The effect of interstimulus procedures on salt taste thresholds

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NaCl detection and recognition thresholds were measured with and without a prior artificial raising of the level of adaptation by a molar salt mouthrinse. In both cases, it was found that an interstimulus procedure involving water mouthrinses yielded lower thresholds than a procedure with no rinses. These results were seen to be predicted from adaptation level changes. The literature was seen to confirm these results, while difficulties in threshold measurement were discussed.

Hahn (1934) noted that NaCl thresholds were determined by NaCl-adapting concentrations; this study, as well as others later summarized by Hahn (1949), also extended the work to other taste stimuli. McBurney and Pfaffmann (1963) showed that NaCl thresholds, measured in situ, were related to the relatively weak salivary Na content in the same way that NaCl thresholds, measured with a flow procedure, were related to the adapting solution concentration; this confirmed an earlier suggestion by Richter and MacLean (1939). Békésy (1965), using a semiautomatic gustometer, later demonstrated how adaptation caused a continuous shift of NaCl threshold.

There being no generally accepted policy on the length of rest interval required between tastings or on the use of mouthrinses, O'Mahony (1972a) investigated the common interstimulus procedures and found they were insufficient to remove NaCl residuals from prior tastings. Furthermore, because of gustatory adaptation, these residuals caused sensitivity drifts (O'Mahony, 1972b). It is expected, then, that a more efficient interstimulus procedure, like mouthrinsing, would maintain a lower general level of adaptation, yielding lower in situ thresholds, than an equivalent procedure that did not involve rinsing.

As with many taste stimuli, the detection of NaCl in water is traditionally described by two thresholds: the recognition threshold, where the salty taste appears, and the detection threshold, where the presence of NaCl is noticed although it is not described as salty. Richter and MacLean (1939) listed early studies, criticizing them for not distinguishing between the two; other early studies (Camerer, 1885; Blakeslee & Salmon, 1935) and some more recent (Schutz & Pilgrim, 1957; Krut, Perrin, & Bronte-Stewart, 1961; Jackson, 1967) can be added to their list. However, there is more than one sensation change below the recognition threshold (O'Mahony, 1973), any one of

which could be taken as the criterion for detection. This means that any comparison of thresholds between Ss is susceptible to criterion variation. Herein lies the advantage of criterion-free signal detection measures of sensitivity (Green & Swets, 1966). Given criterion variation in the definition of detection, and to some extent recognition, any comparison of the effects of interstimulus procedure must be made within Ss, so that there is more chance of constant criteria for different conditions. The present study used such a design to examine the effects of a mouthrinsing interstimulus procedure on detection and recognition thresholds.

EXPERIMENT I

Experiment I was split into a preliminary and a main experiment, which was performed approximately 18 months later.

Preliminary Experiment Procedure

Using two Ss, students at Bristol University, M.Q. (male, 29 years) and B.T. (female, 22 years), the NaCl detection threshold was found by the method of constant stimuli in four conditions: (1) A 10-ml sample of each test solution was tasted immediately following a 15-sec, 10-ml mouthrinse with 1 M NaCl solution. (2) As for Condition 1, except that an approximately 50-ml, 15-sec tapwater mouthrinse was interspersed between the 1M NaCl and the test solution. (3) As for Condition 2, except that a 15-sec period of vigorous sucking ending in expectoration of saliva was interspersed between expectoration of the tapwater mouthrinse and the test solution. (4) As for Condition 2, except that Ss expectorated saliva once immediately after expectorating the tapwater mouthrinse.

Test solution concentrations used were: for Condition 1, 300-950 mM in 50-mM steps, and for Conditions 2, 3, and 4, 70-150 mM in 5-mM steps. The E used trial and error to establish the actual range of concentrations to be presented to each S; having established this, each concentration in the range was presented 10 times. The ranges chosen for Conditions 1, 2, 3, and 4 for each S were: M.Q., 500-850 mM, 100-150 mM, 100-140 mM, 100-140 mM; and B.T., 300-500 mM, 90-130 mM, 70-120 mM, 70-120 mM, respectively.

Test solutions were sipped from 10-ml beakers. Test solutions

and mouthrinses were expectorated. Solutions were made up with Analar grade NaCl in distilled water and presented at room temperature ($\approx 20^\circ\text{C}$).

All four conditions were used simultaneously to eliminate effects of practice, fatigue, and criterion drift. A pilot study showed that an interstimulus procedure of two tapwater mouthrinses followed by a 1-min rest, after each test solution and before each 1M NaCl mouthrinse, was enough to eliminate sensitivity drifts. Rest periods and session lengths (1-4½ h) were determined by S's convenience and motivation; M.Q. took a total of 12 sessions (total experimental time, 19 h) and B.T., 8 sessions (20 h).

Main Experiment Procedure

The procedure was the same as for the preliminary experiment except that Condition 4 was omitted. Five Ss, staff and students at Bristol University, were used: M.Q. (male, 31 years), C.O. (male, 25 years), M.W. (male, 19 years), H.L. and E.W. (females, 20 years).

The test solution concentrations used were: Condition 1, 50-950 mM in 50-mM steps, and Conditions 2 and 3, 35-150 mM in 5-mM steps. The ranges chosen for Conditions 1, 2, and 3 for each S were: M.Q., 450-650 mM, 85-115 mM, 70-125 mM; C.O., 100-400 mM, 40-100 mM, 40-110 mM; M.W., 550-800 mM, 90-150 mM, 95-115 mM; H.L., 200-400 mM, 50-85 mM, 45-65 mM; E.W., 200-600 mM, 100-150 mM, 80-110 mM, respectively.

An interstimulus interval of 2 min, during which two tapwater mouthrinses were taken, was found to be satisfactory. Experimental session lengths (20 min-4½ h) were again determined by S; M.Q. took a total of 5 sessions (total experimental time, 12½ h); C.O., 20 sessions (22 h); M.W., 9 sessions (8½ h); H.L., 3 sessions (7 h), and E. W., 10 sessions (17 h).

Results

Thresholds estimated by eye, using linear-probability plots, are shown in Table 1; error terms were computed from maximum and minimum slopes. Very high thresholds for Condition 1 showed that a molar mouthrinse considerably elevated the threshold. Condition 2 yielded much lower values (no overlap of error terms), showing the potency of rinsing as an interstimulus procedure.

Thresholds were lower in Condition 3 than in Condition 2 (except for C.O.); for E.W., B.T., and M.Q. (preliminary experiment), there was no overlap of error terms. In Condition 4, thresholds were not higher than in Condition 2. This is all strong evidence that further expectoration after a mouthrinse did not result in a higher threshold, showing that the low threshold in Condition 2 was not due to a tapwater residual resting on the tongue.

M.Q. was used for the preliminary and main experiment; in the main experiment, his thresholds were lower, probably due to different criteria, but the trend between conditions was the same.

Ss reported that criterion changes were the main source of variance. Ss reported that only in Condition 1 was there ever a salt taste in the mouth when Ss sipped the test solution; this means that threshold elevation was partially due to masking as well as raising the level of adaptation. The salt taste left in the mouth after adapting to the molar NaCl

Table 1
NaCl Detection Thresholds (in Millimolars) Measured After a Molar NaCl Mouthrinse in Four Conditions

S	Conditions			
	1	2	3	4
Preliminary Experiment				
M. Q.	720 (± 30)	120 (± 7)	108 (± 2)	120 (± 7)
B. T.	380 (± 20)	117 (± 3)	92 (± 3)	92 (± 3)
Main Experiment				
E. W.	420 (± 40)	129 (± 9)	95 (± 1)	
M. Q.	530 (± 30)	96 (± 4)	87 (± 7)	
H. L.	300 (± 5)	65 (± 9)	59 (± 3)	
M. W.	580 (± 90)	119 (± 16)	107 (± 3)	
C. O.	190 (± 40)	67 (± 4)	72 (± 2)	

solution indicates that adaptation was not complete during the 15-sec period. This also tends to be supported by the fact that thresholds in Condition 1 were well below 1 M. Complete adaptation has been reported for lower NaCl concentrations: 100 mM within 40 sec (Bartoshuk, 1968), 150 mM in 50-54 sec (Bujas, 1953), 200 mM in 79-90 sec (Borg, Diamant, & Zotterman, 1970), and 360 mM in 3 min (Meiselman, 1968), though for only one of four Ss. If attempted complete adaptation had been the aim of this experiment, however, a flow procedure with a far longer adaptation time would have been used.

EXPERIMENT II

Procedure

In this experiment, NaCl detection and recognition thresholds were measured for 20 naive Ss, male and female students at Bristol University, aged 19-30 years, without any prior artificial raising of the adaptation level. The commonly used ascending series method was used in this case; in such a procedure, NaCl solutions of increasing concentration are presented to S until he can identify the salt, descending series not being used to avoid masking.

Ten milliliters of test solution were sipped from 10-ml beakers at 15-sec intervals, held in the mouth approximately 3 sec and expectorated. Ss were tested under two conditions; in one condition, an approximately 50-ml tapwater mouthrinse was taken after expectoration of the test solution and was itself expectorated immediately prior to sipping the next test solution. In the second condition, no mouthrinse was used. The two conditions were tested with 1 to 3 tapwater mouthrinses and approximately ½ h rest between, and the order of conditions was counterbalanced. The ascending series test solutions were distilled water, 1, 5, 10, 15, 20, 40, 60, and 80 mM NaCl; each series was presented three times in each condition. All solutions were of the same purity and temperature as in Experiment I. All solutions and mouthrinses were expectorated.

Results

Mean and median detection and recognition thresholds for the 20 Ss are given in Table 2. Despite considerable individual differences, the mouthrinsing interstimulus procedure yielded significantly lower mean detection and recognition thresholds ($p < .01$, Wilcoxon, one-tailed), demonstrating how mouthrinses maintain a lower level of adaptation. The order

Table 2
Ascending Series NaCl Detection and Recognition Thresholds
Measured With and Without Tap Water Mouthrinsing (N = 20)

Interstimulus Procedure		Threshold (mM)	
		Detection	Recognition
15-Sec Rest	Mean	15.4	26.8
	Median	13.3	24.1
	Range	2.3-36.6	8.3-66.6
15-Sec Tap Water Mouthrinse	Mean	8.6	17.9
	Median	7.6	13.3
	Range	1.0-23.3	3.6-60.0

of "mouthrinse" vs "no-mouthrinse" conditions was counterbalanced, though Ss who had the latter condition first, reported some confusion due to its greater difficulty. All but one of the 4 Ss whose thresholds were not in the direction predicted, had the "mouthrinse" condition first; 2 Ss recorded ties. Atypical results were probably due to lack of skill in maintaining a constant criterion.

DISCUSSION

The present study demonstrated directly how mouthrinsing, by maintaining a lower level of adaptation, yielded lower detection and recognition thresholds. This occurred both with and without an artificial raising of the level of adaptation by a molar NaCl rinse, although the effect was more pronounced in the former case.

These results were also predicted by McBurney and Pfaffman (1963) and Dallenbach and Dallenbach (1943), who themselves found lower thresholds (probably detection) with mouthrinses. Richter and MacLean (1939) found higher thresholds for ascending series presentation than for their Choice Methods 1 and 2, which involved frequent tasting of distilled water, having the same effect as mouthrinsing. Unfortunately, only these three studies yield a direct comparison for the same authors, while

only McBurney and Pfaffmann's may have used a within-Ss comparison. However, they all confirm the current findings.

Further comparison with the literature yielded a general confirmation, despite the many methodological variables. Ascending series thresholds tended to be lower when mouthrinsing was used, as did they also when comparison procedures, involving frequent tasting of water, were used. Many studies were precise in defining whether they studied detection or recognition, and their results are given in Tables 3, 4, and 5. Others, which were not so precise in their definitions but were still open to reasonable interpretation, will be discussed along with tabulated studies; only Mayer's (1927) and Irvin and Goetzl's (1952) studies gave insufficient methodological details for comparison. For the purpose of this discussion, all concentration values will be expressed as mM, conversions being performed when necessary.

Turning first to ascending series presentation, detection thresholds are given in Table 3. Despite considerable variation, mean values were lower with mouthrinsing than without. Smaller stimulus samples gave higher thresholds, and this is probably due, certainly with Richter and MacLean's results, to the known relationship between threshold and tongue area stimulated (McBurney, 1969). As already mentioned, Dallenbach and Dallenbach's mouthrinsing values (5.1, 6.8 mM) were lower than their no-mouthrinsing values (38.8, 39.6, 47.4 mM), as were McBurney and Pfaffmann's (2.2 mM vs 8.6 mM). Further no-mouthrinsing values found by the latter authors yielded values ranging 3.4-22 mM. Kahn (1951), using no mouthrinses, found very high detection thresholds (21.4-42.8 mM), but these values can be discounted because only three test solutions were used. Meyer (1952), using the method of limits and distilled water mouthrinses between tastings, obtained a high detection threshold (10-19 mM), probably because of the small stimulus quantities

Table 3
Detection Thresholds for NaCl Found With an Ascending Series Presentation for Rinsing and Nonrinsing Interstimulus Procedures

Authors	Ss	Stimulus Quantity	Detection Thresholds (mM)	
			Mouthrinsing	No Mouthrinsing
Richter & MacLean, 1939	17	3 Drops		Mean 23.1
				Range 7.7-38.4
				Values 22.8, 27.3, 29.5
Mefferd & Wieland, 1968	3	5 ml		Mean 11
Fabian & Blum, 1943	15	5 ml		Mean 8.0
Richter & MacLean, 1939	24	10 ml		Range 2.6-25.6
			Mean 8.6	Mean 15.4
			Range 1.0-23.3	Range 2.3-36.6
O'Mahony & Godman	20	10 ml	Median 7.6	Median 13.3
			Tap Water Rinse	
			Mean 7.4*	
Finkelstein & Pippitt, 1958	10	5-10 ml	Distilled Water Rinse	

*No units, probably millimolars

Table 4
Recognition Thresholds for NaCl Found With an Ascending Series Presentation for Rinsing and Nonrinsing Interstimulus Procedures

Authors	Ss	Stimulus Quantity	Recognition Thresholds (mM)	
			Mouthrinsing	No Mouthrinsing
Richter & MacLean, 1939	17	3 Drops		Mean 32.8 Range 20.5-59.9
Fabian & Blum, 1943	15	5 ml		Mean 39
Mefferd & Wieland, 1968	3	5 ml		Values 25.4, 37.6, 39.0
Richter & MacLean, 1939	24	10 ml		Mean 28.6 Range 6.8-68.4
O'Mahony & Godman	20	10 ml	Mean 17.9 Range 3.6-60.0 Median 13.3 Tap Water Rinse	Mean 26.8 Range 8.3-66.6 Median 24.1
Mackey & Jones, 1954	22			Mean 19.9 Range 3.3-75 Median 13.3
Mosel & Kantrowitz, 1952	4	15 ml		Mean 7.5
Finkelstein & Pippitt, 1958	10	5-10 ml	Mean 10.0* Distilled Water Rinse	
Yensen, 1958, 1959a, b, c, 1964	2-4	8-10 ml	Range 1.5-4.3	
Maga & Lorenz, 1972	6	20 ml	Mean 0.8 Distilled Water Rinse	

*No units, probably millimolars

used (1 drop) and perhaps because of masking effects in the descending series or interference with mouthrinsing effects by his practice of drying the tongue with blotting paper.

Ascending series recognition thresholds are given in Table 4, and again mouthrinsing tended to give lower values, as did larger stimulus quantities. Yensen's values—2.2-3.4 mM (Yensen, 1958, 1959b), 1.9-3.8 mM (Yensen, 1959a), 1.5-4.3 mM (Yensen, 1959c), and 1.7-3.4 mM (Yensen, 1964)—were grouped together in the table and are seen to be very low, comparable even to detection thresholds. This may have been due to the many readings taken with practiced Ss, his use of small stimulus increments,

and the stringent mouthrinsing procedure employed. Mosel and Kantrowitz (1952) and Maga and Lorenz (1972) also gave comparably low values. For the latter, this may be because Ss indulged in excessive rinsing or used a detection criterion, while for the former, large stimulus quantities, few Ss, and repeated determinations may be causal factors. The study of Mackey and Jones (1954) did not mention the use of rinses, and it is assumed that they did not use them.

All recognition studies, not tabulated, used mouthrinses. King (1937), Knowles and Johnson (1941), and Hopkins (1946) found high values (respective medians, 25.6, 19.9, 19.2 mM), compar-

Table 5
Detection and Recognition Thresholds for NaCl Found With Procedures Based on Richter & MacLean's Choice Method No. 2

Authors	Ss	Threshold Values (mM)		Methodological Deviations from Choice Method No. 2 and Other Notes
		Detection	Recognition	
Richter & MacLean, 1939	53	Mean 2.7 Range 1.2-10.3	Mean 14.9 Range 3.4-42.8	
Janowitz & Grossman, 1949	9		Means 11.1, 11.6, 10.9	Means taken 10:30 a.m., 12 noon, and 2:00 p.m.
Cooper, Bilash, & Zubek, 1959	100	Means 5.5, 6.2, 8.0, 21.0, 17.2	Means 21.1, 15.6, 18.8, 46.2, 53.0	Samples aged 15-29, 30-44, 45-59, 60-74, 75-89
Kapur, Collister, & Fischer, 1967	12	Means 22.4, 22.0, 23.6	Means 44.3, 44.5, 41.7	Three samples of denture wearers
Pangborn, 1959	8	Means 21, 8, 5		Three mean control values, decreasing with practice
Furchtgott & Willingham, 1956	18	Mean 7.0		Control value
Fallis, Lasagna, & Tetreault, 1962	20		Mean 9.7	Compare NaCl solution with three distilled water samples
Topinka & Sova, 1967	21		Mean 6.5	Compare NaCl solution with three distilled water samples
DeWardener & Herxheimer, 1957	2		Ranges 1.7-13.7 and 1.3-5.1	Control values

able to tabulated no-mouthrinsing values for the same stimulus quantity, 5 ml. The instructions in the latter two studies could account for this, because Ss were required to report only when they were positive of the taste and this could have raised S's criteria. Brown's (1914) value (102.7 mM) was probably artificially high due to the small stimulus quantities used (1 ml), while Ufland's (1928) and Hermel, Schonwetter, and Samueloff's (1970) high mean values (42.8 and 78.7 mM) were open to question because only three test stimuli were used; the value in the latter paper may not be reliable owing to confusion over concentration values.

The U.S. Department of Agriculture (1943) found large individual differences for recognition thresholds, using mouthrinsing for strong solutions, which fell into three ranges: 2.5-5.0, 7.5-20, and 25-100 mM. Most Ss fell in the medium range, comparable to values in Table 4, but 25% were in the high and lower ranges. Such variation emphasizes the importance of the within-Ss design, in the present study, for examining the effects of mouthrinsing.

Finally, pair comparison methods can be considered. Table 5 shows threshold values found using Richter and MacLean's Choice Method 2, which involves ad lib pair comparisons with distilled water. Thresholds were often comparable to ascending series mouthrinsing values. An exception is the study of Kapur, Collister, and Fischer (1967), which yielded very high thresholds. The most likely explanation is that their Ss, being denture wearers, were elderly, and from Cooper, Bilash, and Zubek's (1959) results, it can be seen that thresholds rise with age.

Fallis, Lasagna, and Tetreault (1962) and Topinka and Sova (1967) used three distilled water samples instead of one and also incorporated mouthrinses; their thresholds can be seen to be predictably lower than other tabulated values. Comparable values (7.4-8.9 mM) were obtained by Furchtgott and Friedman (1960) using the same modified method; this suggests that they were measuring recognition, although this was not made clear. Anderson (1955) also obtained a comparably low recognition threshold (9.2 mM), having modified the procedure by incorporating mouthrinses between tastings.

Although some of De Wardener and Herxheimer's (1957) recognition values were comparably high, they tended to be lower than other values in Table 5. This could be due to an element of detection in the threshold measurement and also to the effects of practice; Pangborn's (1959) results showed how comparable practice could reduce thresholds.

Further comparison methods occur in the literature. Richter and MacLean's Choice Method 1, utilizing only one tasting of each sample, yielded predictably higher threshold values [detection 6.3

(1.2-13.7), recognition 13.6 (5.1-51.3) mM] than their Choice Method 2. The method is briefer and involves the tasting of fewer water samples; nevertheless, these values are comparable to ascending series mouthrinse values.

Also comparable are other pair comparison detection measures: Kelty and Mayer (1971), 11.1 mM, Frings (1948), 5.2 mM, and Renqvist (1919), 10 mM. Schelling, Tetreault, Lasagna, and Davis's (1965) mean recognition threshold of 5.2 mM was comparable to detection values; they reported, however, that in most cases the two coincided. Kelty and Mayer's recognition threshold (27.4 mM), however, was higher than corresponding values in Table 4.

A widely used comparison method for measuring detection thresholds is the Harris-Kalmus test (Kalmus, 1971; Harris & Kalmus, 1949), developed for the study of P.T.C. It involves sorting four equimolar NaCl solutions and four distilled water samples into two groups. Using this method, Wotman, Mandel, Thompson, and Laragh (1967) obtained a median threshold value of 13.7 mM, while modifications of the procedure incorporating mouthrinses gave comparable thresholds: 13.7 and 12 mM (Wotman et al, 1964; Fischer, Griffin, & Kaplan, 1963). The small effects of rinsing are not surprising as a lot of water tasting is involved in the procedure anyway.

The triangular testing methods (to distinguish one NaCl solution from two distilled water solutions) of Henkin and Solomon (1962) and Henkin, Gill, and Bartter (1963) yielded median detection thresholds of 12 mM. These were slightly higher than comparable ascending series values using mouthrinses, probably because of the small stimulus quantities used (1 drop). Triangular testing with larger stimulus quantities (10 ml) yielded lower mean thresholds: 10.6 and 3.4 mM (Hutchinson & Shiller, 1968).

Harries (1973), with an ascending series presentation, provided distilled water for comparison. His mean detection threshold (12.2 mM) is comparable to pair comparison and ascending series values without mouthrinsing while being predictably higher than those with mouthrinsing. Williams (1970) and Pangborn, Chrisp, and Bertolero (1970) both incorporated pair comparison in the method of constant stimuli. The latter provided water for rinsing but unexpectedly found higher detection thresholds (2-6 mM vs 1.5-3.7 mM). However, they used a 75% correct level for the threshold, while Williams used a 50% level.

McFadden, Barr, and Young (1971) used signal detection measures of sensitivity and found a 75% correct response at very low concentrations, 0.8 and 0.65 mM. Their procedure involved vigorous mouthrinsing, with distilled water rinses being

expectorated immediately before tasting NaCl samples. The detection of such low NaCl concentrations is not surprising, considering that small changes in water purity can be detected given appropriate adaptation procedures (O'Mahony, 1972d).

Thus NaCl threshold studies in the literature tend to indicate that procedures involving a higher intake of water, whether by interstimulus rinsing or pair comparison, yield lower thresholds. This confirms the results of the present study. It is likely, then, that for in situ determinations, interstimulus procedures, especially rinsing vs no rinsing, are major determinants of the measured NaCl thresholds. In situ measures probably do little more than monitor the state of the saliva; constant-flow procedures, preferably using signal detection measures (O'Mahony, 1972c), would seem a desirable alternative. It is likely that these mouthrinsing effects reported for NaCl will be general for all stimuli that persist in the mouth.

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(Received for publication May 21, 1974;
revision accepted July 4, 1974.)