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POSSIBILITY OF MAKING HYDRODYNAMIC OSCILLATOR – AS AN ARTIFICIAL TASTE SENSING DEVICE

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Abstract:

The mechanism leading to sensation of taste, which is so very essential for the maintenance of life, are very complex and little understood. Broadly speaking, it can be said that interaction of different chemicals, which may be called as taste stimuli, with taste receptors is converted into information of nerve impulses, which the brain receives to decipher the taste. It is, therefore, necessary to have an excitable oscillatory system on which the phenomenon of taste can be mimicked.

In a recent study, it has been shown that the hydrodynamic oscillator is a good candidate for mimicking the sensing mechanism of taste. It was argued that the hydrodynamic oscillator could be viewed as an analogue of taste buds and the amplitude of electrical potential oscillations in the hydrodynamic oscillator, using a taste stimulant, as an analogue of the receptor potential. The amplitudes of the electrical potential oscillations in the hydrodynamic oscillator were shown to correlate well with the logarithms of the relatives taste indices (The intensitites of taste sensations within a particular taste category are measured by their relative taste indices), concentration, etc. of the substances belonging to different taste categories, and it appears that hydrodynamic oscillator can be used as possible artificial taste sensing device.

Keywords: Receptor potential, taste, sensor, relative taste indices.

Introduction

The sensation of taste is relatively complex and little understood[1, 2]. Developing parameters to describe the sensation of taste, qualitatively and quantitatively, though important in itself, is quite important for the food industry. The food industry, for assessment of taste, has to depend on the individual judgment of tasters employed for this purpose. Broadly speaking, it can be said that interaction of different chemicals, which may be called as taste stimuli, with taste receptors is converted into information of nerve impulses, which the brain receives to decipher the taste. Thus, if one wants to mimic the mechanism of chemical sensing in the biological systems, the development of excitable or oscillatory systems is necessary. Over the years various types of artificial membranes with excitability has been reported in the literature [3-9]. Because of their experience [3-7]of reproducibility of oscillations in the liquid membrane systems consisting of an aqueous phase containing a cationic surfactant/oil phase, Yoshikawa et al. [10] chose to study electrical oscillations across a liquid membrane consisting of an oil layer, nitrobenzene laid between two aqueous layers one of which contained a soap, sodium oleate or sodium steareate. Variations in the characteristics of the oscillations with the addition of various chemical species were qualitatively assigned to their respective taste categories.

If one looks at the anatomy of taste buds and the process involved [11-13], one realizes that the liquid membrane system chosen by Yoshikawa et al. [10], though reproducible, does not quite correspond to the in vivo system.

The hydrodynamic oscillator, which also developed by Yoshikawa et al.[14-15] is a good candidate for mimicking the sensing mechanism of taste. It was argued that the hydrodynamic oscillator can be viewed as an analogue of taste buds and the amplitude of electrical potential oscillations in the hydrodynamic oscillator, using a taste stimulant, as an analogue of the receptor potential. The amplitudes of the electrical potential oscillations in the hydrodynamic oscillator were shown to correlate well with the logarithms of the relatives taste indices, concentration, etc. of the substances belonging to different taste categories.

In the present communication, we have obtained from the hydrodynamic oscillator, data on the electrical potential oscillations in the case of substances belonging to four different primary taste categories, i.e., sweet, sour, salty and bitter, and a few mixtures of substances belonging to two different taste categories. In this way, an attempt has been made to establish hydrodynamic oscillator as an artificial taste sensing device.

2. **Visualization of hydrodynamic oscillator as taste bud.**

Taste is sensed through taste buds. A taste bud is composed of about 40 modified epithelial cells some of which are supporting cells and others are taste cells. The outer tips of the taste cells are arranged around a minute taste pore [Figure 1]. Each taste cell has got microvilli or taste hair of 2 to 3 micron in length and 0.1 to 0.2 micron in width that are projected in the taste pore ; the taste hair protrudes outward through the taste pore to approach the cavity of the mouth. These microvilli are believed to provide the receptor surface for taste sensation.

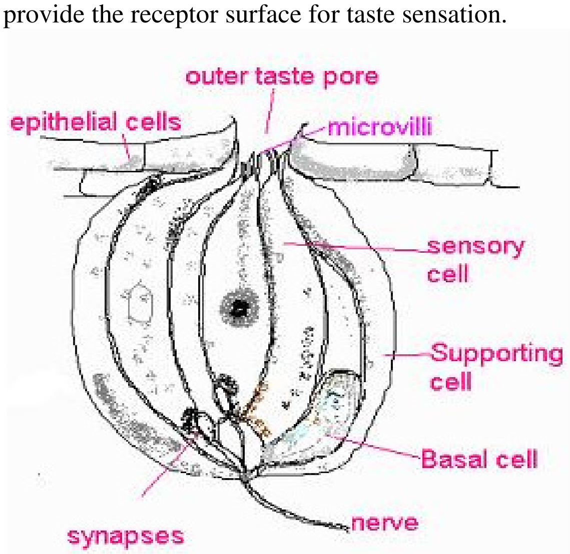

Figure 1: A Taste Bud

The membrane of the taste cell, like that of other sensory receptor cells, is normally negatively charged on the inside with respect to out side. Application of taste substance to the taste hairs causes partial loss of negative potential. This change in potential, which sometimes is called **«Generator Potential»,** [Part-I, Figure 2] is believed to be stimulus for the generation of nerve impulses, which the brain receives to decipher the taste [Part-II, Figure 2]. A schematic representation of the taste signal transmission has been depicted in Figure 2. Although generator potentials might be produced by all four categories of taste stimuli, only the one to which the cell is most sensitive might produce a response strong enough (i.e. greater than the threshold value) to excite the axon.

Although the nature and origin of generator potential are mostly unknown, we suggest the following possibility. It is a common experience that one does not get a full sensation of taste just by keeping the solution of taste stimuli on the tongue; one has to repeatedly press the tongue with the palate of the mouth and release the pressure. When one pressurizes the tongue the solution of the taste stimulus compound is forced to pass through the taste pore and when the pressure is released the solution of the taste stimulus moves upward through the pore. Since the diameter of the pore is very small the upward movement may be due to capillary action, since microvilli are charged, formation of an electrical double layer around them cannot be ruled out. Therefore, it is logical to postulate that when the tongue is pressed on the palate the mobile phase of the double layer is pushed downwards and when the pressure is released it moves upward in the opposite direction. Thus the generator potential should be streaming potentials.

The action can be very conveniently mimicked by the hydrodynamic oscillator or its non-electrolyte analogue. The system consists of an open glass tube with capillary attached at one end. The capillary is filled with solution of salt or suitable non-electrolyte and the whole system is suspended in a glass vessel containing water such that the level of the solution in the inner tube and that of water in the outer vessel is the same. Owing to imbalance of hydrostatic pressure arising due to the difference in the densities of the liquid in the inner tube and in the outer vessel, the solution in the tube begins to flow downwards. This flow terminates after sometime and then upward flow of the water from the outer vessel into inner tube through the capillary begins. When the upward flow terminates the down flow again sets in & so on. If sensing electrodes are introduced in the inner tube and in the outer vessel the potential difference across the electrodes oscillates with time. It has been shown in our earlier publications[16-17] that these oscillating potentials are streaming potentials due to the up and down movement of the mobile phase of the double layer when the liquid flows up and down in the capillary.

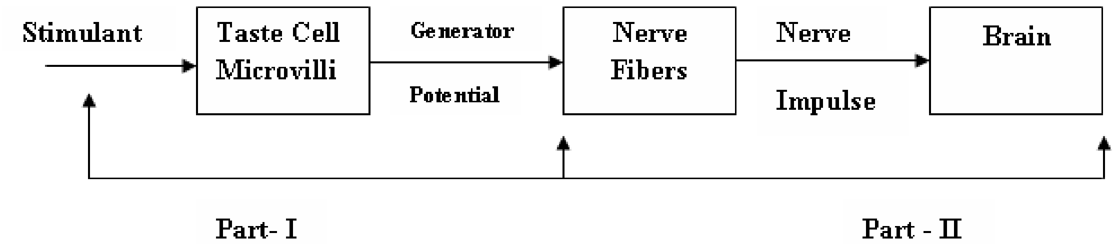

Figure 2: Schematic representation of Taste Signal Transmission to brain.

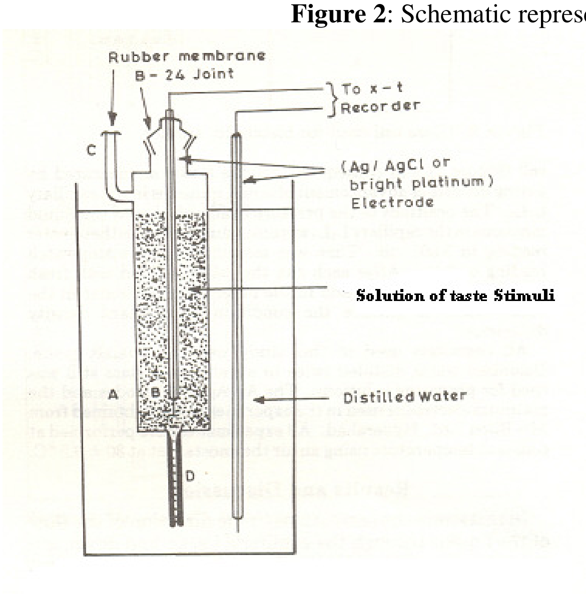

Figure 3: Schematic representation of the Hydrodynamic Oscillator

In view of the discussion, it appears that the hydrodynamic oscillator can be taken to be an analogue of the in vivo taste sensing system in terms of mimicking the mechanism related to the generation of **"Generator Potential"** i.e. part I, Figure 2 and the amplitudes of the electrical potential oscillations in the hydrodynamic oscillator as an analogue of generator potential for different taste stimuli taken in the oscillator. As already mentioned, the amplitudes of the electrical potential obtained from the hydrodynamic oscillator have been shown to correlate well with the logarithms of the relative taste indices, concentration etc. for different taste stimuli.

3. Experimental

The experimental set up is depicted in Figure 3 and the procedure adopted was the same as described in the earlier publications[16-17]. An aqueous solution of the taste stimulant substance of desired concentration was filled in the inner tube B through the side tube C. When the inner tube was completely filled the side tube was sealed off with a stretched rubber membrane to ensure that the aqueous solutions stayed in the inner tube and did not flow out of the capillary. The inner tube filled with aqueous solution was then hung into a bigger glass vessel, A, containing distilled water such that the level of the liquids in the inner tube and the outer vessel was the same. The rubber seal over the side tube was then ruptured and the electrical potential differences across the electrodes in the inner tube and in the outer vessel were recorded with time using the x-t recorder.

4. Result and discussion

The amplitudes of electrical potential oscillations have been found to vary with various concentrations of substances belonging to different taste categories using hydrodynamic oscillator. Traces of oscillations in few represented cases of different taste categories are shown in Fig. 4. Different substances used in the present study for each of the taste categories, sweet, salty, sour and bitter are listed in Table 1 along with their relative taste indices as documented in literature [11]. The intensities of the four different primary sensation of taste are referred, respectively to the intensities of taste of sucrose, sodium chloride, hydrochloric acid and quinine, each of which is considered to have a taste index of 1.

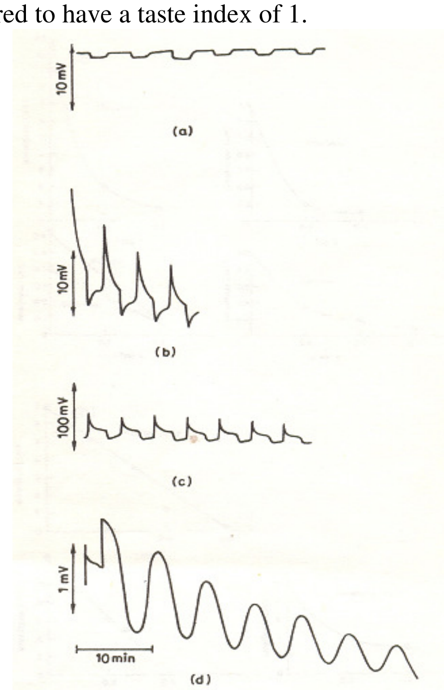

Figure 4: Traces of electrical potential oscillations using aqueous solutions of substances belonging to different taste categories: (a) 1.00 M sucrose; (b) 1.00 M tartaric acid; (c) 1.00 M sodium chloride; (d) 0.14 M caffeine

It is well known [11] that the generator potential, or the receptor potential as it is also some times called, within a wide range, is approximately proportional to the logarithm of the concentration of the stimulating substances. Consistent with the proposal made in this paper, it has found that the amplitudes of the electrical potential oscillations for different taste stimulants increase with the increase in the value of the logarithm of their concentration (log c).

The intensity of the sour taste sensation is known to be approximately proportional to the logarithm of the hydrogen ion concentration. Data on the variation of amplitude of the electrical potential oscillations with pH for solutions of different acids are plotted in Figure 5 The plots are linear (Figure 5) ; the amplitude increases with the decreases in pH in all cases.

The intensitites of taste sensations within a particuler taste category are measured by their relative taste indices (Table 1). If, as proposed in this paper receptor potential is the oscillating streaming potential due to the up and down movement of the solution of the taste stimulant in the taste pore around the taste hair, for solution of same concentration of different taste stimuli the gredation of the amplitudes of electrical potential oscillation should be in accordance with the gradation in their relative taste indices, I. This expectation is corroborated by the data summarized in Table 1. The data on the variation of the amplitudes with logarithme of the relative taste indices log I, are plotted in Figure 6 The variation is linear in case of salty and sour taste stimuli. In the case of sweet taste category also, except for saccharin, data for all other substances fall on linear plot (Figure 6). This is understandable because saccharin is structurally different from others, which are sugars.

It has been suggested [11-13] that there may be four distinct types of taste buds, each specialized to respond to certain types of stimuli more effectively than others ; this suggestion is backed by several electrophysiological and psychophysical evidences [11-13]. The buds for sweet, salty, sour and bitter tastes are located at the tip, on the dorsum anteriorly, at the sides and at the back of the tongue respectively. It is also documented [11-13] that : (i) intensity of taste sensation depends upon the total surface area stimulated, as for instance stimulation of a single papilla by a drop of solution produces weaker sensation than does tasting of the same solution by a larger area ; and (ii) when one tastes a mixture of stimuli belonging to two or more taste categories one is able to recognize the taste of each constituent of the mixture ; for example, when one tastes a mixture of sweet and salty components, one is able to recognize both tastes. In terms of electrical analogues, these observations suggest that the taste buds of the same category may be joined in series whereas those of different categories may be joined in parallel. For example, all taste buds for the sweet category may be in series whereas those for sweet may be joined in parallel with those for salty or sour category. Prompted by this surmise, we performed the following experiments. Two solutions of same concentration of the same substances (belonging to the same taste category) were taken in two oscillators and joined in series ; the experimental arrangement is shown in Figure 7(a), and the electrical potential oscillations were monitored with time. In the second experiment, solutions of same concentration of two substances belonging to different taste categories were taken in two different oscillators and joined in parallel as shown in Figure 7(b), and the electrical potential oscillations were monitored with time.

It has been found that amplitude of the electrical potential oscillations in the experiment with the series arrangement is more or less equal to the sum of the amplitudes in the individual constituent oscillators [Figure 8]. This is consistent with the observation [11-13] that intensity of taste sensation is enhanced when more papillae are stimulated and our suggestion that the taste buds of the same taste category may be joined in series. Similarly, the electrical potential oscillations in the experiments with the parallel arrangement can be seen to be a mix-up of the oscillations in the constituent oscillators [Figure 9]. This observation is consistent with the experience that one can recognize the taste of the individual constituents in a mixture of substances of different taste categories and our suggestion that the taste buds of different categories may be joined in parallel.

5.Conclusion

The present study indicates that the hydrodynamic oscillator is a good candidate for mimicking the sensing mechanism of the taste. We, however, confess that the mimicries reported in this paper are only partial because a part of it has been mimicked **(Generation of Generator potential)** and otherwise also the taste of food is significantly influenced by other factors like texture of food, sensed by tactual receptors of the mouth, temparature and most significantly by the sense of smell which as of now is also not well understood.

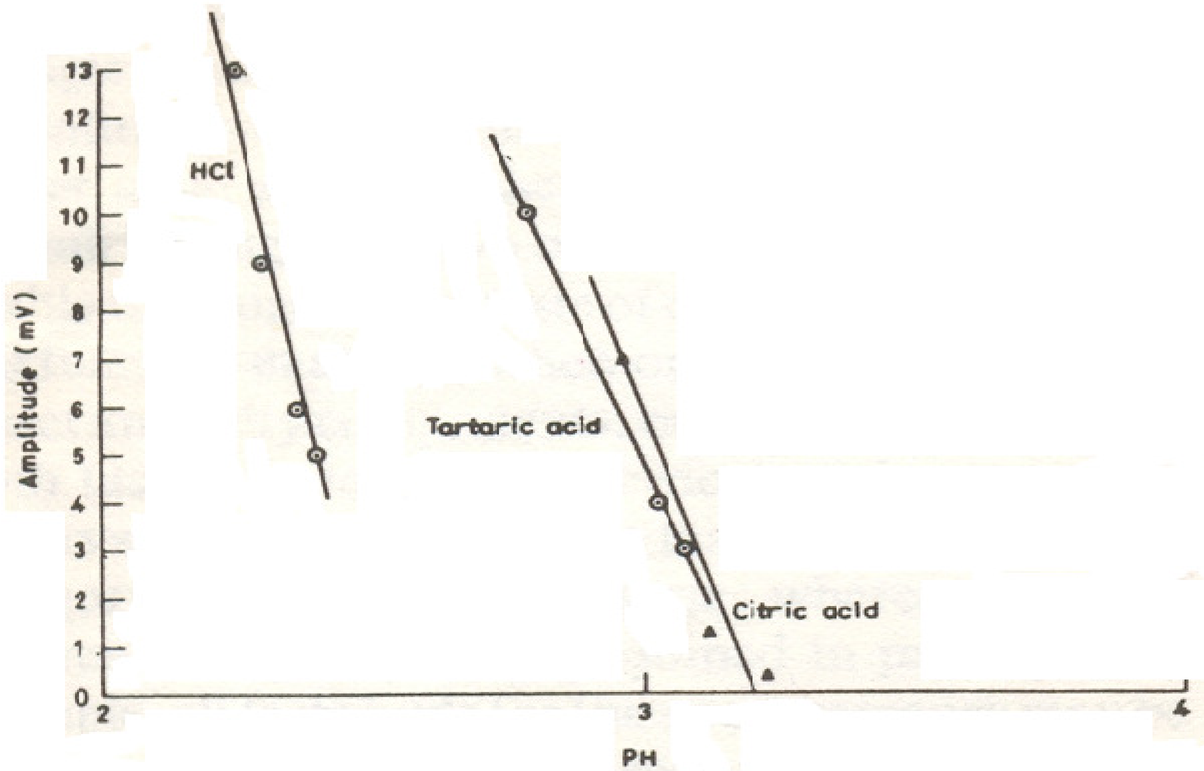

Figure 5: Variation of amplitudes of electrical potential oscillations with pH of aqueous solutions of sour stimulants.

Table 1 : Variation of amplitude of electrical potential oscillations using aqueous solutions of same concentration (1M) of the substances belonging to different taste categories with their relative taste indices (I)

Category	Substances	Index(I)*	Amplitude(mV)
Sweet	D-Galactose	0.32	0.4
	Maltose	0.45	0.64
	Sucrose	1.0	1.0
	D-Fructose	1.7	1.3
	Saccharine-sodium	675	11
Sour	Citric acid	0.46	7
	Tartaric acid	0.7	10
	Lactic acid	0.85	12.5
	Hydrochloric acid	1.0	13
Salty	Potassium chloride	0.6	24
	Sodium chloride	1.0	35
	Ammonium chloride	2.5	65
Bitter	Caffeine	0.4	1.7**

*Values taken from reference no.11. pp. 776
** Concentration used = 0.14 M, which is the maximum solubility of caffeine in water.

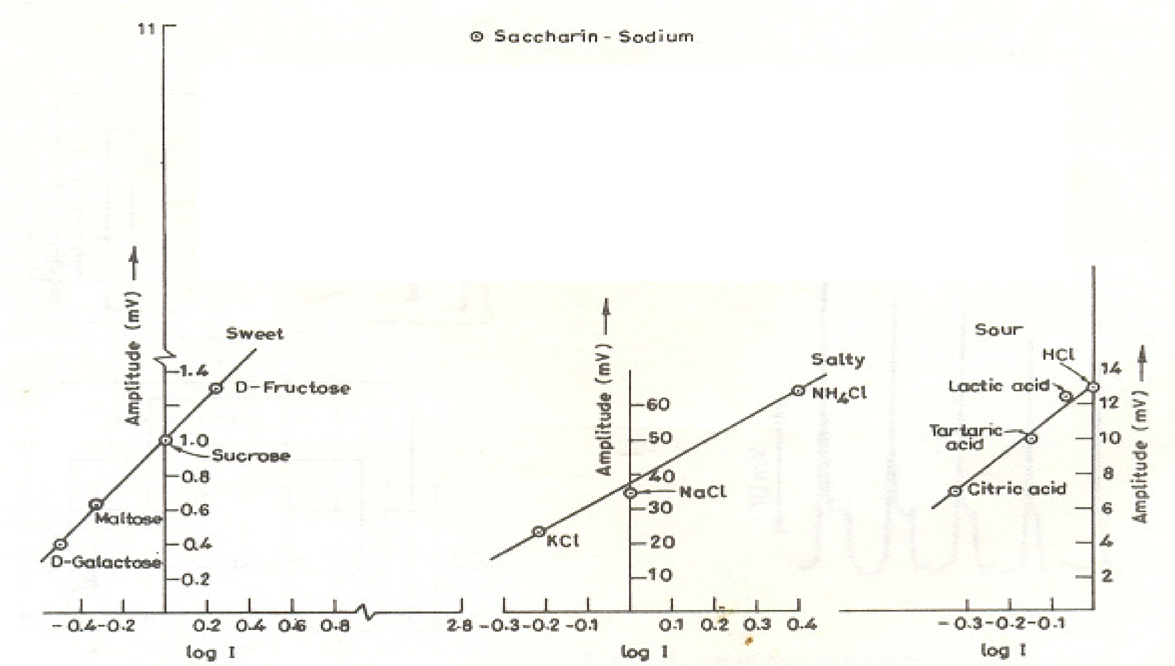

Figure 6: Variation of amplitudes of electrical potential oscillations using aqueous solution of same concentration (1.00M) of the substances belonging to different taste categories with the logarithm of their relative taste indices.

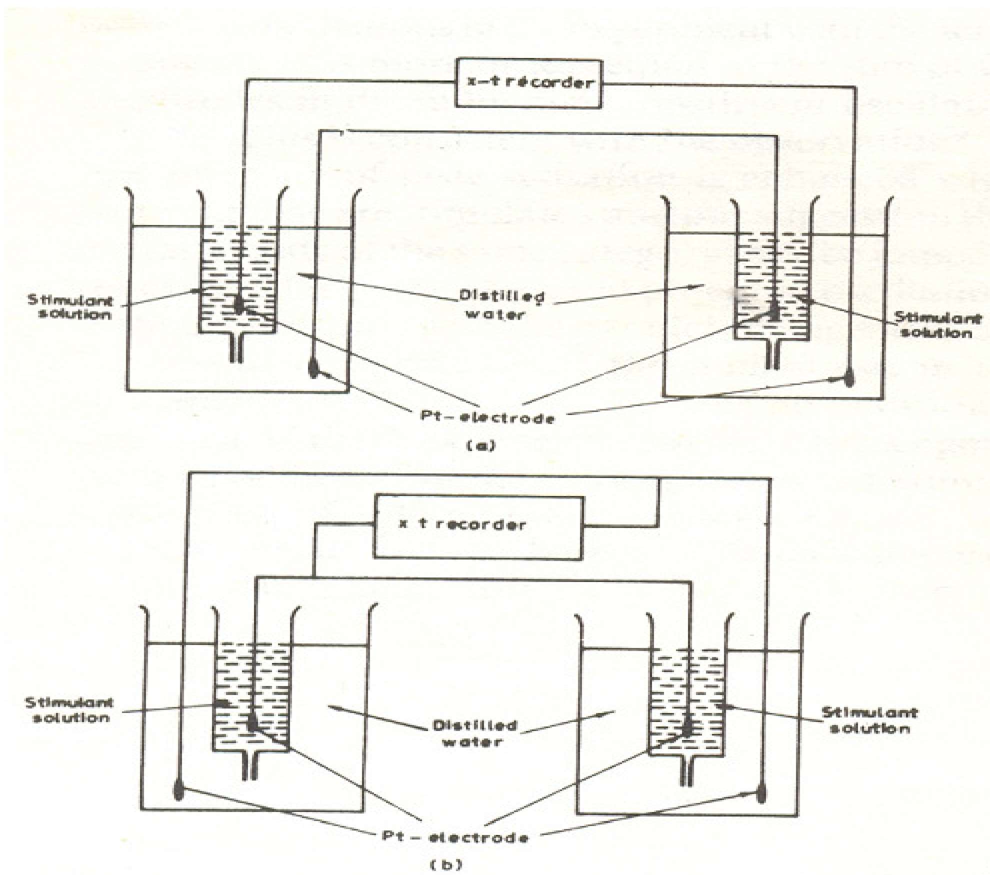

Figure 7: Schematic representation of the two oscillators: (a) in series (b) in parallel arrangement

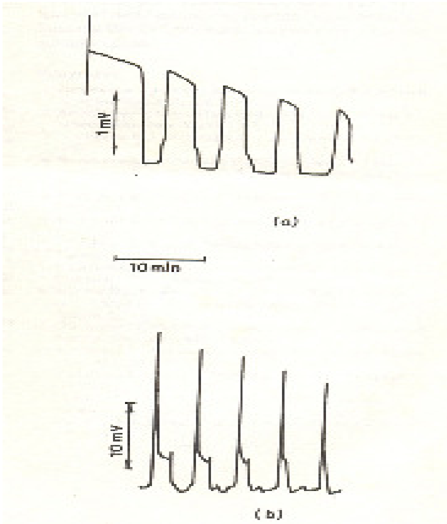

Figure 8: Traces of electrical potential oscillation using aqueous solution (1.0M) of substances belonging to same taste categories in two oscillators joints in series. (a): 1.0M Sucrose, (b) 1.0 M Tartaric acid. For electrical potential oscillations of constituent oscillators see figure 4, traces (a) & (b).

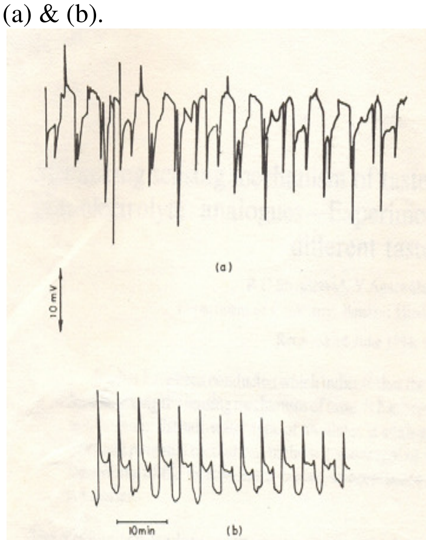

Figure 9: Traces of electrical potential oscillations using aqueous solution (1.0M) of substances belonging to different taste categories in two oscillators joints in parallel. (a) 1.0 M Tartaric acid + 1.0M NaCl (b) 1.0 M Tartaric acid + 1.0M sucrose. For electrical potential oscillations of constituent oscillators see figure 4, traces (a), (b) & (c).

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