 vol. level for the trained panel. This comparison would indicate that the temperature effect was more influential on carbonation perception for the naive panelists. Panelists may concentrate either on pain perception or bubbling feeling as the major part of carbonation perception; both pain perception and bubbling feeling may be

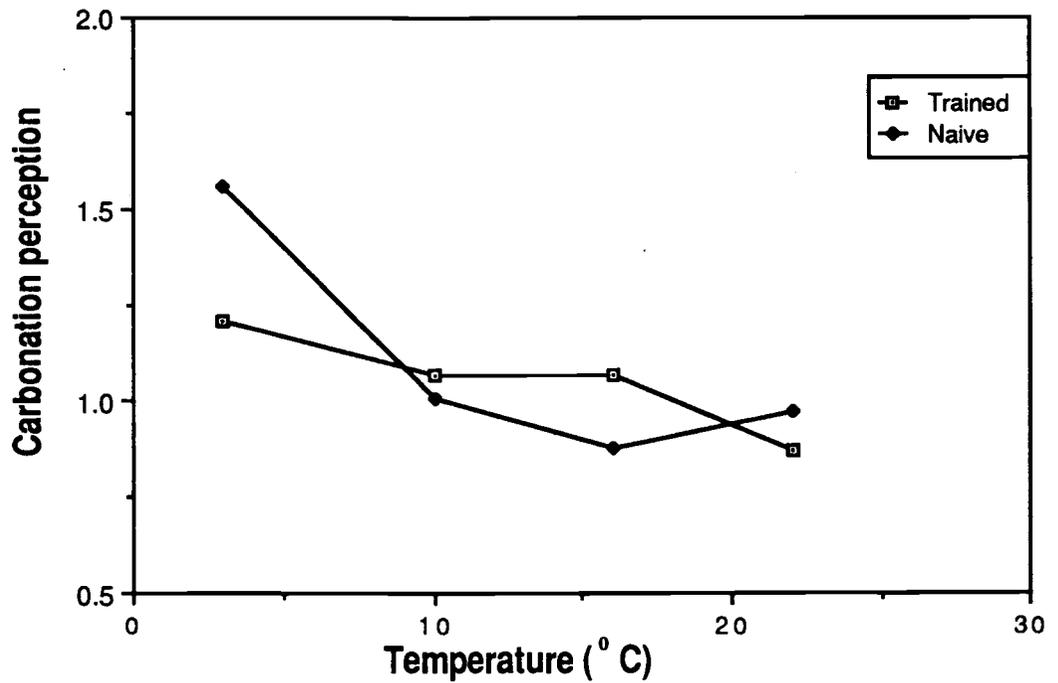


Fig. 2.7 Temperature versus carbonation perception for 2.4 vol. for swallowing from the trained and naive panels (Y axis: rescaled magnitude estimates of response)

affected by temperature. A descriptive study of carbonation perception which would divide carbonation perception into different attributes should be an approach considered in the future.

CONCLUSION

The perception of carbonation intensity decreased significantly as the temperature of the carbonated spring water increased within the range of 3°-10°C, even after having taken into account the fact that there was less CO₂ in the samples at higher temperature. This temperature effect on carbonation perception maybe carbonation level dependent, as the differences were more obvious at the 3.0 vol. level than at the 2.4 vol. level. This effect should be investigated at a broader range of carbonation levels to confirm the phenomenon. Panelists evaluated the samples differently in rating carbonation perception regardless of the degree of panel training.

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**EFFECTS OF CARBONATION
ON
SWEETNESS AND SOURNESS**

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ABSTRACT

The effects of CO₂ level on sweetness and of sweetener level on carbonation perception were measured in both sucrose and aspartame sweetened systems. The effects of CO₂ level on sourness and of acid level on carbonation perception were measured in both citric acid and phosphoric acid acidulated systems. The effects were measured at concentrations ranging from 2-16% (w/v) sucrose, 0.015-0.12% (w/v) aspartame, 0.02-0.29% (w/v) citric acid, and 0.015-0.06% (v/v) phosphoric acid. Higher carbonation reduced sweetness ratings in aspartame-sweetened samples but had no effect on sweetness in sucrose-sweetened samples. There was more variability in sucrose-sweetened samples. Only the highest concentration of sucrose (16% w/v) reduced carbonation perception. Carbonation enhanced sourness ratings at the lower acid levels and had no effect at higher acid levels for both acids. No effect of acid level on carbonation perception was found.

INTRODUCTION

In addition to the classic sensations of gustation and olfaction, the sensations from thermal, mechanical and common chemical stimuli also play an important role in food and beverage perception. The interactions between these modalities in the oral cavity are of interest in psychophysical research as well as sensory evaluation. This research addresses the possible interactions between trigeminal and olfactory sensations (Cain and Murphy, 1980; Cain, 1981), as well as trigeminal and gustatory sensations (Berridge and Fentress, 1985; Lyman and Green, 1990).

The chemical irritation from capsaicin or pepperine is believed to be mediated by trigeminal nerves. Lawless and Stevens (1984) studied the effect of oral chemical irritation on the four basic tastes. They reported that the taste intensities of citric acid and quinine when tested at two levels are reduced by chemical irritation from capsicum, oleoresin and piperine. The sweetness of sucrose is reduced only at the higher level (11.5%, w/v). Saltiness of NaCl is not affected at the two levels tested. In contrast, Cowart (1987) found that natural capsaicin did not mask the four basic tastes. Stevens and Lawless (1986) found that citric acid, sucrose, NaCl, water and quinine could reduce the perceived intensities of capsaicin to different degrees. The decline in irritation was the largest with citric acid and sucrose, intermediate with NaCl and water, and the least with quinine.

A few researchers have studied the interactions between the common chemical sensation from CO₂ and the classic olfactory or

gustatory sensations. Cain and Murphy (1980) found mutual inhibition between the modalities of odor and nasal irritation from both CO₂ and amyl butyrate. They reported that CO₂ (at 30 parts per hundred) reduced odor intensity by about 12%. McLellan et al. (1984) found that sourness is enhanced as carbonation levels increase in carbonated apple juice. Cometto-Muñiz et al. (1987) studied the interactions between oral pungency from CO₂ and sweetness (sucrose), sourness (tartaric acid), saltiness (NaCl), and bitterness (quinine sulfate). The concentration of CO₂ was controlled by diluting a supersaturated solution of CO₂ (4.7 vol. CO₂) with distilled and deionized water to different percentages. Actual CO₂ level was not measured. They found no interaction between sucrose sweetness and CO₂ oral pungency while tartaric acid sourness and CO₂ oral pungency enhanced each other. NaCl enhanced oral pungency throughout the CO₂ range employed, but CO₂ enhanced saltiness only at the lowest NaCl concentration (0.4% w/v). Quinine sulfate reduced oral pungency at low CO₂ concentrations and had no effect at high CO₂ concentrations. CO₂ enhanced bitterness at low quinine sulfate concentrations and suppressed bitterness at high quinine sulfate concentrations.

Sucrose and aspartame are known to differ in temporal (Larson-Powers and Pangborn, 1978) and other qualities (Tunaley, 1988), therefore their interactions with carbonation may also differ. Acidulants such as citric acid and phosphoric acid are also known to differ in temporal (Straub, 1989) and other qualities (Rubico and McDaniel, 1991), therefore differences in their interactions with carbonation may be expected.

The objectives for experiment 1 were to measure how CO₂ level affects ratings of sweetness of sucrose and aspartame, and to measure how sucrose and aspartame levels affect ratings of carbonation perception. The objectives for experiment 2 were to measure how CO₂ level affects ratings of sourness of citric acid and phosphoric acid, and to measure how citric acid and phosphoric acid levels affect ratings of carbonation perception. All tests utilized a simple system of carbonated water with sweeteners or acidulants only.

MATERIALS AND METHODS

Sample production

Concentrations of 2, 4, 8 and 16% (w/v) sucrose (commercial source), and 0.015, 0.03, 0.06 and 0.12% (w/v) aspartame (A00120, Nutrasweet Co., Skokie, IL), were used in experiment 1. Concentrations of 0.02, 0.048, 0.12 and 0.29% (w/v) anhydrous citric acid (FCC, Miles Inc., Elkhart, IN), and 0.015, 0.024, 0.038 and 0.06% (v/v) 75% phosphoric acid (Food grade, Monsanto Co., St Louis, MO), were used in experiment 2. For the noncarbonated samples, bottled water (Aqua-Cool, Portland, OR) was blended with the sweeteners or acidulants and stored in volumetric flasks. For the carbonated samples, seven and a half liters of each sweetened (or acidulated) solution, prepared as above, were carbonated in a Zahm and Nagel 18.9-liter stainless steel carbonator (Zahm and Nagel Co., Buffalo, NY). The samples were bottled in 355 ml clear bottles and stored at 1° C

for 1-3 weeks. Two carbonation levels, 2.0 and 3.0 volumes CO₂, were employed for each treatment.

Analytical measurement

Carbonation levels were measured with a Zahm and Nagel piercing device (Zahm and Nagel Co., Buffalo, NY) and expressed as "volumes CO₂ per volume water" (Zahm and Nagel Co. Inc., 1964). The pH of the samples in experiment 2 was measured by using a Corning 125 pH meter (Scientific Instruments, Medfield, MA).

Sensory measurement

In experiment 1, nine students of the Department of Food Science and Technology at Oregon State University volunteered to evaluate the samples. Magnitude estimation was employed for rating the sweetness and carbonation intensities. There were three carbonation levels (0, 2 and 3 vol. CO₂) for each sweetener level of each sweetener.

For the evaluation of sweetness, a noncarbonated 4% (w/v) sucrose solution and a noncarbonated 0.03% (w/v) aspartame solution were used as references for the sucrose and aspartame systems, respectively, and both were assigned a sweetness intensity value of 100. Four levels of each sweetener at the same carbonation level with their respective reference were presented in one set. Two sets of samples, one for each sweetener, were presented to each panelist per session. The presentation orders of the samples within sets as well as the sets were randomized. Each set was replicated three times.

Carbonation intensity was rated only on the carbonated samples. The 4% (w/v) sucrose and 0.03% (w/v) aspartame solutions at 2.0 vol. CO₂ were the references for the samples sweetened with sucrose and aspartame, respectively. The intensity of carbonation for the references was assigned a value of 100. Four levels of each sweetener at the same carbonation level with their reference were presented in one set. Two sets of the same sweetener were served in the same session. The presentation orders of the samples within sets as well as carbonation levels (sets) were randomized. Each set was replicated three times.

The serving temperature of the samples was 9°-12° C. For the carbonated samples, the samples were poured at the time of serving. Each bottle was stoppered with a rubber stopper after opening. A bottle opened 15 min or with less than 5 cm of sample remaining was discarded.

In experiment 2, nine students volunteered to rate the samples. Magnitude estimation was used to rate sourness and carbonation intensities. There were three carbonation levels (0, 2 and 3 vol. CO₂) for each acidulant level of each acidulant.

For the evaluation of sourness, a noncarbonated 0.048% (w/v) citric acid solution and a noncarbonated 0.024% (w/v) phosphoric acid solution were used as references for the citric acid and phosphoric acid systems respectively, and were assigned a sourness value of 100. Four concentrations of each acid at the same carbonation level with their respective reference were presented in one set. Two sets of samples, one for each sweetener, were presented to each panelist per session. The presentation orders of the samples

within sets as well as the carbonation level (sets) were randomized. Each set was replicated twice.

Carbonation intensity was again rated only on the carbonated samples. The 0.048% (w/v) citric acid and the 0.024% (w/v) phosphoric acid solutions at 2.0 vol. CO₂ were chosen as the references for each acidulated system. Four levels of each acid at the same carbonation level with their respective reference were presented in one set. The two sets of the same acid were served in the same session. The presentation orders of the samples within sets and the sets were both randomized. Each set was replicated twice. The rest of the sensory conditions and steps were the same as described in experiment 1.

Data analysis

The magnitude estimates were rescaled for each panelist across both sweetener (or acidulant) and carbonation levels in each experiment (Yau and McDaniel, 1991). For the evaluation of sweetness (or sourness), the rescaled data was then averaged across replications for each panelist and each carbonation level in each experiment. The geometric mean of the sweetness ratings for the whole panel was taken for each sweetener (or acidulant) level. The power functions of sweetness (or sourness) were established by determining the regression line on a log-log basis for each carbonation level. Multiple regression analysis (MRA) (Neter et al., 1983) was employed to test the differences in slopes and elevations between the power functions. The rescaled data was also tested by ANOVA for both the evaluation of sweetness (or sourness) and

carbonation. The F-values were calculated by employing a compound F-test (Anderson and Bancroft, 1952). The Least Square Difference (LSD) test was employed for the multiple comparisons and the paired t-test was used for the paired comparisons.

RESULTS AND DISCUSSION

Experiment 1

The power functions of sweetness for both sweeteners were determined in a noncarbonated system and a carbonated system at two carbonation levels. The parameters of the linear regression models are shown in Table 3.1. The slopes and intercepts of the models were compared by using Multiple Regression Analysis (MRA). There were no significant differences between the slopes of the sweetness power functions of the carbonated and noncarbonated systems for either sweetener. For the elevation of the functions, there was a significant ($p \leq 0.05$) difference among the functions for the aspartame-sweetened system, but not for the sucrose-sweetener system. For the aspartame samples, the elevation of the function of the noncarbonated samples was significantly ($p \leq 0.05$) higher than that of the samples at 3.0 vol. CO₂ (Table 3.1). This indicates that carbonation did not affect sweetness perception in the sucrose-sweetened system, but it reduced the sweetness across all sweetener levels in the aspartame-sweetened system at 3.0 vol. CO₂. However, this effect was small, since no significant ($p > 0.05$) differences among the samples at each sweetener level were found by using the paired

Table 3.1. Parameters from the regression analysis of sweetness intensity versus stimuli concentration in experiment 1

Sweetener	Carbonation level*	slope	intercept	r	p-value
Sucrose	none	1.34 ^a	- .90 ^a	1.00	0.005
	2.0 vol.	1.48 ^a	-1.14 ^a	0.99	0.014
	3.0 vol.	1.18 ^a	- .87 ^a	0.99	0.008
Aspartame	none	1.04 ^a	1.50 ^a	1.00	0.001
	2.0 vol.	1.06 ^a	1.48 ^{ab}	0.99	0.009
	3.0 vol.	0.90 ^a	1.25 ^b	1.00	0.005

* Carbonation level is expressed as volume CO₂ per volume water
 ab- values with common superscripts are not significantly different
 (p > 0.05)

t-test. This held true for both sweeteners. There was more variability in the sucrose data.

From the ANOVA results, there was no significant ($p > 0.05$) effect of carbonation on sweetness for either sweetener (Table 3.2). This finding was similar to that of Cometto-Muñiz et al. (1987) who found CO₂ oral pungency had no effect on sucrose sweetness. There was a significant ($p \leq 0.001$) effect of sweetener level on sweetness for both sweeteners (Table 2) with sweetness increasing with increasing sweetener concentrations as expected. There was also a significant ($p \leq 0.001$) interaction of panelist and sweetener level on sweetness for both sweeteners (Table 3.2). Panelists rated the sweetness in the same direction but at different rates of increase, which caused the interaction effect.

For the rating of carbonation intensity, there was a significant ($p \leq 0.001$) effect of carbonation level for both sweetener systems (Table 3.2), as expected. Carbonation was perceived 2.5 times higher at 3.0 vol. CO₂ than at 2.0 vol. CO₂. For aspartame-sweetened samples, there was a significant ($p \leq 0.01$) interaction of panelist and carbonation level. All panelists rated carbonation intensity as increasing with increased carbonation level but at different rates. Again, the rates should be due to the different sensitivities to carbonation. This is supported by a previous study (Yau and McDaniel, 1990), in which differences in individual sensitivity to carbonation perception were reported. For sucrose-sweetened samples, there was a significant ($p \leq 0.01$) effect of sweetener level on carbonation. Samples sweetened with 16% (w/v) sucrose were rated significantly lower in carbonation intensity than the others

Table 3.2. The ANOVA table for sweetness and carbonation perception of sucrose and aspartame samples in experiment 1

Source	DF	F value	
		Sucrose	Aspartame
Sweetness			
Panelist (P)	8		
Carbonation level (C)	2	2.08	1.20
Sweetener level (S)	3	19.50***	14.55***
PxS	24	7.77 ***	3.16 ***
Carbonation			
Panelist (P)	8		
Carbonation level (C)	1	99.79***	31.15***
Sweetener level (S)	3	4.64**	1.44
PxC	8	1.88	4.25**

*** $p \leq 0.001$ ** $p \leq 0.01$

(Table 3.3). This was in agreement with the report of Sizer and Harris (1985), who found that the highest level of sucrose (9.9%, w/v) produces a masking effect on capsaicin pungency. This was, however, in contrast with the finding of Cometto-Muñiz et al. (1987), in which no effect of sweetener level on CO₂ oral pungency was found. However, a range of 3%-12% (w/v) of sucrose was employed in the previous study, while 16% (w/v) of sucrose was the highest level employed in the current study. This suppression of carbonation may be due to the viscosity contributed by sucrose, or panelists may have been distracted by the high sweetness in the sample.

Experiment 2

The pH values of the citric-acidulated samples ranged from 2.5 to 3.3 for the high to low acid levels, respectively, and those of the phosphoric-acidulated samples ranged from 2.2 to 2.7 for the high to low acid levels, respectively. Carbonation did not significantly ($p > 0.05$) change pH in the samples.

The power functions of sourness for both acids were determined in a noncarbonated system and in a carbonated system at two CO₂ levels. The parameters of the linear regression models are shown in Table 3.4. Even though the models were not significant at the 3.0 vol. level for both acids, they were compared with the other models. The 3.0 vol. level data for both acids did not fit a second-order polynomial model either. There was a significant ($p \leq 0.05$) difference in slopes between the power functions in the carbonated and noncarbonated systems for both acids (Table 3.4). The exponents in the noncarbonated systems were higher than those

Table 3.3. The means of carbonation perception of the four sucrose levels in experiment 1

Sucrose conc. (w/v, %)	Carbonation perception*
2	1.31 ^a
4	1.36 ^a
8	1.32 ^a
16	1.09 ^b

* normalized response intensity

a,b - means with common superscripts within each column are not significantly different ($p > 0.05$), tested by using LSD test

Table 3.4. Parameters from the regression analysis of sourness perception versus stimuli concentration in experiment 2

Acids	Carbonation level*	slope	intercept	r^2	p-value
Citric	none	0.88 ^a	0.87 ^a	1.00	0.001
	2.0 vol.	0.54 ^b	0.68 ^b	1.00	0.001
	3.0 vol.	0.39 ^b	0.57 ^{ab}	0.93	0.067
Phosphoric	none	1.05 ^a	1.52 ^a	0.99	0.011
	2.0 vol.	0.56 ^b	0.93 ^b	0.96	0.037
	3.0 vol.	0.38 ^b	0.70 ^b	0.87	0.129

* Carbonation level is expressed as volume CO₂ per volume water
 ab- values with common superscripts are not significantly different
 (p> 0.05)

in the carbonated systems for both carbonation levels. Carbonation lowered the exponents of the power function of sourness (flattened the power function). The elevation of the linear functions for the carbonated samples, however, was above those for the noncarbonated samples, with all lines merging at the highest acid levels. This held true for both acids (Figs. 3.1 and 3.2).

Although the effect of carbonation level on sourness was not significant in the ANOVA test (Table 3.5), sourness was perceived to be higher in carbonated samples than in noncarbonated samples at the lower acid levels as tested by the paired t-test (Table 3.6). For citric acid, at 0.02% (w/v), the sourness of the samples at 3.0 vol. CO₂ was 1.5 times higher than that of the samples at 2.0 vol. CO₂ which was 2.2 times higher than that of noncarbonated samples. Therefore, the sample at 3.0 vol. CO₂ was 3.3 times higher in sourness than the noncarbonated sample. For the 0.048% (w/v) acid level, there was no significant ($p > 0.05$) difference between the samples at 2.0 and 3.0 vol. CO₂ but both of them were 1.6 times higher than that of the noncarbonated samples. For the 0.12% (w/v) citric acid level, the samples at 3.0 vol. CO₂ were perceived to be more sour (1.4 times) than the noncarbonated samples. No difference was found among the three carbonation levels for the highest acid level tested.

For phosphoric acid at 0.015% (v/v), there was no significant ($p > 0.05$) difference between the two carbonated samples; both of them were rated 2.5 times higher in sourness than the noncarbonated sample. At the 0.024% (v/v) level, the sourness of the samples at 3.0 vol. CO₂ was twice as high as that of the noncarbonated sample. No difference in sourness was found among

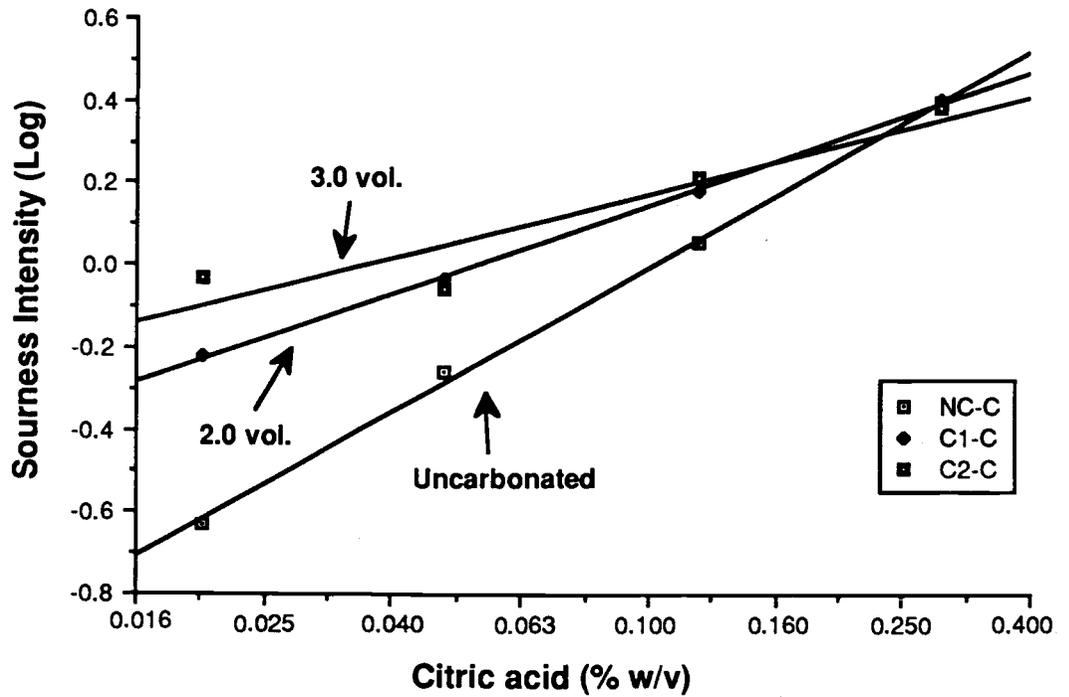


Fig. 3.1. The power functions of sourness for the citric acid-acidulated samples at the three carbonation levels (Y axis: rescaled sourness intensity, NC-noncarbonated samples, C1-carbonated at 2.0 vol. CO₂, C2-carbonated at 3.0 vol. CO₂)

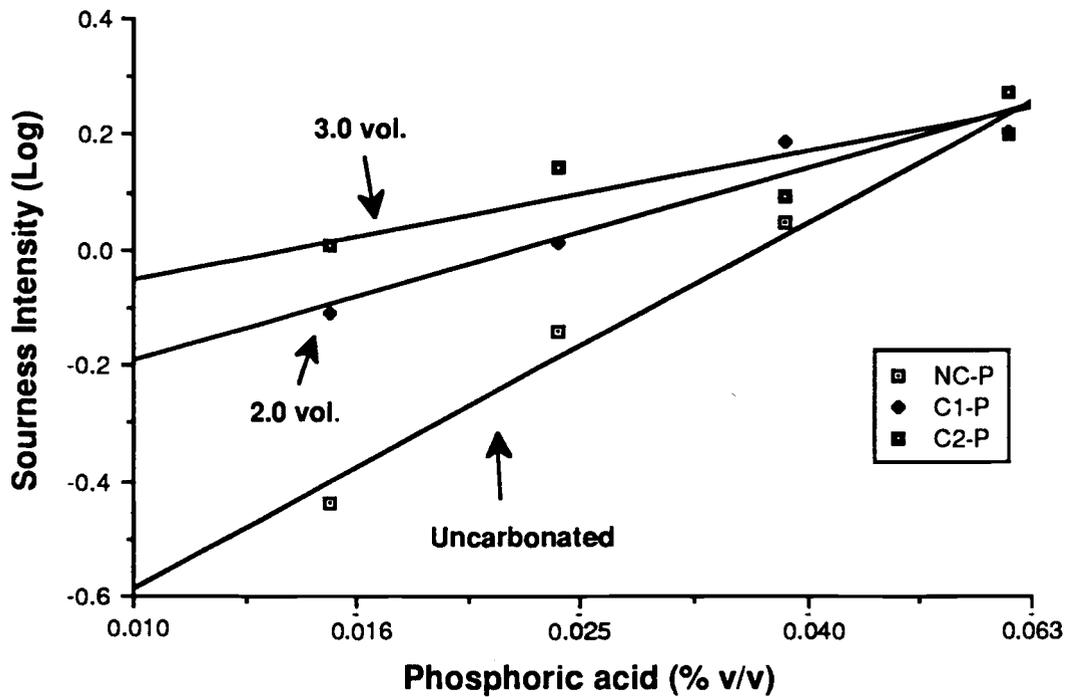


Fig. 3.2. The power functions of sourness for the phosphoric acid-acidulated samples at the three carbonation levels (Y axis: rescaled sourness intensity, NC-noncarbonated samples, C1-carbonated at 2.0 vol. CO₂, C2-carbonated at 3.0 vol. CO₂)

Table 3.5. The ANOVA table for sourness and carbonation perception of citric and phosphoric acids in experiment 2

Source	DF	F value	
		Citric	Phosphoric
Sourness			
Panelist (P)	8		
Carbonation level (C)	2	2.32	2.77
Acid level (A)	3	31.80***	10.24***
PxA	24	2.17**	1.47
PxC	16	2.03	2.25*
CxA	6	1.43	2.30*
Carbonation			
Panelist (P)	8		
Carbonation level (C)	1	21.97***	32.63***
Acid level (A)	3	1.05	1.95
PxC	8	4.56***	3.01*
CxA	3	0.69	4.13**
*** p≤ 0.001		** p≤ 0.01	* p≤ 0.05

the three carbonation levels for the two higher acid levels (0.038% & 0.06%). Carbonation enhanced sourness perception at the lower acid levels and had no effect at the highest acid level for both acids. This finding agrees with the reports of McLellan et al. (1984) and Cometto-Muñiz et al. (1987). McLellan et al. (1984) reported that sourness of apple juice was enhanced by increasing carbonation levels. Cometto-Muñiz et al. (1987) found CO₂ oral pungency enhanced tartaric acid sourness within a range of 0.3-1.2% (w/v).

Acid levels had a significant ($p \leq 0.001$) effect on sourness for both acids (Table 3.5). In general, sourness increased with acid concentration for both acids (Table 3.6). There was a significant ($p \leq 0.05$) interaction of panelist and carbonation level for phosphoric-acidulated samples (Table 3.5), which is shown in Figure 3.3. Four panelists rated sourness highest at 2.0 vol. CO₂ and found reduced sourness at 3.0 vol. CO₂, while another four panelists found sourness increasing with each increased carbonation level. For the panelists who rated the 3.0 vol. CO₂ sample lower in sourness than the 2.0 vol. CO₂ sample, the increased carbonation may have masked some of the sourness. This mixed pattern may also be due to the high astringency from phosphoric acid. Phosphoric acid was reported to be more astringent than sour (Rubico and McDaniel, 1991). For citric-acidulated samples, there was a significant interaction of panelist by acid level. Again, the interaction resulted from the different increasing rates, although all the panelists rated samples in the same direction (increasing with increased acid concentration). There was a significant ($p \leq 0.05$) interaction of carbonation level by acid level for

Table 3.6. The means of sourness perception* of the three carbonation levels and the four acids levels of citric and phosphoric acids in experiment 2

acid/carbonation level	0.0 vol.	2.0 vol.	3.0 vol.
<u>Citric acid</u>			
0.020%	0.31 ^a	0.69 ^b	1.04 ^c
0.048%	0.61 ^a	1.01 ^b	0.96 ^b
0.120%	1.22 ^a	1.59 ^{ab}	1.69 ^b
0.290%	2.57 ^a	2.74 ^a	2.60 ^a
<u>Phosphoric acid</u>			
0.015%	0.41 ^a	0.94 ^b	1.13 ^b
0.024%	0.81 ^a	1.06 ^{ab}	1.60 ^b
0.038%	1.21 ^a	1.55 ^a	1.28 ^a
0.060%	1.68 ^a	1.72 ^a	2.07 ^a

* normalized response intensity

a,b,c - means with common superscripts within each row are not significantly different ($p > 0.05$), tested by using paired t-test

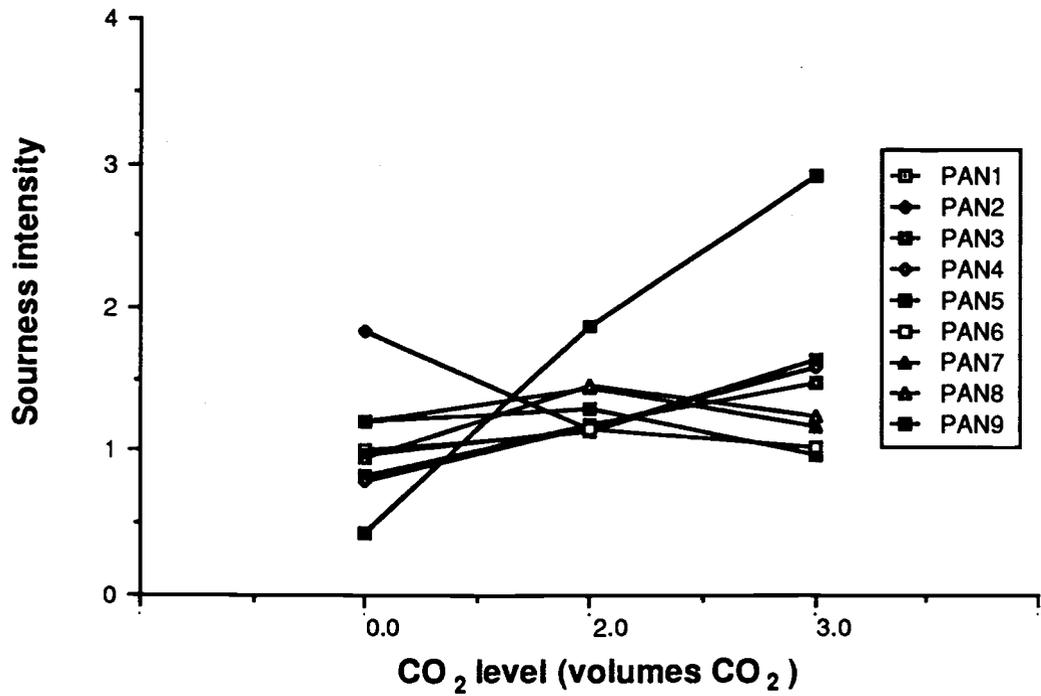


Fig. 3.3. The interaction of panelist and carbonation level for sourness in the phosphoric acid-acidulated samples (Y axis: rescaled sourness intensity)

phosphoric-acidulated samples (Table 3.5). This interaction can be observed in Fig. 3.2. The F-value of this interaction for citric-acidulated samples did not reach significance (Table 3.5).

Carbonation level had a significant ($p \leq 0.001$) effect on carbonation perception (Table 3.5), as carbonation perception increased with carbonation level. Carbonation perception was not affected by the acid level for either of the acid systems (Table 3.5). This was not in agreement with Cometto-Muñiz et al. (1987), who reported that increasing level of tartaric acid enhanced CO₂ oral pungency. This discrepancy may be due to the different properties of the different acids tested. In our study there was a significant interaction of panelist and carbonation level for both acids (Table 3.5). Panelists' ratings of sourness increased as carbonation level increased but with different rates of increase. This was the observation for both acids. There was also a significant ($p \leq 0.01$) interaction of carbonation level and acid level for the phosphoric-acidulated samples (Table 3.5). Carbonation perception was not affected by the acid level at 2.0 vol. CO₂ (Fig. 3.4). At the carbonation level of 3.0 vol., carbonation perception for acid level 1 was significantly ($p \leq 0.05$) higher than that for acid level 3 as detected by a paired t-test. Therefore, there was an effect of acid level on carbonation perception at 3.0 vol. CO₂. This effect appears to depend on carbonation level.

Interactions of tastes and carbonation

Overall, the effect of carbonation on sourness ratings was stronger and more readily perceived compared to its effect on

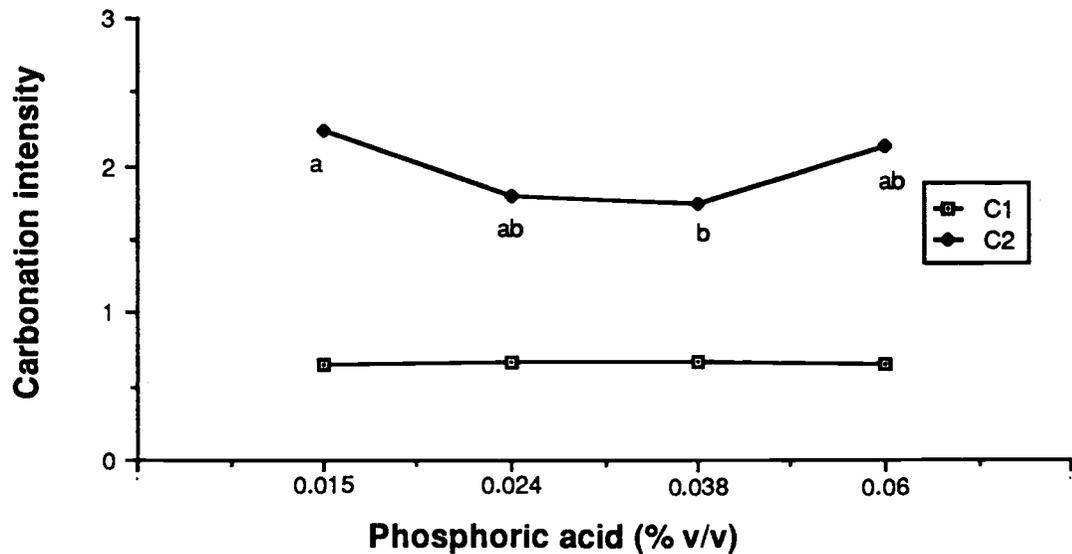


Fig. 3.4. The interaction of carbonation level and acid level for carbonation perception in the phosphoric acid-acidulated samples (Y axis: rescaled carbonation perception intensity, C1-carbonated at 2.0 vol. CO₂, C2-carbonated at 3.0 vol. CO₂, ab-the points with common letter are not significantly different, $P \leq 0.05$)

sweetness ratings. Cometto-Muñiz et al. (1987) suggested that sweetness may be more distant in quality from CO₂ oral pungency than is sourness, since the trigeminal nerve has been reported to be activated by a high concentration of tartaric acid but not by any level of sucrose. According to this concept of perceptual proximity, the more easily two modalities can be distinguished from each other, the less likely there will be interaction between them. Results from the present study supports this theory.

Carbonation is a complex perception (Yau and McDaniel, 1991). Carbonation introduces mouthfeel components such as tingle, bite, burn and numbing. Sometimes pain is reported at high carbonation levels. Sourness may be contributed by carbonic acid which is produced when water is carbonated. The calculated amount of carbonic acid formed by carbonating water ranged from 0.036-0.57% (w/v) for the CO₂ concentration range of 1.2-3.7 vol.. The sourness threshold of carbonic acid and the intensity of sourness contributed by varying amounts of carbonic acid are unknown. Further investigation is required to quantify this effect. Acidulants introduce astringency in addition to sourness into a system. How all these sensory components might interact in a beverage system has not been determined. The higher sourness in the carbonated versus noncarbonated samples in this study may have resulted from an interaction between the mouthfeel from carbonation and sourness from an acidulant; or pain and sourness; or a combined degree of sourness from both the acidulant and formed carbonic acid.

Carbonation perception is believed to be mediated by the trigeminal nerve while sourness is mediated by the chorda tympani.

The interaction between carbonation perception and sourness could occur at two steps (Lawless et al., 1985). First, the interaction may occur at a peripheral level. The signal (sensory input) mediated by trigeminal nerves interacts with that mediated by the chorda tympani as they are fired. The signals (inputs) may be suppressed or enhanced by each other to some degree, or the trigeminal stimuli may cause direct action on taste receptors. Secondly, the interaction may occur at a central level. As both signals (inputs) reach the brain, the information integrates. This second hypothesis is supported partially by the finding of Berridge and Fentress (1985). Using rats as the model they found that there is interaction between somatosensation (trigeminal) and gustation in the processing of palatability. The transection of the trigeminal nerves reduced the ingestive action elicited by preferred tastes. The reduction, referring to preference and behavior, indicates that central (brain) integration is involved.

Another trigeminal stimulus, chemical heat (irritation), has also been studied. The interactions between chemical heat from capsaicin and basic tastes have been investigated intensively (Lawless and Stevens, 1984; Lawless et al., 1985; Stevens and Lawless, 1986). All studies found that there is an inhibitory effect of irritation on taste intensities of sucrose and citric acid. One of the studies (Stevens and Lawless, 1986) also reported that the irritation intensity was reduced during trials with citric acid and sucrose. No enhancement in any taste intensity from chemical heat (capsaicin and piperine) was reported. This suggests that there may be an important difference in

how chemical heat and carbonation stimulation are processed, even though both are mediated by trigeminal nerves.

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