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TASTE THRESHOLDS IN A SUBMARINE ENVIRONMENT

by

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MR005.19-6024.04

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SUBMARINE MEDICAL RESEARCH LABORATORY
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SUMMARY PAGE

THE PROBLEM

To determine if objective changes in the taste sense occur during long term exposure in the self-contained FBM submarine atmosphere.

FINDINGS

(1) A simple and rapid method for determining taste thresholds of personnel aboard an operating FBM submarine is presented.

(2) There is no significant change in the sweet or salt modality, and a slight but significant increased sensitivity to the sour modality.

APPLICATIONS

These findings indicate that no really great changes in sweet, salt and sour taste thresholds occur on an FBM patrol. No particular application is indicated in the dietary aspects of submarine life. The techniques and basic data of this study should be applied to a more detailed study of dietary practice and taste threshold relationships.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MR005.19-6024—Effect of Stresses of Submarine Service on Oral Health. This report has been designated as Submarine Medical Research Laboratory Report No. 530. It is Report No. 4 on this Work Unit, and was approved for publication as of 28 May 1968.

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ABSTRACT

Personnel aboard an operating FBM submarine live in a sealed self-contained atmosphere for approximately 60 days. During this period carbon dioxide and various other atmospheric contaminants are considerably higher than are normally encountered.

It has been shown in past studies that the body's internal environment determines and modifies taste discrimination to a considerable degree.

This study was undertaken to develop a practical method for the determination of taste changes of personnel aboard an operating FBM submarine and to determine if taste thresholds do change in the submarine environment. Such changes would be of great interest in studies of diet and nutrition from a dental and general medical view.

Taste thresholds of sour (citric acid), salt (sodium chloride), and sweet (sucrose) were determined aboard an operating FBM submarine for two patrols. Determinations were done before submergence, at regular intervals during the submerged period, and upon surfacing.

No significant change in the taste thresholds of sweet or salt were observed during this period. There was a slight but significant increased sensitivity to sour which was observed by the end of patrol and after surfacing.

TASTE THRESHOLDS IN A SUBMARINE ENVIRONMENT

INTRODUCTION

Man's senses include the "higher senses" of vision and hearing and the "lower senses" of smell, taste, and the so-called chemical senses. Of the lower senses, in the order of thresholds, olfaction is the most sensitive, taste is intermediate, and common chemical sensitivity is the least sensitive.²

There are four basic taste modalities; sweet, salt, sour, and bitter.^{2,3} Tastes in everyday life, that is apart from laboratory experiments, are generally a mixture of gustatory, tactile, thermal, kinesthetic and olfactory sensations.²

Taste discrimination is an important factor in the selection of food, both in the quantitative and qualitative sense. The internal environment determines and modifies taste discrimination to a great degree. Increased sensitivities in the four taste modalities have been reported for patients suffering from cystic fibrosis.¹² In some women, taste sensitivity for 6-n-propylthiouracil (PROP) and quinine fluctuate with the phases of the menstrual cycle.⁹ Duodenal ulcer is associated with an increased sensitivity to PROP.¹³ A systemic salt depletion state lowers the taste threshold for sodium chloride.²⁰ The sour taste associated with an acid solution is influenced by the buffering capacity of the saliva present in the mouth.¹⁸

There are a variety of means to measure objectively the response to a known gustatory stimulus. For example, various electrophysiological methods have been devised to measure quantitatively the neural response at the receptor site or at the various nerve pathways when a taste stimulus is introduced.^{14, 15, 16} Parotid secretion flow rates in relation to various taste stimuli provide another method for objectively determining a taste response.^{7, 17} The maximum dilution of taste producing substance that a subject can consistently differentiate from distilled water provides a "taste threshold" which is relatively constant for an individual.^{3, 10, 11} Once this taste threshold is established, an investigator can then observe changes in the

threshold under the influence of various factors in the external and internal environment. This latter method is relatively simple in technique, rapid, accurate, and requires minimum apparatus. For these reasons, it was felt that this method was best suited for detecting taste changes of personnel aboard an operating FBM submarine.

The FBM submarine is manned during each 90 day period by alternate crews (Blue and Gold). It initially spends approximately 30 days of this time on the surface during an upkeep period. During this time it is constantly ventilated with large quantities of outside air. After the upkeep period, the submarine goes to sea, submerges, and remains sealed for approximately 60 days. The self-contained atmosphere is kept habitable by various systems for oxygen introduction and contaminant removal. During this period the concentrations of carbon dioxide, carbon monoxide, and other organic compounds are considerably higher than what is normally encountered in the outside atmosphere. For example, the CO₂ usually runs between 1.0-1.5%, the CO approximately 25 ppm, and the freon 50-75 ppm.^{1, 5, 19}

Upon surfacing, large quantities of fresh air are again supplied by the ship's ventilation system. Within a week after surfacing, the original crew is replaced by a relief crew and the original crew is then away from the submarine for approximately 90 days.

Thus, the submerged FBM submariner lives for long periods in a self-contained atmosphere which contains a higher concentration of carbon dioxide and various organic compounds than encountered under normal atmospheric conditions.

Past studies have shown that adequate physiological adaptation occurs to long exposure to 1-1.5% CO₂.⁴ While it is known that man can live and function in such environments, many of the mechanisms of adaptation and some of the less apparent effects of this CO₂ level are unknown. Takaoka¹⁸ found an increase in salivary pCO₂ when inspired air was high in CO₂. A recent pilot study also indicated this to be true.¹⁶

This study was undertaken to see if taste thresholds do change in the FBM submarine environment. If changes occur, they would be of great interest in the studies of diet and nutrition from a dental and general medical view.

A preliminary study was done by the author during a patrol of the U.S.S. JOHN MARSHALL (SSB(N)611). The study utilized nine subjects who had taste threshold determinations in sour, sweet, and salt during the upkeep, the first week of submergence and the last week of submergence. This study showed no change in salt or sweet but a slight but significant increased sensitivity to sour. This data is presented in greater detail with the results of a later study.

These data was not regarded as entirely satisfactory for a variety of reasons. The molar strength gradations of the various test solutions were felt to be too great to detect a small but significant change in taste thresholds that might be present. The method of taste threshold determination by Yensen²⁰ had been employed. With this method the subject must differentiate between a cup containing distilled water and a cup containing test solution. However, it was felt that this method allowed the subject too much opportunity to provide a correct answer when guessing. Finally, it was found that the subject's work requirements while aboard the submarine made threshold determinations at a set time during the day impossible. The possibility of significant taste threshold changes in relation to eating or diurnal factors had to be evaluated.

To determine these factors an off-submarine study was conducted. This study had three objectives. First, was to obtain a large number of random taste threshold determinations on subjects in a normal daily routine and detect any significant variations, if present. Second, was to establish the minimal changes in a given solute concentration that could be detected consistently by a subject. The third objective was to develop a method of threshold determination that minimized the possibility of successful guessing on the part of the subject.

Taste threshold determinations were done

with salt (sodium chloride), sweet (sucrose), and sour (citric acid) on four subjects for five consecutive days. The determinations were done four times a day with the subjects engaged in their normal daily routines. There was no set pattern as to the dietary habits of the subjects, time of day, or fixed relationship to meals except at least a half hour delay after eating before running a determination.

In these studies no significant variation of the subject's taste threshold could be noted at any particular time of day or in relation to eating. The minimum gradation of solute concentration which could be consistently detected by the subject in the threshold range was 2×10^{-5} molar for citric acid, 2×10^{-3} molar for sucrose, and 2×10^{-3} molar for sodium chloride. This data is presented in greater detail in the material-methods section of this paper.

Finally, the methods of taste threshold testing by Yensen were discarded in favor of a modified form of the method devised by Henkin.^{11,12} It was felt that this method when learned by the subject was simple, fast, and minimized the probability of correct guessing. This method is discussed in greater detail in a later section of the paper.

The information gained in this laboratory phase of the study was utilized in a second series of taste threshold determinations done during a later patrol of the U.S.S. JOHN MARSHALL (SSB(N)611). Due to operational requirements, the period of continuous submergence was 30 rather than 60 days during the patrol.

MATERIALS AND METHODS

Nine volunteer subjects were selected from the crew of the U.S.S. JOHN MARSHALL (Gold). Each subject was thoroughly indoctrinated in the procedure outlined in this section.

Each subject had a taste threshold determination done in sour, sweet, and salt at the following intervals: Three separate daily determinations while on the surface during the upkeep; two after 3 weeks submergence; two after 4 weeks submergence; and two within 72 hours after surfacing. The work demands placed on the subjects made it

impossible to have any definite regularity as to testing at a particular time of day or in any set relation to meals except that tests were done a least one hour after eating.

The sour solution was prepared from citric acid monohydrate (molecular weight 210.4). Test solutions of known molarity ranging from 4.5×10^{-4} down to $.5 \times 10^{-4}$ mole were prepared by the proper dilution of a 0.1 M working stock. The test solutions were prepared from the dry reagent 24-48 hours before a test run and stored in closed glass bottles. The test solutions were prepared in gradations of $.5 \times 10^{-4}$ mole in the 4.5×10^{-4} to the 2.0×10^{-4} molar range and in gradations of $.2 \times 10^{-4}$ mole in the 2.0×10^{-4} to $.5 \times 10^{-4}$ molar range.

The sweet solution was prepared in a similar fashion using sucrose (molecular weight 342.2) from a 1.0 M working stock. The molarity range was 2.0×10^{-2} down to $.2 \times 10^{-2}$ mole. The gradations were $.4 \times 10^{-2}$ mole in the 2.0×10^{-2} to 1.0×10^{-2} molar range and $.2 \times 10^{-2}$ mole in the 1.0×10^{-2} to $.1 \times 10^{-2}$ molar range.

The salt solution was prepared from sodium chloride (molecular weight 58.5) in a 1 and 0.1 mole working stock solution. Test solutions of 0.020 and 0.010 mole and 8.0×10^{-3} down to 1.0×10^{-3} mole in 2.0×10^{-3} molar gradations were prepared.

For each threshold determination the subject was seated comfortably in a chair. He rinsed his mouth with distilled water several times and finally closed his mouth, pressed his tongue against the palate, and swallowed. He was then presented with three cups each containing 10 milliliters of solution. Two of these cups contained distilled water and one contained the test solution. The cup containing the test solution could be identified by the recorder but not by the subject.

At the onset of the test the subject sampled a small quantity of distilled water and then proceeded to sample each of the three cups. The solution was held in the mouth for approximately three to four seconds and swallowed. He reported to the recorder which of the three cups contained the test solution. This process was continued in

progressive increasing dilutions of test solution until the subject either by default or error could no longer discriminate the test solution from the other two cups of distilled water. The rate at which a new sample was presented to the subject was one every 45 seconds.

The greatest dilution of test substance the subject could consistently discriminate from distilled water during three consecutive attempts was defined as the threshold for that run.

Once the subject is familiar with the technique and his threshold range is known, the entire test can be done in approximately fifteen to twenty minutes.

RESULTS

The data were analyzed by applying the t test to the mean differences between the prepatrol thresholds and subsequent test thresholds for each subject (the expected mean difference equals zero).

In the first patrol experiment (Table I) this mean difference was significantly greater than zero only in the sour thresholds between the prepatrol and the fifty-six day tests (the mean difference being $-.6 \times 10^{-4}$). This difference is of borderline significance ($P < .05$). A mean difference of $-.3 \times 10^{-4}$ was noted between the prepatrol tests and the tests after one and one-half week submerged time. This difference was not significant.

No differences were noted between the thresholds to sucrose in the three test periods.

A progressive decrease in the salt threshold was noted. None of the mean differences were significant, however.

Table I
First Patrol Taste Thresholds
Sour Sweet Salt

	Sour	Sweet	Salt
Prepatrol	2.0×10^{-4} *	.0111*	.0106
10 days submerged	1.7×10^{-4}	.0097	.0084
56 days submerged	1.4×10^{-4} **	.0109	.0069
Range	$1.0 - 2.5 \times 10^{-4}$.0025 - .017	.003 - .02

*Molar concentration of mean threshold.

**Mean differences from prepatrol thresholds significantly greater than zero ($P < .05$).

The second patrol data reveals essentially the same results as those from the first patrol (Table II). Again, the thresholds to sweet and salt modalities differed only slightly, and randomly, from the prepatrol values. The mean taste thresholds to citric acid differed significantly ($P < .05$) in the tests run twenty-one and twenty-eight days after submergence when compared with the prepatrol values. The mean sour taste threshold remained depressed in the test run within 72 hours after surfacing. The mean difference in this case, however, was not significantly lower than the prepatrol value. There was a greater variability in these post patrol values than in the other test values.

Table II
Second Patrol Taste Thresholds

	Sour	Sweet	Salt
Prepatrol	$1.8 \times 10^{-4*}$.0063	.0034
21 days submerged	$1.3 \times 10^{-4**}$.0072	.0038
28 days submerged	$1.1 \times 10^{-4**}$.0059	.0032
Postpatrol (first 72 hrs.)	1.1×10^{-4}	.0062	.0036
Range	.45 - 3.9×10^{-4}	.001 - .0135	.001 - .0095

*Molar concentration of mean threshold.

**Mean differences from prepatrol thresholds significantly greater than zero ($P < .05$).

DISCUSSION

Testing for taste changes in the bitter modality was not done for several reasons. Since the study utilized personnel on an operational submarine consideration had to be made for the subject's limited time and motivation. The unpleasant sensation and additional testing time made this modality difficult to incorporate into a series using the number of volunteers required to produce statistically significant results. However, further studies with this modality may provide significant data.

One major contribution to the sensation of sour taste is the free hydrogen ion in acid solutions.^{1,2,4} The fact that sour taste sensitivity showed a slight but significant change during patrol, would lead one to believe that the carbon dioxide content of the atmosphere may play some role in these observations.

The mechanism of the changes can, at this time, only be discussed by means of conjecture and hypothesis. A previous submarine pilot study and a recent chamber study have shown that a slight elevation of total salivary CO_2 occurs in individuals exposed to elevated ambient CO_2 in the 1.0-1.5% range.⁸ One might assume that the salivary CO_2 by its increased concentration has "used up" a great proportion of the available base, thus making the subject more sensitive to any addition of hydrogen ions.

This study was not designed to explain the mechanisms of the change, but merely to ascertain if any changes did occur. Certainly, it would be desirable to repeat these studies along with blood and salivary chemical analysis.

SUMMARY AND CONCLUSIONS

1. Taste threshold tests on nine subjects during two FBM submarine patrols revealed a decreased taste threshold in the sour modality. No change was observed in the sweet and salt modalities.

2. Dietary preference studies should be accomplished in conjunction with taste threshold surveys.

3. A possible practical application of taste threshold tests is in the area of personal psychophysiological monitoring.

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<p>Personnel aboard an operating FBM submarine live in a sealed self-contained atmosphere for approximately 60 days. During this period carbon dioxide and various other atmospheric contaminants are considerably higher than are normally encountered.</p> <p>It has been shown in past studies that the body's internal environment determines and modifies taste discrimination to a considerable degree.</p> <p>This study was undertaken to develop a practical method for the determination of taste changes of personnel aboard an operating FBM submarine and to determine if taste thresholds do change in the submarine environment. Such changes would be of great interest in studies of diet and nutrition from a dental and general medical view.</p> <p>Taste thresholds of sour (citric acid), salt (sodium chloride), and sweet (sucrose) were determined aboard an operating FBM submarine for two patrols. Determinations were done before submergence, at regular intervals during the submerged period, and upon surfacing.</p> <p>No significant change in the taste thresholds of sweet or salt were observed during this period. There was a slight but significant increased sensitivity to sour which was observed by the end of patrol and after surfacing.</p>			

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