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Electronic Senses: Digitalizing Smells and Tastes

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Towards Developing an Electronic Tongue: pH on Liquids to Investigate Sour

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Abstract

How the human tongue processes taste is still a relatively unknown process. While academic research has been done to explain different taste sensations on their own, few have been able to successfully connect multiple gustatory sensations together. In general, research has found that the threshold of pure free hydrogen directly relates to the liquid's overall sour taste perception. This paper looks into how pH can affect the taste of different liquids. We focused on recording the pH of common household drinks and relating them to the pH of a lemon. Doing this allows us to group all of our tested liquids onto one comprehensible chart. Our results show that the pH of a liquid does correlate to sour taste perception in humans. This can be shown in the case of milk, having a pH of 6.63, and virgin lemon margarita mix, having a pH of 2.40, tasting differently. However, there must be other aspects that effect sour taste perception shown by both pink lemonade and cranberry juice having similar pH values, 2.59 and 2.55 respectively. We suggest that the visual perception, olfactory perception, and conductivity of the liquid also affects taste perception. If one were able to control all four of these aspects, we believe that complete control of gustatory perception is possible, if not probable.

Keywords

Chemical Senses; Taste; Smell; Sour; pH; Tongue; Conductivity.

Introduction

Sour taste perception is still a very large unknown in the scientific community [1]. In recent times, several breakthroughs have been made towards our understanding of sour taste perception such as (1) the threshold of pure free hydrogen [2], (2) the proposition that sour taste intensity is a linear function of the total molar concentration of all organic acid species that have one or more protonated carboxyl group(s) plus the concentration of free hydrogen ions [3], (3) the anionic acid species itself doesn't produce a sour taste, but can intensify or weaken the intensity of a sour taste [2], and (4) that the molar potency of several organic acids was inversely related to the 1st pKa [4]. It is evident that our tongue plays a large role in all taste perception. The tongue is a muscular organ in the mouth which contains thousands of taste buds [Huang, 2006]. A taste bud is the collection of nerve-like cells that connect the tongue to nerves connected to the brain [5]. Our ability to taste food is thought to have developed to provide critical information about the nature and quality of the food being ingested [5]. More specifically, sour taste is believed to have evolved to help solve the two primary food problems for animals: (1) the identification and (2) ingestion of nutrients and the avoidance of poisons (acidic food) [6]. The sensory input of acidic food sources creates an innate rejection response in humans and many other animals [7]. This is because large quantities of acidic food sources can damage tongue tissue and create problems of systemic acid-base regulation [8]. However, sour taste is acceptable or even desirable when mild as it helps aid in the recognition of complex foods[1] [8]. There have been a broad range of cell types, receptors, and other mechanisms proposed to mediate salt and acid sensing in taste receptor cells (TRCs) such as pain receptors and ion (Na^+, K^+, H^+, Ca^{++}, etc.) channels [5]. TRCs demonstrate a linear relationship between intracellular and extracellular pH changes (ΔpHi and ΔpHo, respectively) with a slope of unity [7]. This is believed to occur because the tight junction[2], which closes the extracellular space of a taste bud towards the oral space, is permeable to H^+ ions [8]. H^+ ions then may invade the taste

[1] Complex Food: a food (such as rice or pasta) composed primarily of polysaccharides (such as starch or cellulose).
  a. https://www.merriam-webster.com/dictionary/complex%20carbohydrate

[2] Tight Junction: a type of cell junction formed between epithelial cells of vertebrates wherein the outer layers of two adjacent cells fuse, thereby serving as a barrier to the passage of fluid between cells.
  a. https://www.biology-online.org/dictionary/Tight_junction

bud and initiate intracellular “pH tracking,” which is thought to contribute to sour transduction [8].

Sour taste is mediated by acids with the degree of sourness being a function of proton concentration [3, 9, 10]. The negative algorithm of proton concentration or hydrogen ion concentration is defined as pH. Both organic and inorganic acids produce a sour taste perception when ingested by humans; in addition to hydrogen ions, anions and/or protonated (undissociated) acid species play a role in determining sour taste intensity [10, 11] Multiple scholars believe that the intensity of a sour taste is determined by the total concentration of free hydrogen ions and undissociated hydrogen ions [2, 3, 9]. The anionic acid species (without hydrogen ions) does not produce a sour taste itself, but it can intensify or weaken the sour taste perceived [2, 11]. Because of this, many scientific tests of sour taste perception use HCl as a control; this is because HCl dissolves into just H^+ ions allowing for results uninfluenced by said anionic acid species. To gain a basis of perceived sour taste, aqueous solutions containing different concentrations of free hydrogen ions were evaluated [1]. These tests resulted in the finding that the threshold of sour taste of pure free hydrogen was determined to be 0.575 mM, which corresponds to a pH of 3.24 [1]. These results indicate the limit of sour intensity that humans can perceive. Sour taste intensity has also been associated with the capacity of the acid to dissociate, which is dependent upon the pKa values of the acids. In a test done by Makhlouf and Blum (1972), they found that the molar potency of several organic acids was inversely related to the 1st pKa [11]. This caused them to conclude that acids having a higher capacity to dissociate (a small pKa) were able to elicit higher sour taste responses [11].

Every test on humans, in relation to perceived acidic taste, has the H^+ ions coming in contact to saliva. Saliva also has many factors. Saliva is the main fluid that comes in contact to the outside location of the taste receptor [12]. This causes many to believe it may play a large factor in taste sensitivity [12]. Two of its main roles are the transportation of taste substances to the taste receptors as well as the protection of said taste receptors. For this initial process of taste perception, saliva acts as solvent for taste substances [12]. This is done through the salivary water dissolving the taste substance. The saliva then diffuses with the broken-down taste substance through the taste receptor sites [12]. This process has shown that some salivary constituents can chemically interact with taste substances. For example, salivary buffers (bicarbonate ions) react with a taste substance containing free hydrogen ions, this causes the perceived sour taste to decrease [12, 13]. Another change saliva has over taste receptors is that it may continuously stimulate a taste receptor [12]. As saliva is a liquid with a much larger area than an individual taste receptor cell, during diffusion a taste receptor cell may be stimulated multiple times [12]. This can cause a single taste receptor to believe a larger amount of food substance is present than there actually is. Another effector of taste perception is salivary flow rate. Every individual has a different natural amount of saliva in their mouth; every type of saliva flow rate has been broken down into two categories, high flow (HF) and low flow (LF) [14]. There are also two states of flow rate, unstimulated and stimulated; salivary flow rate can be stimulated, or influenced, by any taste stimuli. In general, sour tastes (e.g. citric acid) creates the highest stimulated flow rate [14]. Even though each individual has a different flow rate of saliva, when in reference to taste perception of food stimulus, they are all used to their personal flow rate causing no difference to perceived taste [14]. In simple terms, two different people, one with high flow and one with low flow, will perceive the same taste from a food stimuli even though their saliva creates different sensory ratings.

Electrolytes (any substance that conducts electricity when dissolved in water) are essential for a number of bodily functions [Henney, 2010]. This is because many automatic processes in the human body need a small electric current to function [Henney, 2010]. This electric current is found through the consumption of electrolytes. The main electrolytes found in the human body include: sodium, bicarbonate, magnesium, chloride, potassium, calcium, and phosphate [6]. As electrolytes can be many different types of salts, each type can elicit a different taste response. The most common electrolyte, sodium (Na), is widely accepted to give off only a salty taste [6]. A common substitute for sodium, potassium (K), also gives off a salty taste; however, when on its own it also gives off a bitter taste which is unpleasant for consumption [15]. Because of these findings, many food companies have started to use mixtures of fifty percent potassium and fifty percent sodium to decrease sodium intake while also mitigating the bitter taste of potassium [15]. Calcium is another electrolyte responsible for changing taste perception; while the research is new, and very little has been done, Calcium may even be human's sixth basic taste (akin to sweet, sour, salty, umami, and bitter). [16].

Electronic tongues and electronic noses (ETs and ENs respectively) are developed to sense human's basic tastes through a multitude of sensors. The designated name of "tongue" and "nose" are very misleading terms as both systems do not look nor act like normal animal tongues or noses [17, 18]. These technological advances were created to measure both odor and tastes quickly [17]; this is useful to drink manufacturers as they can test their products quickly and at low cost. While both ETs and ENs allow for very accurate results when both data sets are combined together, they also are accurate when separated [18, 19, 20]. Focusing more on ETs, they are able to analyze liquids based on pulse voltammetry [19]. This is based off of sensor arrays [21]. During the start of ETs, they focused on the development of very selective sensors.

This process quickly ran into problems even with simple liquids. [21]. As such, ETs now use an array of non-selective sensors connected to multiple pattern recognition methods to produce their ending data [19, 20, 21]. Typical sensor arrays (ETs or ENs) incorporate anywhere from ten to forty-five sensors [21, 22]. Some of the most common tests the sensors run are: Cu, Mn, Fe, Zn, Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{+}, and SO_4^{2-} [21]. When using pre-set sensors, along with mathematical algorithms to sort the data, ETs have shown promising results for quick liquid sorting [18]. But, these positive test results need to be taken with skepticism. No ETs or ENs have been tested in successful real-world applications [17].

Towards the development of an electronic tongue, in this article, we focused how pH values differ for various liquids. Several commercial drinks were tested for their pH. Moreover, lemon water solutions were measured for their pH levels to put commercial drinks pH values into perspective.

Methods

For our primary tests, we focused on measuring the pH of several common household liquids. These items include: Lemon Juice, Pink Lemonade, Orange Juice, Milk, Pomegranate Berry Juice, Pomegranate Blueberry Juice, Cranberry Juice, Lime Margarita Mix, Coconut Water, Soy Almond Creamer, Pomegranate Soda, Gatorade Lemon-Lime. With the pH of all the common household drinks categorized from highest pH to lowest, we needed a control for perspective of what each value meant understand what the values meant. To do this we took normal tap water and began adding drops of pure lemon juice into it. This gave us a standard line to be able to connect all the household items onto for reference.

For the tests, Raspberry Pi (model B, version 3) was used with a pH probe (Atlas Scientific). The Raspberry Pi was hooked up to a keyboard, mouse, and monitor to display images. Atlas Scientific provided the sample code to run the pH probe off of the Raspberry Pi's built in python systems. The pH probe was connected to the Raspberry Pi through a breadboard and jumper wires. The pH probe was then calibrated using the three pH buffers that came with the pH probe (7.00, 4.00, 10.00 respectively calibrated). Then the pH probe was placed in cups containing the household liquid being tested. After a minute to adjust to the pH, the probe was set to poll data every two seconds for two minutes. After the tests, the average of all data points was collected to allow for our final number.

Results and Discussion

Table of measurements

Liquid	Average pH measured
Lemon Juice	2.12 pH
Pink Lemonade	2.59 pH
Orange Juice	3.81 pH
Milk	6.63 pH
Pomegranate Berry Juice	3.31 pH
Pomegranate Blueberry Juice	3.66 pH
Cranberry Juice	2.55 pH
Margarita Mix	2.40 pH
Coconut Water	4.50 pH
Soy Almond Creamer	8.77 pH
Pomegranate Soda	2.56 pH
Gatorade Lemon-Lime	2.97 pH

Table 1: This table shows the numerical pH value of each household liquid. It allows for a clean and clear layout for easy understanding. This shows how many of the selected liquids had a very acidic pH, with only two out of the twelve being near or above a neutral pH.

Figures

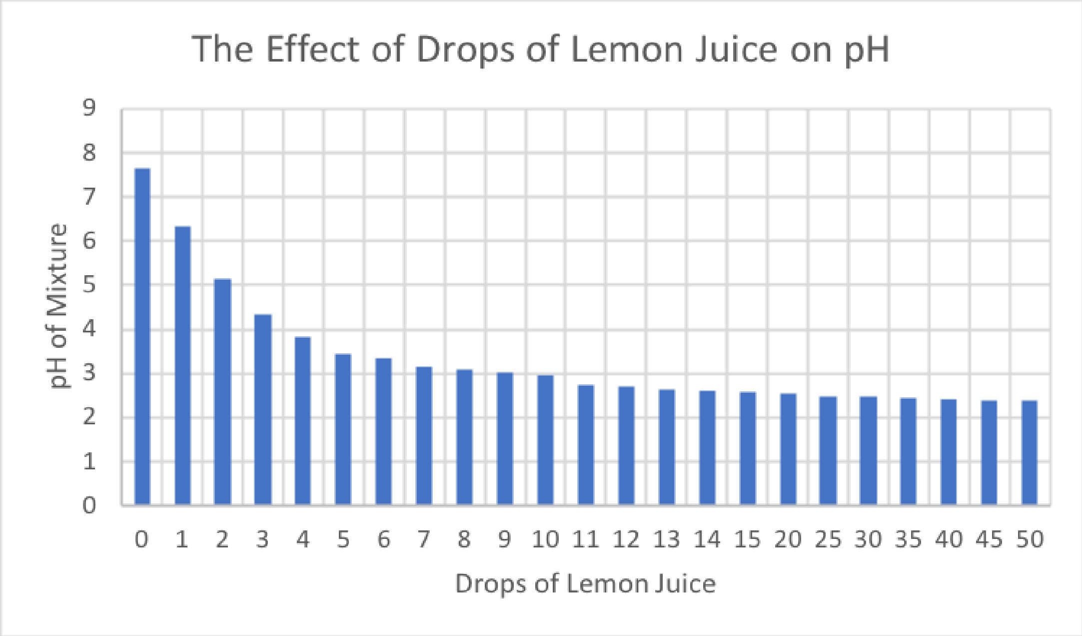

Figure 1: This table shows the relationship between drops of lemon juice into a cup of tap water. The relationship shown proves how acidic elements effect the pH of water in a non-linear way. This is significant because it allows consumers to understand why, and how, many of the household liquids have a pH slightly above 2.

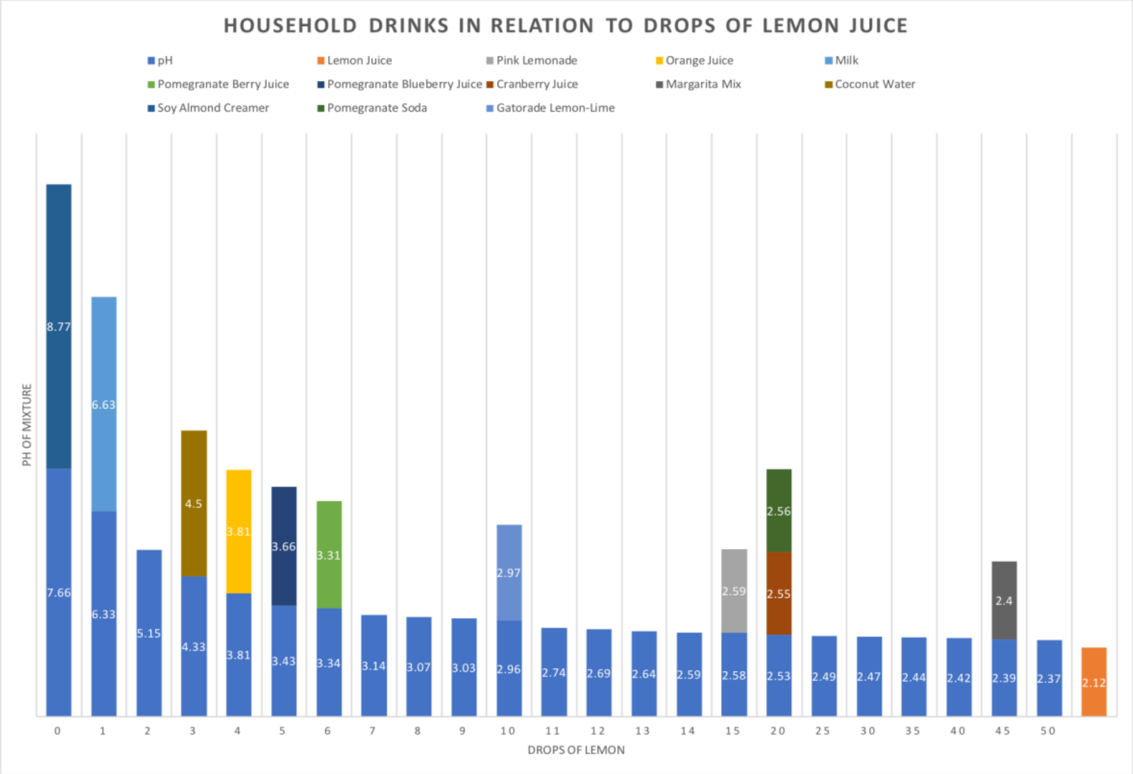

Figure 2: This table shows where all of the tested household liquids fall on the pH scale in relation to the drops of pure lemon juice. This allows for a clearer perspective and understanding as to what the numbers actually mean in relation to each other.

Our results indicate that pH plays a major factor in the perceived sour intensity of liquid substances. This can be shown through Milk (pH = 6.63), Coconut Water (pH = 4.50), and Soy Almond Creamer (pH = 8.77) tasting much differently than Lime Margarita Mix (pH = 2.40), Lemon Juice (pH = 2.12), and Pomegranate Soda (pH = 2.56). However, our results also show that there are other factors to determining perceived sour taste intensity of liquids. This can be shown through our results that Pink Lemonade (pH = 2.59) and Cranberry Juice (pH = 2.55) taste very differently while having a pH within 0.05. Our results also indicate that pH changes at lower values are more significant than ones closer to neutral pH values. This can be shown through our graph of all the pH values (Figure 1). The neutral water had drastic pH changes at one and two drops of pure lemon juice yet changed very slightly when closer to the pH threshold of the pure lemon juice. This result is minimized, however, by the finding that the human tongue has a sour taste threshold near a pH of 3.24; as such anything below this pH, which many of our common household drinks were, has little significance in creating a different taste perception.

Conclusion

This research is an important first step in understanding the way liquids and our tongue interact with each other. It concludes that pH is an integral part of the perceived sour intensity of any liquid, but that it is not the only factor. We propose three other major factors for perceived taste of liquids: visual perception, olfactory perception, and conductivity of the liquid. As many senses within the human body are linked together, we believe that when researching one independently from the others there is no possibility of complete understanding. However, if one were able to connect all three of our proposed extra factors along with pH of a liquid, we believe one could create tastes from scratch. This could lead to a completely new understanding of chemical food manipulation as a whole. If we are able to control both the taste and the components inside of a liquid, one could chemically engineer a drink that contains many healthy nutrients while tasting like anything they want (ex. Coffee). This could also lead to a completely new understanding of which components of a food effects taste sensation; with this understanding one could write simple binary code for creating foods. If this were possible, then one could realistically send a code from one side of the world to another; this, in essence, would be e-mailing a taste from one person to another. While these ideas are out of reach with today's understanding of food taste in its relation to our tongue, with only a few steps of scientific understanding it is a real possibility.

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