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Repeatability of the Measurement of Electrical Taste Detection Thresholds in Healthy Young Females

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Purpose: The aim of this study was to assess the repeatability of the electrical measurement of taste detection on different dates and in different sessions in healthy young females.

Methods: The sites of electrical stimulation were the tip of the tongue, the posterolateral border of the tongue and the soft palate on the right side unilaterally. The measurements were repeated over three consecutive days, three sessions per day and three times for each session in seventeen healthy females. The repeatability of the measurement was assessed by the intraclass correlation coefficient (ICC).

Results: In the dB unit, the ICC of the tip of the tongue and the soft palate was good (61.03 and 66.03, respectively); however, the lateral border of the tongue was a little lower (58.07). In the μA unit, all three test sites had poor ICC. Variability was more significantly associated with the subject factor than with other factors such as trials, sessions and days in dB and μA units.

Conclusions: Electrogustometry, which measures electrical taste detection thresholds in the dB unit, is repeatable and acceptable for clinical use in assessing taste function in healthy young females.

Keywords: Electrical stimulation; Electrogustometry; Repeatability; Taste; Taste perception

INTRODUCTION

The human sense of taste, a complex physiological process, plays a fundamental role in food preferences, nutritional intake and general well-being. Central to this sensory experience is the ability to detect and discriminate various tastes, facilitated by the taste buds in the oral cavity. The electrical method of taste detection, using an electrogustometer, has been used to evaluate taste function. Having come to prominence in the 1950s [1,2], electrogustometry (EGM) is now firmly established as a clinical tool for assessing taste detection thresholds [3,4]. EGM allows the investigation of taste function by applying a weak electric current to a specific area with taste buds in the oral cavity. Its clinical usefulness is highlighted by advantages such as the ability to quantitatively control the intensity of electrical current stimulation. In addition, it proves to be more convenient and easier to use than chemical taste tests, with a shorter overall test time than chemical taste testing [5].

Several studies have reported favorable test-retest reliability in estimating the EMG threshold. Estimates obtained at intervals of three or four show strong correlations in the same conditions, before and after surgery or between different treatments [3,4,6]. However, Føons [7] identified significant variability in threshold measurements in studies involving normal, healthy adults. Furthermore, Stillman et al. [4] and Lobb et al. [8] reported variability in repeatedly measured threshold values, suggesting that measurements obtained from individuals should be interpreted with caution.

Repeatability, as a metric, measures the likelihood that the same observer can replicate results by repeating measurements using the same procedure. Limited information is available on reproducibility under various repeated conditions, such as sessions, dates and trials. Consequently, this study aims to investigate the repeatability of electrical taste detection tests by taking measurements on different dates and during different sessions in healthy young adults. As previous studies using EGM have employed two units of measurement, dB and μA, a secondary objective was to investigate the repeatability of measurements expressed in these units.

MATERIALS AND METHODS

1. Participants

The study participants were recruited between January and May 2023 and visited the Chonnam National University Dental Hospital for measurements. The subjects of this study were healthy adult females aged between 19 and 29. Individuals with the following diseases or conditions were excluded: olfactory disorders, chronic sinusitis, chronic otitis media, diabetes, thyroid disease, cerebral infarction, Alzheimer's disease, mental illness, pacemaker, history of gastrectomy, use of medications such as weight loss drugs, pregnancy, taking birth control pills and smoking. Additionally, those with confirmed tongue dysplasia, oral mucosal disease, dry mouth, burning mouth syndrome and individuals wearing dentures or oral appliances were excluded.

General health and oral health were assessed by medical history and clinical examination, and suitable individuals were selected for this study. Seventeen healthy females (mean±standard deviation: 20.5±0.5 years) were finally enrolled after a screening assessment. Each participant was informed about the study procedure and the associated risks, and written informed consent was obtained before participation. Ethical approval was obtained from the Institutional Review Board of Chonnam National University Dental Hospital (Gwangju, Korea) (CNUDH-2023-001). This board ensured that participants in this study had been appropriately informed about the research procedure, potential risks, benefits, and their rights before agreeing to participate.

2. Experimental Protocol

The EGM test procedures were conducted in a quiet room with a dental chair, controlled lighting and regulated temperature. The participants received meticulous instructions on the experimental protocol. The subjects assumed a sitting position with their upper body resting on the back of an upright dental chair and their heads not resting on the headrest.

An electrogustometer (EG-IIB; Nagashima Medical Instrument Co.) was used to measure electrical taste detection thresholds. The electrogustometer's current stimulation range is from −6 dB to 34 dB (4-400 μA) in 2 dB increments. Electrical stimulation was administered via a stainless-steel probe with a 5 mm diameter tip (contact area: 19.6 mm^2). The stimulation time for electric currents ranged from 0.5 seconds to 2.0 seconds, with a standardized application of 1.0 seconds for all stimulation conditions [9]. The positive electrode, in the shape of a plate, was placed in contact with the skin of the subject's arm. The perception of electrical stimulation was considered when the subject recognized a sour or metallic taste. Using a non-forced-choice staircase threshold protocol, the stimuli started at the lowest intensity (−6 dB) and progressively increased until the subject recognized the stimulation. The electrical threshold of the taste was measured in dB units and then converted into μA units (Fig. 1).

The sites of electrical stimulation were the tip of the tongue, the posterolateral border of the tongue and the soft palate on the right side unilaterally. The location of the tip of the tongue was defined as the anterior border at a distance of 1 cm from the apex of the tongue. The posterior lateral border of the tongue was defined as the lateral border of the tongue orthogonal to 4 cm from the apex of the

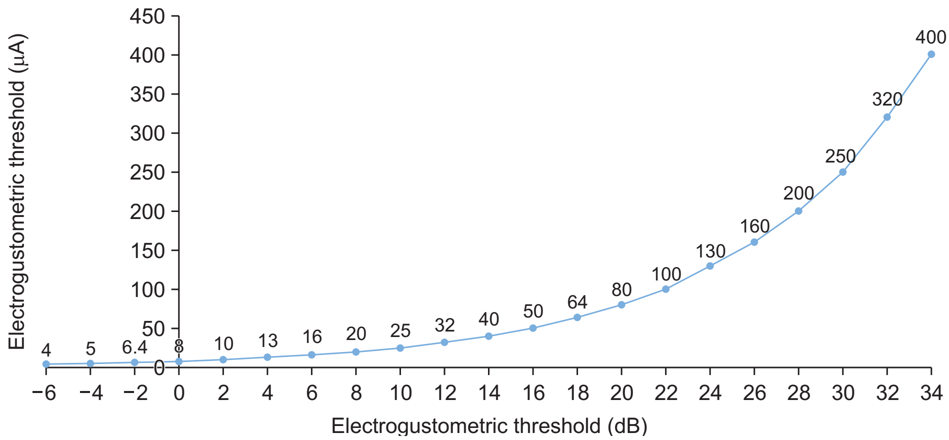

Fig. 1. Conversion of measurement units for electrogustometric values.

tongue toward the root of the tongue. The soft palate site was located 1cm laterally from the midline of the soft palate adjacent to the hard palate.

The EGM test was conducted over three consecutive days, with three sessions per day and three repetitions for each session. The test sessions were scheduled from 9:00 AM-9:30 AM, 12:00 PM-12:30 PM, and 5:30 PM-6:30 PM. The first session took place 2 hours after breakfast, while the second and third sessions were held before lunch and dinner, respectively.

3. Statistical Analysis

The repeatability of the electrical taste detection thresholds measured three times during three sessions over three days was assessed using the intraclass correlation coefficient (ICC). The ICC was defined as follows:

$$\mathrm{ICC}=100\times\frac{\sigma_s^2}{\sigma_t^2+\sigma_c^2+\sigma_d^2+\sigma_s^2}$$

where σ_t^2=variance due to trial-to-trial variability, σ_c^2=variance due to session-to-session variability, σ_d^2=variance due to day-to-day variability, and σ_s^2=variance due to inter-subject variability. Four types of variance were estimated using the statistical equations suggested by Rainoldi et al. [10,11]. The percentages of variance due to trial-to-trial, session-to-session and day-to-day variability were calculated as $100\times\sigma_t^2/\sigma_{tot}^2$, $100\times\sigma_c^2/\sigma_{tot}^2$, and $100\times\sigma_d^2/\sigma_{tot}^2$, respectively, where the total variance $\sigma_{tot}^2=\sigma_t^2+\sigma_c^2+\sigma_d^2+\sigma_s^2$. Variability was calculated in the order of trial, session, day and subject. Detailed formulas are given in the Appendix. Version 3.3.3 of the R language (R Foundation for Statistical Computing) was used to calculate the ICC. According to Bartko [12], ICC values above 80% suggest excellent repeatability, values between 61% and 80% suggest good repeatability and values below 60% indicate poor repeatability.

For subsequent statistical analysis, the electrical taste detection threshold values measured three times over three sessions per day were averaged to produce daily mean values. A one-way Friedman ANOVA test was used to compare the differences between the three mean daily values. Subsequently, the average of the three daily mean values was calculated to obtain the total mean values. The Shapiro–Wilk test revealed that the total mean values in the dB unit followed a normal distribution, while those in the μA unit did not. Repeated measures ANOVA and a post hoc paired t-test for values in the dB unit were used to compare the differences in total mean values between the three test sites. A Friedman one-way ANOVA with Wilcoxon signed-rank post hoc test was performed for those in the μA unit. For the repeated measures ANOVA and Friedman's one-way ANOVA tests, $p<0.05$ was considered statistically significant. A significance level for post hoc analyses performed with Bonferroni correction was set at $p<0.017$. The statistical analysis was carried out using IBM SPSS Statistics for Windows, Version 23.0 (IBM Co.).

RESULTS

For electrical taste detection thresholds in the dB unit, the tip of the tongue and the soft palate exhibited similarly good repeatability (ICC: 61.03 and 66.03, respectively); however, the posterior lateral border of the tongue showed slightly lower repeatability (ICC: 58.07) compared to the tip of the tongue or soft palate. All three test sites showed low repeatability for values in the μA unit, with the posterior lateral border of the tongue showing the lowest ICC (36.35). The tip of the tongue and the soft palate showed similar ICC (42.26 and 41.64, respectively). Variance due to inter-subject variability (σ_s^2) was the highest among the four types of variances (σ_t^2, σ_c^2, σ_d^2, and σ_s^2) in dB and μA units for all three test locations. Regarding the three types of variance due to trials, sessions and days, day-to-day variability (σ_d^2) was the lowest, followed by session-to-session (σ_c^2) and trial-to-trial variability (σ_t^2) was the highest in the μA unit at all three test sites. In the dB unit, trial-to-trial variability (σ_t^2) was greatest on the tip of the tongue and the posterior lateral border of the tongue, while inter-session variability (σ_c^2) was most significant on the soft palate (Table 1).

The total mean electrical taste detection thresholds in the dB unit differed statistically significantly between the three test sites (F[1.2, 19.9], 11.7; p=0.002). Post hoc analysis revealed that the total mean values for the tip of the tongue were significantly lower than those for the posterior lateral border of the tongue 4.71 (95% confidence intervals [CI], 3.04-6.37; p<0.001) and also lower than those of the soft palate 7.88 (95% CI, 3.65-12.11; p=0.001). However, there was no statistically significant difference between the posterior lateral border of the tongue and the soft palate 3.18 (95% CI, −0.76-7.11; p=0.106) (Fig. 2A). Similarly, there was a statistically significant difference in the total mean values in the μA unit depending on the test sites (χ^2(2)=13.968, p=0.001). The total mean values for the tip of the tongue were significantly lower than those for the posterolateral border of the tongue (Z=−3.411, p=0.001) and lower than those for the soft palate (Z=−3.010, p=0.003). There was no statistically significant difference between the posterior lateral border of the tongue and the soft palate (Z=−1.501, p=0.133) (Fig. 2B). The daily mean values on the second

Table 1. ICC and percentage of variance due to trial-to-trial (σ_t^2), session-to-session (σ_c^2), day-to-day (σ_d^2) and inter-subject (σ_s^2) variability for electrical taste detection thresholds

Test site	Unit: dB					Unit: μA				
	ICC	σ_t^2	σ_c^2	σ_d^2	σ_s^2	ICC	σ_t^2	σ_c^2	σ_d^2	σ_s^2
Tip of the tongue	61.03	6.81	5.37	3.09	23.92	42.26	113.15	28.58	9.69	110.82
Lateral border of the tongue	58.07	11.90	7.94	8.62	39.42	36.35	855.04	526.34	144.45	871.30
Soft palate	66.03	13.69	15.10	4.78	65.29	41.64	1,420.29	1,294.59	459.06	2,265.04

ICC, intraclass correlation coefficient.

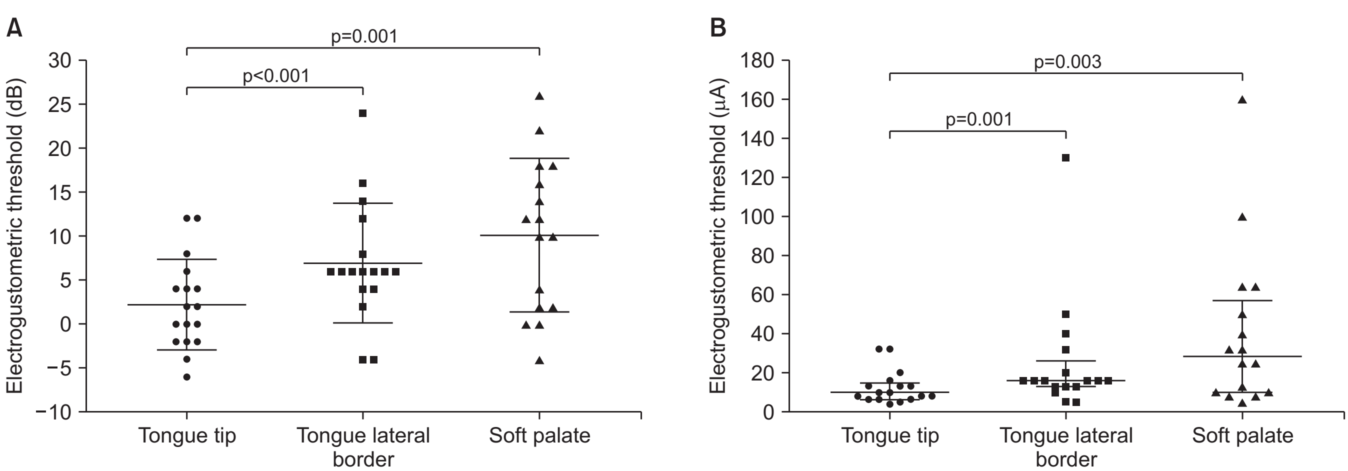

Fig. 2. Distribution of the total mean electrical taste detection thresholds of the three test sites (N=17, mean age: 20.5±0.5 years). (A) Electrogustometric thresholds in the dB unit. The horizontal lines represent the mean and standard deviation. Repeated measures ANOVA and post hoc paired t-test. (B) Electrogustometric thresholds in the μA unit. The horizontal lines represent the median, first quartile and third quartile values. Friedman one-way ANOVA with Wilcoxon signed-rank post hoc test.

Table 2. Average daily and total electrical taste detection thresholds for the three test sites

Test site	Unit: dB				Unit: μA			
	Day 1	Day 2	Day 3	p-value*	Day 1	Day 2	Day 3	p-value*
Tip of the tongue	1.8±5.2	2.8±6.6	3.2±6.3	0.717	11.13±8.39	14.97±14.16	14.86±11.43	0.449
Total mean		2.2±5.1				12.4±8.5		
Lateral border of the tongue	6.4±6.9	6.2±7.8	7.4±7.7	0.225	22.94±22.53	24.84±28.88	27.15±26.12	0.285
Total mean		6.9±6.8				25.1±29.5		
Soft palate	9.4±8.5	10.2±9.9	10.5±8.6	0.589	36.28±35.21	48.05±61.70	42.47±45.37	0.589
Total mean		10.1±8.5				39.6±40.1		

Values are presented as mean±standard deviation.
*Friedman one-way ANOVA test.

and third days at all three test sites tended to be higher than those on the first day, but were not statistically significant (Table 2).

DISCUSSION

In this study, the repeatability of electrical taste detection thresholds was analyzed through repeated measurements over multiple sessions and days. Notably, the electrical taste detection thresholds in the dB unit showed superior repeatability compared to those in the μA unit. The difference or variation observed could be explained by the inherent characteristics of how the subjects provide their evaluations. The discrepancies or variations observed in the results of the study are not due to a direct or linear relationship between the stimulus and the subjects' evaluations, but are influenced by a more complex, potentially exponential relationship. In EGM, a current intensity of 0 dB corresponds to 8 μA, and the interval between current stimulations in 2 dB increments is converted into current intensity μA on an exponentially increasing scale (Fig. 1). Consequently, measurements in the μA unit show a skewed data distribution in relation to the median value, in contrast to the normal distribution observed in the dB unit.

The study revealed that the variance attributable to the subjects exceeded that due to other factors, such as attempts, sessions and days. This finding underscores the substantial impact of the subject as the main factor influencing variability. The EGM and chemical taste tests are psychophysical tests that depend on the subject's perception and judgment of the stimulus. Weiffenbach [13] suggested that incorrect responses to chemical taste stimuli can be attributed to the stimulus not being recognized, with the response occurring due to assumptions. Running [14] demonstrated high false positive rates in common sensory threshold tests and proposed that staircase methods may be more reliable than ascending methods, despite an associated increase in false positive rates with the duration of the test run.

EGM thresholds may decrease with repeated measurements. Kuga and Ikeda [15] reported a significant reduction in EGM thresholds for many individuals during the second and third estimates made at intervals of 4 weeks or more. In a study by Stillman et al. [4], the second estimate of tongue stimulation was equal to or lower than the first estimate for 72% of the subjects. In another study by Lobb et al. [8], the tongue of two subjects was repeatedly examined 80 times, revealing significant variability between sessions in both subjects. This suggests that estimates based on a small number of tests should be interpreted with caution. In this study, the daily mean values on the second and third days tended to be higher than on the first day at all three test sites, although the difference was not statistically significant.

In this study, among the three test sites, the tip of the tongue and the soft palate showed better repeatability than the posterior lateral border of the tongue. This improved reproducibility can be attributed to the reduced deviation of a test probe from the precise location when repeatedly applying current stimulation. As the tongue is mainly made up of muscles, its shape can change depending on the function required. Therefore, the tip-of-the-tongue site facilitated a more direct determination of the test site and the consistent application of the current stimulus in almost the same location compared to the posterior lateral border-of-the-tongue site.

In the present study, the mean electrical thresholds for taste were lowest on the tip of the tongue and highest on the soft palate. This result is in line with the findings of other studies [16-19]. In addition, Miller et al. [16] demonstrated a correlation between EGM thresholds and the number of fungiform papillae in the stimulated areas.

In this study, the posterolateral border of the tongue was selected in addition to the tip of the tongue. Many EGM studies often include the locations of foliate papillae or circumvallate papillae as test sites [5,18,20]. Testing foliate papillae or circumvallate papillae offers the advantage of assessing the taste function of the glossopharyngeal nerve. However, it is not easy for the examiner to reach deep into the oral cavity and apply stimulation with a test probe to these structures, and it can be challenging for the patient to keep their tongue forward during a prolonged examination. The test site on the posterior lateral border of the tongue can be examined more conveniently. In addition, the result of the lateral border of the tongue test can complement or strengthen that of the tip of the tongue, since both sites are innervated by the same branch of the chorda tympani of the facial nerve.

This study has several limitations. First, the limited sample size of 17 subjects raises concerns about the robustness of the analysis. The unknown probability distribution of the ICC applied in this study hindered the ability to test hypotheses related to the ICC and calculate the necessary sample size. Second, the exclusive inclusion of healthy young females in this study may limit its applicability to a wider population. Investigating age-related variations in electrical taste detection thresholds and evaluating potential differences between the sexes could provide valuable information. Furthermore, this study would have been more important if it had included patients with taste disorders. Third, this study focused on short-term repeatability, but investigating long-term trends in electrical taste detection thresholds could provide a more comprehensive understanding of the stability of taste function over long periods. Despite its limitations, this study contributes to understanding the clinical usefulness of EGM. The repeatability demonstrated in the dB unit suggests its potential for reliable assessment of taste function in clinical settings, particularly among healthy young females.

In conclusion, the electrical taste detection test, measuring the EGM threshold in dB, demonstrates repeatability and can be considered acceptable for clinical use in assessing taste function in healthy young females. Future studies should aim for larger and more diverse samples, consider long-term trends and investigate correlations with various influencing factors to advance our understanding of taste perception and its clinical evaluation.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

DATA AVAILABILITY STATEMENT

The data sets used in this study are available from the corresponding author upon reasonable request.

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AUTHOR CONTRIBUTIONS

Conceptualization: YGI. Formal analysis: HN, YGI. Methodology: YGI. Project administration: BGK. Writing - original draft: HN, YGI. Writing - review & editing: HN, YGI, BGK.

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Appendix

Table 1. Mathematical formulas used to calculate the ICC

Formula	Definition
$MSE_{(t)} = \frac{1}{n_s \times n_d \times n_c} \sum_{i=1}^{n_s} \sum_{j=1}^{n_d} \sum_{k=1}^{n_c} \sum_{l=1}^{n_t} \frac{(x_{i,j,k,l} - x_{i,j,k,-})^2}{n_t - 1}$	Mean squared error due to trials
$MSE_{(c)} = \frac{n_t}{n_s \times n_d} \sum_{i=1}^{n_s} \sum_{j=1}^{n_d} \sum_{k=1}^{n_c} \frac{(x_{i,j,k,-} - x_{i,j,-,-})^2}{n_c - 1}$	Mean squared error due to sessions
$MSE_{(d)} = \frac{n_c \times n_t}{n_s} \sum_{i=1}^{n_s} \sum_{j=1}^{n_d} \frac{(x_{i,j,-,-} - x_{i,-,-,-})^2}{n_d - 1}$	Mean squared error due to days
$MSE_{(s)} = n_d \times n_c \times n_t \times \sum_{i=1}^{n_s} \frac{(x_{i,-,-,-} - \bar{x})^2}{n_s - 1}$	Mean squared error due to subjects
$\bar{x} = \frac{1}{n_s \times n_d \times n_c \times n_t} \sum_{i=1}^{n_s} \sum_{j=1}^{n_d} \sum_{k=1}^{n_c} \sum_{l=1}^{n_t} x_{i,j,k,l}$	Overall mean
$x_{i,-,-,-} = \frac{1}{n_d \times n_c \times n_t} \sum_{j=1}^{n_d} \sum_{k=1}^{n_c} \sum_{l=1}^{n_t} x_{i,j,k,l}$	Mean of the i-th subject
$x_{i,j,-,-} = \frac{1}{n_c \times n_t} \sum_{k=1}^{n_c} \sum_{l=1}^{n_t} x_{i,j,k,l}$	Mean of i-th subject and j-th session
$x_{i,j,k,-} = \frac{1}{n_t} \sum_{l=1}^{n_t} x_{i,j,k,l}$	Mean of the i-th subject, j-th session and k-th day
$\sigma_t^2 = MSE_{(t)}$	Variance due to trials
$\sigma_c^2 = \frac{MSE_{(c)} - MSE_{(t)}}{n_t}$	Variance due to sessions
$\sigma_d^2 = \frac{MSE_{(d)} - MSE_{(c)}}{n_c \times n_t}$	Variance due to days
$\sigma_s^2 = \frac{MSE_{(s)} - MSE_{(d)}}{n_d \times n_c \times n_t}$	Variance due to subjects
$ICC = \frac{\sigma_s^2}{\sigma_t^2 + \sigma_c^2 + \sigma_d^2 + \sigma_s^2} \times 100$	ICC
n_t	Number of trials per session
n_c	Number of sessions per day
n_d	Number of days
n_s	Number of subjects

ICC, intraclass correlation coefficient.