Electrogustometry II, part II

The electrode polarization

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Introduction

Some of the most intriguing problems in electrogustometry are connected with the design and properties of the tongue electrode. Part I of the present publication evaluated one aspect of these problems, the spread of the current around the stimulating electrode. Part II is concerned with the electrode polarization and its relation to the threshold determination.

The use of metal electrodes in biology is encumbered by artefacts due to electro-chemical processes in the metal-electrolyte interface. The most important of these disturbances is caused by polarization effects. When a metal electrode is immersed in a saline solution or brought in contact with living tissue, a dc-boundary potential is usually found to exist between the electrode and the surrounding fluid. When a direct current is passing the electrode, this interface process represents an ohmic resistance and a capacitance which change gradually under the influence of the current.

Many investigators have tried to avoid the problem of electrode polarization by using so-called unpolarizable electrodes for their experiments. The principle has usually been to ensure reversibility of the electro-chemical interface process by means of a salt barrier such as silver–silver chloride–chloride (Ag–AgCl–Cl).

Bujas and Chweitzer (1934) used a test tube which was cut off at the rounded end and sealed with an agar gel tip. The tube was filled with a 1 per cent NaCl-solution in which a chlorided wire was immersed. Dzendolet (1957) objected that agar can act as an ion-interchanging substance and preferred a different electrode design. He made a cylindric plastic chamber which was small enough (1·5 mm. inner diam.) to adhere to the tongue surface and then be filled with the electrolyte. Ichioka *et al.* (1963) used a thin glass tube (1 mm. inner diam.) sealed at the open end with a small cotton wool wad.

From these examples it will be evident that unpolarizable electrodes are rather inconvenient for clinical routine examinations. Krarup (1958) who first designed a clinical method of electrical taste examination used a flat circular-steel electrode, 5 mm. in diameter (= 20 mm.^{2}) which is easy to clean and ready for use without any other preparations. These practical advantages are opposed by the fact that it is highly polarizable.

https://doi.org/10.1017/S0022215100071218 Published online by Cambridge University Press

None of the authors mentioned above have investigated experimentally the possible influence of the polarization phenomenon on the threshold level. From a theoretical point of view, the electric taste stimulus should be unaffected by the electrode polarization. It is generally accepted that the effect of the stimulus depends on the current rather than on the voltage. The gustometer should therefore be designed as a constant current generator, meaning that the stimulating current should be independent of the variable electrode resistance. If this is ensured, the polarization phenomenon should not be able to change the shape or size of the rectangular impulse, as measured in micro-amp.

Unfortunately, these theoretical arguments do not offer a satisfactory solution of the problem. The many different electrode designs express a widespread uncertainty as to the complex behaviour of electrodes in biology. The unknown mechanism by which the electric stimulus elicits a taste sensation is another source of uncertainty. Even a subliminal NaCl-concentration in the electrode chamber might facilitate the response to the electric stimulus.

An experimental evaluation is therefore the only direct and dependable solution of the polarization problem. From a clinical point of view, the question is whether the electrode polarization disturbs the threshold determination to such an extent that it makes the steel electrode inacceptable even for clinical use. This question can be answered by a simple psycho-physical experiment without any knowledge of the metal-electrolyte interface process or the mechanism of electric taste.

Method

For comparison with Krarup's steel electrode an unpolarizable electrode was designed as shown in Fig. 1. A carefully chlorided 4×40 mm. pure silver plate was fitted into a 10 cm. long glass tube with an inner diameter of 5 mm. The tube was closed at the upper end by an acrylic plug which covered the place where the flex was soldered to the silver plate. A foam rubber wad at the other end of the tube prevented the electrolyte from running out and provided a contact area of 20 mm.^{2} for transmission of the stimulus from the electrolyte to the tongue surface.

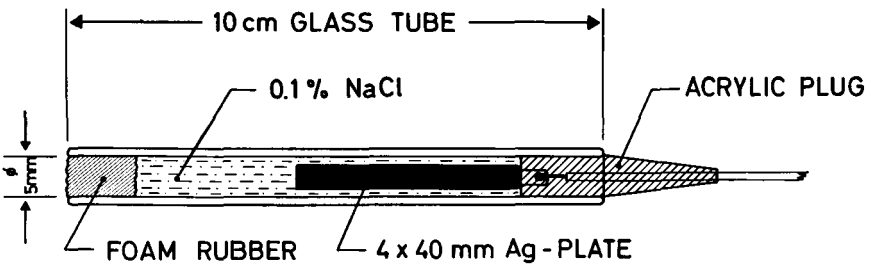


FIG. 1.
The fluid electrode used for comparison with Krarup's steel electrode.

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The concentration of the NaCl-solution which formed the salt barrier of the electrode called for special consideration. It is evident that the electrolyte should not in itself elicit a salty taste sensation before the electric stimulus is applied. In a survey of the thresholds for NaCl found by various authors, Pfaffmann (1959) gives 0·01 molar as a median threshold and a range of threshold concentrations from 0·001 to 0·08 molar. On this background it may seem surprising that Bujas used a 1 per cent NaCl-solution (= 0·17 molar), Dzendolet up to 0·2 molar NaCl and Ichioka a Ringer solution (0·9 per cent NaCl = 0·15 molar). The summation phenomenon demonstrated in a previous study (Føns and Osterhammel, 1966) may hold an explanation of this in the cases of Dzendolet and Ichioka, who both used very small electrodes (1·5 mm. and 1 mm. diam. resp.). It is more surprising that Bujas's test tube electrode with a 1 per cent NaCl solution (= 1·7 molar) did not give a salty taste sensation even without an electric stimulus. We found that a physiological saline solution (0·9 per cent NaCl = 0·15 molar) has a pronounced salty taste. Diluted to 0·1 per cent (= 0·017 molar) it was reported by the two subjects used in the present investigation to have no taste at all, even when swirled around in the mouth. This concentration was therefore used in our experiments.

Due to the low concentration of the electrolyte and the fairly small electrode area the ohmic resistance of our electrode was different from that of Krarup's steel electrode. The resistances given in Table I were calculated from registrations of corresponding values of current and voltage. Our original electrogustometer which was a modification of Krarup's had three measuring scales with different series resistances chosen according to the highly variable electrode resistance (Krarup, 1958). Instead of increasing the inner resistance at the highest measuring scale a new transistorized stimulator was designed which ensured a constant current output within a wide range of electrode resistances.

TABLE I.

ELECTRODE RESISTANCES AS A FUNCTION OF THE CURRENT.

I	20 mm.² fluid electrode	20 mm.² steel electrode
10 μA	60 Kohm	120 Kohm
30 μA	52 Kohm	57 Kohm
100 μA	46 Kohm	30 Kohm
300 μA	33 Kohm	18 Kohm

A method of adjustment very similar to Békésy audiometry was preferred for the threshold determinations. The stimulus duration was 1 sec. and the intervals of 6 secs.' duration. The intensity was first set at a

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level well over the threshold. A number of rectangular stimuli were presented to the subject who held the electrode on the tongue surface The subject then adjusted the stimulus intensity by means of a round knob on the gustometer until he felt that he had found the lowest detectable stimulus intensity. The reading on the potentiometer was then recorded by the examiner. A total of fifty threshold values with each of the two electrodes were recorded in each of the two subjects.

It is generally agreed that anodic taste stimulation at low intensities elicits a sour, metallic taste sensation, while at high intensities a stinging or burning sensation prevails. This may indicate that different mechanisms dominate at low and high intensities. Furthermore, the electrode polarization is known to vary with the current intensity. For these reasons it was considered necessary to compare the two electrodes also at high intensities.

A method based on the differential sensitivity was used for this part of the experiment. The details of this method were described in a previous study (Føns and Osterhammel, 1968) in which the 'just noticeable difference' (jnd) for electrical taste was found to be approximately 20 per cent. With a potentiometer range of intensities from 0–300 micro-amp. and thresholds in the area of 10–20 micro-amp., 230 and 276 micro-amp. were chosen as the two 'high' intensities to be compared. The two stimuli were both of 500 m.sec's. duration (Føns and Osterhammel, 1968) and were applied with 6 sec's. interval. The two electrodes were now compared according to the following principle. Suppose the stimulus pair 230–276 micro-amp. applied with one electrode makes the subject experience a certain difference in intensity. If the first stimulus (230 micro-amp.) is then applied with electrode K, and the second (276 micro-amp.) with electrode U, the difference will only appear to be the same as before, provided the two electrodes convey the impulse with the same intensity. If electrode U tends to be felt more strongly than K, the stimulus pair K_{230}–U_{276} will give better discrimination than the stimulus pair U_{230}–K_{276}. This can be registered as a difference in discrimination score, e.g. given in per cent right answers to a number of stimulus presentations. With two different stimulus intensities, two different electrodes and two different intensity sequences, we get the four combinations shown in Table II. To a total of 128 paired applications in each of two subjects, the replies were registered according to the 'forced choice procedure' as first/second stimulus stronger.

TABLE II.

THE FOUR COMBINATIONS OF PAIRED STIMULI.

K 230–U 276
U 230–K 276
K 276–U 230
U 276–K 230

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This rather complicated discrimination method was chosen for two reasons. A large number of data could be collected and evaluated statistically. Experienced subjects with normal and constant taste thresholds could be used. The alternative solution would be threshold determinations on patients with very high threshold levels and still not ageusia. Most of the patients we see belonging to this category are cases of rheumatic facial palsies undergoing spontaneous remission. Besides their inexperience as experimental subjects their taste thresholds often improve almost from day to day. They are therefore unsuitable for our experiment.

Results

Table III gives the comparative results of the threshold determinations. A statistical evaluation showed no significant difference between the two electrodes.

TABLE III.

AVERAGE THRESHOLDS WITH THE TWO ELECTRODES AND THE CORRESPONDING P-VALUES.

	Steel electrode	Unpol. electrode	P–values
Subject I	10·3 μA	9·7 μA	$0{\cdot}8 < P < 0{\cdot}9$
Subject II	7·2 μA	7·3 μA	$0{\cdot}1 < P < 0{\cdot}05$
Subject I+II	8·8 μA	8·4 μA	—

At high intensities the discrimination experiment gave practically the same score with the two electrodes, a χ^2-test showing no significant difference. The results are given in Table IV.

TABLE IV.

THE RESULTS OF THE DISCRIMINATION EXPERIMENT.

Stronger stimulus on	No. of right answers	No. of wrong answers	Total	χ^2–test
Subject I				
K	41	23	64	$\chi^2 = 0$
U	42	22	64	
(Total)	83	45	128	
Subject II				
K	38	26	64	$\chi^2 = 2{\cdot}6$
U	34	30	64	20% P 10%
(Total)	72	56	128	
Subject I+II				
K	79	49	128	$\chi^2 = 0{\cdot}07$
U	76	52	128	80% P 70%
(Total)	155	101	256	

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The results of the comparative threshold and discrimination experiments were almost the same in the two subjects. It will also be seen that between the two subjects there was only a moderate difference in threshold level and discrimination ability.

Comments

The investigations outlined above do not pretend to be a complete evaluation of the polarization phenomenon. On the contrary, it has been attempted to avoid many theoretical aspects of the problem which have been dealt with by other authors in recent publications (Greatbatch, 1967; Weinman and Mahler, 1964). We wanted to know if the simple metal electrode designed by Krarup could be used for clinical electrogustometry despite its being highly polarizable. The above results raise no objections to this. Tested under clinical circumstances Krarup's electrode showed no deviation from an unpolarizable electrode.

This leaves only the practical qualities of the electrodes to be considered. The steel electrode is of a simple, durable and inexpensive construction, it is easily cleaned and sterilized and no other preparations are needed before use. It is therefore the most suitable for clinical electrogustometry.

In certain experimental situations an important difference will be noted between an unpolarizable electrode and a simple metal electrode. The voltage of the stimulating impulse can be registered on a dc-writing recorder or an oscilloscope, e.g. for calculation of the electrode resistance as mentioned above. Such voltage curves are given in Fig. 2. It will be seen that with Krarup's electrode (Fig. 2a) the voltage increases slowly and does not reach a constant maximum level. Consequently, only the approximate resistances can be calculated from the recordings. The curves in Fig. 2*b*, *c* and *d*, were registered with a platinum electrode, a chlorided silver electrode and our fluid electrode, all 5 mm. in diameter. The fluid electrode gives a rectangular curve which makes the reading easy and accurate. The curves in Fig. 2*b* and *c* represent intermediary stages between the two extremes (*a* and *d*). It should be noted that due to the constant current output from the stimulator, the current of the impulse will always be rectangular and independent of the voltage variations shown in Fig. 2.

Krarup was the first to recognize the importance of this constant current output from the electrogustometer. He provided the apparatus with series resistances which were so high that the variable electrode resistance never exceeded 5 per cent of the total resistance. The present study demonstrates the necessity of measuring the resistance of any new electrode before it is used for electrogustometry. The high resistance of our fluid electrode was found to reduce the current output from the gustometer with 10–20 per cent at high intensities. This could have been

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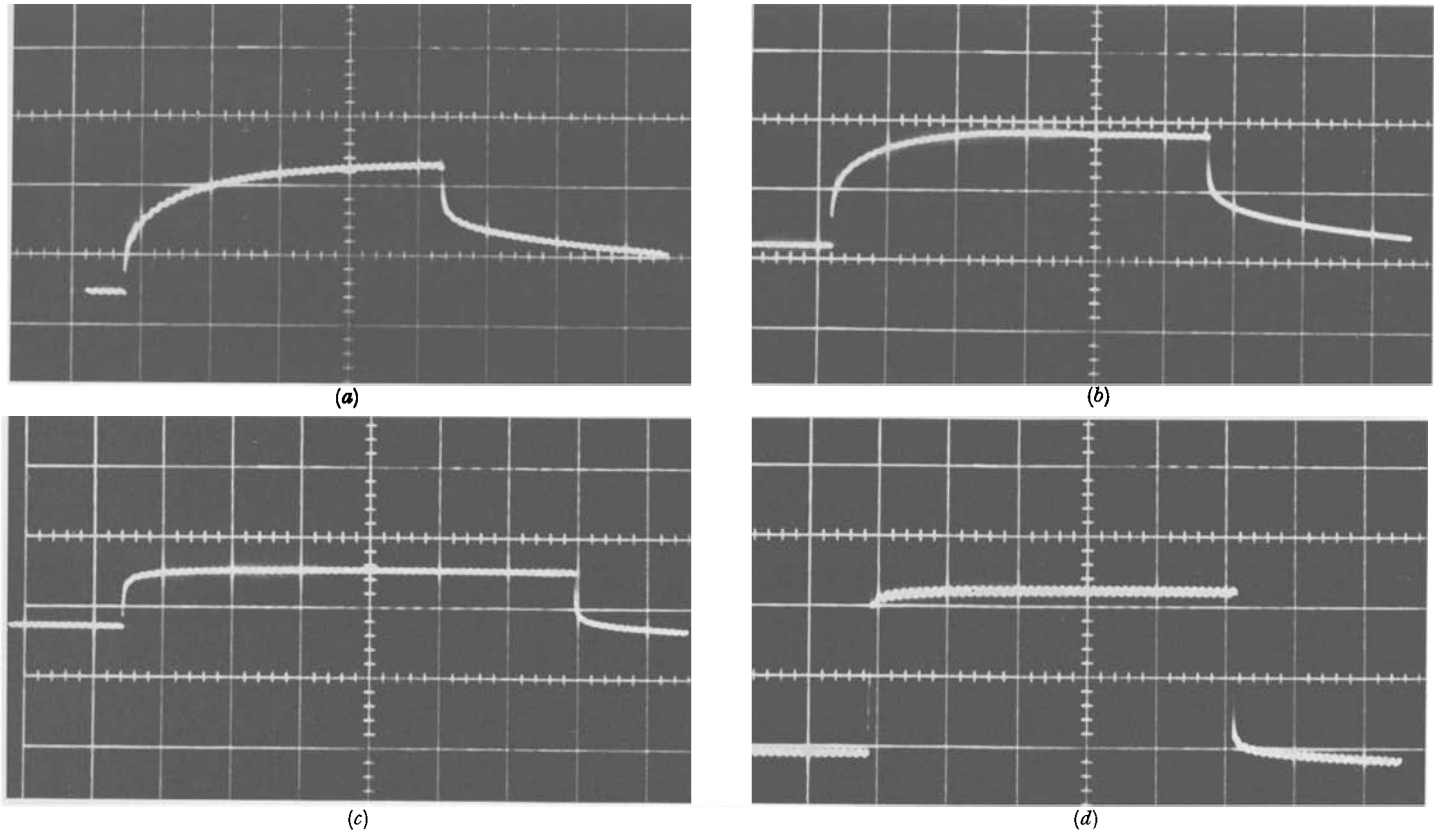


FIG. 2.

Voltage variations measured at 30 uA with

(*a*) Krarup's steel electrode
(*b*) A platinum electrode
(*c*) A chlorided silver electrode
(*d*) A fluid electrode.

Abscissa: 200 m.sec./division.
Ordinate: 500 mV/division.

avoided by a further increase of the inner resistance of the gustometer, but a considerable increase of the battery voltage would then have been necessary. It was therefore preferred to use the transistorized stimulator mentioned above. Even with changes of the electrode resistance from 0–300 Kohm the current output was found to change with less than 1 per cent.

Conclusions

(1) Experimental comparison of a steel electrode and an unpolarizable fluid electrode showed no difference in threshold level or discrimination ability.

(2) Due to its practical advantages, a steel electrode is therefore most suitable for clinical electrogustometry.

(3) If an unpolarizable electrode has a small contact area and low electrolyte concentration, its ohmic resistance may be too high for an electrogustometer like Krarup's. In such cases a transistorized constant current stimulator can be used.

Summary

Many investigators of electrical taste have preferred to use unpolarizable electrodes. As these are rather impracticable for clinical purposes, Krarup designed a simple steel electrode for clinical electrogustometry. A steel electrode is highly polarizable but this does not necessarily disturb the threshold determination. In the present study Krarup's steel electrode and an unpolarizable fluid electrode were compared under clinical circumstances. No significant difference was found between the two electrodes. It is therefore concluded that due to its practical advantages the steel electrode is more suitable for clinical electrogustometry. A constant current output from the stimulator was found to be very important, especially when electrodes of a high ohmic resistance were used.

REFERENCES

Bujas, Z., and Chweitzer, A. (1934) *L'année psychologique*, **35**, 147.

Dzendolet, E. (1957) *Intensity-duration relation for taste using electrical stimulation.* Thesis, Brown Univ.

Føns, M., and Osterhammel, P. A. (1968) *Journal of Laryngology and Otology*, **82**, 85.

——— and ——— (1968) *Journal of Laryngology and Otology*, **82**, 95.

——— and ——— (1966) *Archives of Otolaryngology*, **83**, 538.

Greatbatch, W. (1967) *Medical Research Engineering*, **6**, 13.

Ichioka, A., Ohba, A., and Shimizu, H. (1963) *Zeitschrift für Biologie* **113**, 461.

Krarup, B. (1958) *Acta oto-laryngologica (Stockholm)*, **49**, 294.

Pfaffmann, C. (1959) 'The Sense of Taste'. In *Handbook of Physiology*, Neurophysiology. Edited by Field, Magoun and Hall, Washington. Vol. **1**, chapter 20.

Weinman, J., and Mahler, J. (1964) *Medical Electrical Biology Engineering*, **2**, 299.

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https://doi.org/10.1017/S0022215100071218 Published online by Cambridge University Press