Tongue Size, Oral Cavity Size and Speech

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Methods of measuring tongue size are evaluated, and protruded tongue size is related to sex, malocclusion, and speech. Significant correlations are found with sex and speech.

KEY WORDS: • SPEECH • TONGUE •

Form and function of the oral soft tissues, and the tongue in particular, have been related to the growth of the oral cavity (MOSS 1969), the size of the oral cavity (MCGLONE AND PROFFIT 1972), the development of malocclusion, and speech defects (FOSTER 1975). Tongue function has been studied to observe the direction and amount of movement (ADRAN AND KEMP 1955), and the pressures exerted (FAIRBANKS AND BEBOUT 1950, PROFFIT ET AL. 1965). The form of the tongue has been studied directly in cadavers by HOPKIN (1967), radiographically using cephalometric techniques by EIFERT (1960), HOPKIN (1963), COOKSON (1966/67), and COHEN AND VIG (1976), and using computerized tomography by ROEHM (1982).

Direct measurements of the tongue in vivo have been attempted by Bandy and HUNTER (1969), and TAKADA ET AL. (1980). Bandy and Hunter acknowledge the shortcomings of their method, but Takada et al. quote an unreported pilot study which apparently showed their technique to be reliable and reproducible.

Articulatory defects have been related to malocclusion in survey articles (ROTH 1940, MOORE 1956). Faulty soft tissue function, involving the tongue in particular, has been reported by HARRINGTON AND BREINHOLT (1963), and BLOOMER (1963), although as WEINBERG AND PARAS (1970) report, the tongue is not essential for successful articulation. HARVOLD (1970) points out that the effect of oral morphology on articulatory ability does not present as an obvious and simple anatomical link.

This study investigates a method for measurement of the tongue and relates the findings to dimensions of the oral cavity.

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— Methods and Materials —

The aims of this study are:

1. To assess the reliability of a method of recording tongue volume using an impression technique, and compare this with a calculated volume from direct linear measurements.
2. To investigate the correlation between tongue dimensions and oral cavity dimensions.
3. To examine the sex differences in tongue dimension and oral cavity dimensions.
4. To examine speech samples of the subjects and evaluate correlations between articulatory defects and oral morphology and dimensions.

Thirty-five healthy Caucasian dental students (23 male, 12 female) were chosen on the basis of willingness to cooperate in the study. No consideration was given to malocclusion, missing teeth, or speech defects.

Direct Tongue Measurements

The amorphous nature of the tongue presents problems for in vivo mensuration. An attempt was made to reduce these to a minimum by utilizing the most easily reproducible position for measurements, recording the tongue in maximum protrusion. The following dimensions of the protruded tongue were recorded:

Length, measured as protrusion beyond the lower incisors

Breadth, measured at the oral commissure

Thickness, measured above the lower incisor edges.

Length and breadth were measured using a millimeter ruler, and thickness with a specially adapted Boley gauge. These measurements were carried out independently by two observers at the same sitting.

An alginate impression of the protruded tongue and lower teeth was obtained, using a convenient size vessel specially constructed to accommodate the size of the protruded tongue, in a manner similar to Takada et al. (1980).

Conventional upper and lower alginate impressions of the dental arches were also taken, along with a wax bite register in habitual occlusion.

Speech recordings were made of each subject reading a phonetically balanced passage (Arthur the Rat), using a good quality stereo cassette machine.

For twelve subjects, all the above records were repeated after an interval of three weeks. Direct measures were repeated on a thirteenth subject.

Impressions were immediately cast in dental stone.

The tongue casts were trimmed distal to the last standing molar, and to the level of the occlusal surfaces of the mandibular teeth visible on the cast.

The maxillary and mandibular casts were trimmed in occlusion to the last standing molar on each side. The floor of the mouth was taken as the caudal extent of the impression on the lingual side, with the lingual frenum trimmed off.

All casts were waterproofed by dipping in molten wax to seal the surface, boiling off the excess wax.

Tongue volume was then measured by water displacement.

Oral cavity volume was measured by first sealing the casts together on the buccal and labial surfaces of the teeth with wax, then filling with water and measuring the water volume. The oral cavity volume measurements for the whole sample were repeated to check the error of the method.

Using the direct tongue measurements, two methods of calculation were used to estimate tongue volume.

First, considering the tongue as a rectangular block, tongue volume (V) was calculated as:

$$V = l \times b \times t$$

where: l = protruded tongue length plus lower dental arch length from the study cast
b = breadth, and
t = thickness.

Second, considering the tongue as a cone, the volume was calculated using the formula:

$$V = \pi r^2 l$$

$$\text{Where: } r = \sqrt{(b^2 + t^2)/2}$$

Direct measurements of the maxillary and mandibular casts were taken using dividers and a contour gauge. All direct measurements are recorded to the nearest 0.5mm or $0.5cm^3$.

The dividers were used to measure the intercuspid and intermolar width of each arch, measuring from the palatal or lingual gingival margins at the midpoints of the cuspids and last standing molars. The height of the palatal vault in these same regions was measured from the highest point on the crown of the relevant tooth, using a contour gauge similar to HOWELL (1981). Arch length was measured in the midline at the level of the occlusal plane from the incisal edge of the lower incisor to the distal margin of the terminal molar.

Incisor relationship was noted from the casts.

The equivalent measures of length, breadth and thickness were taken on the cast of the tongue.

Means and standard deviations of recorded dimensions were calculated. On repeated measurements the root mean square difference and paired 't' tests were also recorded. The students 't' test for comparison of two means was also carried out for the male vs. female sample.

Correlation coefficients and their significance were calculated for various oral dimensions and tongue dimensions after SWINSCOW (1977), using the formula:

$$t = r\sqrt{\frac{n-2}{1-r^2}}$$

The tape recordings were played to a group of second-year speech therapy students as part of a phonetic exercise where they were expected to note the type and extent of speech defects, voice quality, speed, fluency, pitch and intonation. They were not aware that some of the voices were repeated.

With this type of phonetic exercise it is impossible to assign suitable statistical tests, so only trends, with no statistical significance attached, are noted.

— Results and Discussion —

Differences between first and second direct measures of the tongue were found to not be significant, with root mean square differences of 4.5mm for tongue breadth, 2.9mm for length, and 2.6mm for thickness.

Some significant differences between operators do emerge for tongue length and breadth under the paired t-test (Table 1). Although the root mean square difference for tongue thickness is of the same order of magnitude as length and breadth, the difference loses its significance because the mean difference values are very low.

Also of interest are the consistently lower readings for tongue length and thickness, with higher readings for tongue breadth, by operator 2. A possible explanation is that operator 1 managed to persuade the subjects to protrude their tongues farther for the first two measurements (length and breadth), which would tend to make the tongue longer and thinner; by the time the thickness was measured, fatigue of the genioglossus and the intrinsic transverse muscles caused the muscle bulk of the tongue to fall back and hence produce a higher thickness reading.

These results indicate that even though each operator is reasonably consistent in their technique, direct observation of the tongue is not reliable between operators.

In addition to the direct tongue measurements, the same measures of the tongue were taken on the tongue casts (Table 2). This shows significant differences for all measures, with the tongue cast being shorter, less broad, and thicker. This alteration in morphology to a more cone-like shape may be presumed to facilitate penetration into the viscous alginate impression material which might restrict the full extension of the tongue.

Theoretically, one might expect the volume of the tongue to remain unchanged, but the difficulties of extending a tongue impression onto the pharyngeal surface, together with the hydraulic nature of the floor of the mouth and mobility of the hyoid bone, all contribute to confounding any effort to achieve a truly consistent and accurate assessment of the tongue volume.

At best, this technique can produce a moderately reproducible cast of the mobile oral portion of the tongue.

Assessment of Tongue Volume

If the direct measures obtained above are used to calculate the volume of the

Table 1

Inter-examiner Variability
Direct Tongue Measurements
(mm)

N	Operator 1 Mean±SD	Operator 2 Mean±SD	R.M.S. Diff.	Mean Diff.	Paired t test Sig.
		Tongue Length			
23♂	36.9±6.6	25.2±5.7	3.2	-1.6	**
12♀	33.7±4.6	32.3±4.6	2.2	-0.7	
35♂♀	35.7±6.1	34.2±5.5	2.9	-1.5	***
		Tongue Breadth			
23♂	44.9±5.4	45.7±4.9	2.7	+0.7	
12♀	39.5±3.8	41.7±3.8	3.8	+2.3	*
35♂♀	43.0±5.5	44.4±4.9	3.1	+1.3	**
		Tongue Thickness			
23♂	11.0±3.1	10.9±2.5	3.2	-0.1	
12♀	10.0±2.4	9.7±2.5	2.5	-0.2	
35♂♀	10.7±2.9	10.5±2.5	3.0	-0.2	

* P<.05 ** P<.01 *** P<.001

tongue, either considering the organ as a rectangular block or as a cone, there are no significant intra- or inter-operator differences. The cone method of calculation produces consistently higher values for tongue volume than the rectangular block method (Table 3).

Bearing in mind the noted inconsistencies of direct tongue measurements, tongue volume by calculation from these measures must also be considered unreliable, because the errors may be compounded.

The volume of the tongue was also recorded by water displacement, using the cast (Table 3). Reproducibility of the water displacement method for recording oral cavity and tongue volumes was tested by repeating the measurements on all 47 casts. The mean difference between the first and second measures was −0.04cc, with a root mean square difference of 1.29cc.

As there were no significant differences on repeated tongue impressions, and the water displacement method is more reliable than calculation from direct measurements, the volume of the tongue as determined by water displacement of the tongue cast is utilized in all further calculations.

Although there is a degree of variation in recording tongue volumes, the use of massed data for comparison with other variables is considered valid for indicating underlying associations, with the proviso that significance involving tongue volumes at the 95% and perhaps even the 99% level should be interpreted with caution.

Table 2

Tongue Measurements
Direct and Plaster Cast
(mm)

N	Direct Mean+SD	Model Mean±SD	R.M.S. Diff.	Mean Diff.	SD Diff.	Paired t test Sig.
		Tongue Length				
23 ♂	36.9±6.6	22.1±6.9	16.4	−14.8	7.2	***
12 ♀	33.7±4.6	17.7±6.1	17.2	−15.9	6.8	***
35 ♂♀	35.7±6.1	20.6±6.9	16.7	−15.2	7.0	***
		Tongue Breadth				
23 ♂	44.9±5.4	36.4±5.5	9.8	− 8.4	5.1	***
12 ♀	39.5±3.8	33.6±7.0	10.6	− 5.9	8.4	*
35 ♂♀	43.0±5.5	35.4±6.1	10.1	− 7.6	6.5	***
		Tongue Thickness				
23 ♂	11.0±3.1	15.0±2.8	5.5	+ 3.9	3.9	***
12 ♀	10.0±2.4	12.9±3.4	3.9	+ 2.8	2.9	**
35 ♂♀	10.7±2.9	14.3±3.1	5.0	+ 3.6	3.6	***

* P<.05 ** P<.01 *** P<.001

Tongue Dimension vs. Oral Cavity Dimension

Table 4 shows the varying levels of correlation between the oral cavity and the tongue. The probability value is a measure of the r value difference from 0 (no correlation), and such r values below 0.7 are generally accepted to indicate little clinical significance.

The correlation coefficient values are generally higher for the females, but in only two instances (intermolar width vs. oral cavity volume, and tongue volume vs. oral cavity volume) does the r value exceed 0.7.

Sex Differences

Statistically significant differences between males and females were found for tongue breadth and volume (but see caveat above), and for all oral dimensions except palate height in the intermolar region. The small sample size must also be considered in evaluating these results.

Table 3

Tongue Volume

N	1st Measure Mean±SD	2nd Measure Mean±SD	R.M.S. Diff.	Mean Diff.	SD Diff.	Paired t test Sig.
		Water Displacement (cc)				
7♂	31.6± 6.6	33.0± 6.6	6.4	+1.4	6.7	
5♀	28.8± 7.1	26.0± 6.5	5.5	−2.8	5.3	
12♂♀	30.4± 6.6	30.1± 7.2	6.0	−0.3	6.3	
		Block (Operator 1)				
7♂	35.2±10.7	38.6±14.6	11.3	−3.4	11.7	
5♀	29.8± 8.1	33.6± 8.3	5.4	−3.8	4.3	•
12♂♀	32.7± 9.6	36.3±11.9	9.1	−3.6	8.7	
		Block (Operator 2)				
7♂	38.0±12.1	35.7±14.2	6.4	−2.3	6.4	
5♀	34.0± 8.8	30.7±10.1	6.6	−3.4	6.0	
12♂♀	36.2±10.5	33.4±12.3	6.4	−2.8	6.0	•
		Cone (Operator 1)				
7♂	45.0± 9.8	46.7± 7.7	8.6	+1.7	9.1	
5♀	34.3± 7.5	35.0± 7.4	6.9	+0.7	7.5	
12♂♀	40.1±10.1	41.3± 9.4	7.8	+1.2	8.1	
		Cone (Operator 2)				
7♂	46.0± 8.2	46.4±10.2	8.5	+0.4	9.2	
5♀	36.2± 7.3	35.0± 5.5	2.6	−1.2	2.6	
12♂♀	41.5± 9.1	41.1±10.0	6.5	−0.3	6.7	

In all cases except palate height in the intercuspid region, the male is larger than the female. This marked sex difference is not contrary to expectations, although the explanation for a significantly greater intercuspid palate depth in females perhaps lies in the findings of EIFERT (1960) and COOKSON (1966/67) that females hold a significantly greater portion of their tongue above the occlusal plane level.

Speech

The incisor relationship of each subject was noted, and those individuals assessed by the phonetic exercise as acceptable or inferior articulators were examined for the incidence of malocclusion. There was an equal distribution between the different incisor classifications of both the acceptable and poor articulators, so incisor relationship per se seems to have no effect on articulatory ability. Other variables, e.g. overbite, spacing, crossbites, also failed to demonstrate a consistent relationship with articulatory proficiency.

However, Table 4 indicates a tendency for poor articulators to have smaller than normal oral dimensions, (maxillary and mandibular intercuspid and intermolar width, palate depth, oral cavity volume, tongue length, breadth, thickness and volume), although there is not a higher incidence of females in the poor speech group despite their smaller oral size.

— Discussion —

FAIRBANKS AND BEBOUT (1950) used an identical method for direct tongue length measurements. There is an agreement with our figures for female tongue length, but male tongues in our sample were larger. HOPKIN (1967), using cadaver tongues of adults, found no significant sex differences in size.

Table 4

Correlation Coefficients
Volumes measured by Water Displacement

	Males	Females
$\underline{3-3}$ width : Tongue Volume	+0.05	+0.20
$\underline{7-7}$ width : Tongue Volume	+0.33	$\underline{+0.67}$
$\underline{3-3}$ depth : Tongue Volume	−0.05	−0.10
$\underline{7-7}$ depth : Tongue Volume	$\underline{+0.51}$	+0.05
$\overline{3-3}$ width : Tongue Volume	−0.01	+0.52
$\overline{7-7}$ width : Tongue Volume	$\underline{+0.47}$	+0.50
$\underline{3-3}$ width : Oral Cavity Volume	+0.18	+0.47
$\underline{7-7}$ width : Oral Cavity Volume	+0.28	$\underline{+0.79}$
$\underline{3-3}$ depth : Oral Cavity Volume	−0.06	−0.43
$\underline{7-7}$ depth : Oral Cavity Volume	+0.27	−0.23
$\overline{3-3}$ width : Oral Cavity Volume	$\underline{+0.57}$	+0.32
$\overline{7-7}$ width : Oral Cavity Volume	$\underline{+0.44}$	+0.50
Tongue Volume : Oral Cavity Volume	+0.13	$\underline{+0.8}$

$\underline{\leq 0.05}$ $\underline{\leq 0.01}$ $\underline{\leq 0.001}$

Table 5

Sex Differences
Student's t Test

	Males (23) Mean±SD	Females (12) Mean±SD	
Tongue Dimensions			
Length (mm)	36.9±6.6	33.7±4.6	
Breadth (mm)	44.9±5.4	39.5±3.8	••
Thickness (mm)	11.0±3.1	10.0±2.4	
Volume (cc)	33.8±7.6	26.8±5.5	••
Arch Width (mm)			
$\underline{3-3}$	24.6±1.2	23.5±1.5	•
$\underline{7-7}$	41.7±3.2	38.5±2.8	••
$\overline{3-3}$	19.9±1.9	18.2±1.5	•
$\overline{7-7}$	43.7±3.7	38.9±3.0	•••
Arch Depth (mm)			
$\underline{3-3}$	7.4±1.3	8.9±3.0	•
$\underline{7-7}$	19.0±2.1	17.4±2.3	
Oral Cavity Volume (cc)			
	40.22±6.2	33.67±4.9	••

• P=<.05 •• P=<.001 ••• P=<.001

Table 6

Speech Articulation
Numbers of Measures Deviating from Mean

−>1 SD	±<1 SD	+>1 SD
Normal Articulators (n=23)		
24(10%)	53(23%)	29(13%)
3 subjects with all measures ±<1SD		
Poor Articulators (n=11)		
21(19%)	28(25%)	7(6%)
1 subject with all measures ±<1SD		

Bandy and Hunter (1969) measured tongue volumes by protruding the tongue into a sheet of rubber connected to a water column, recording the displaced volume. They related tongue volume to mandibular arch dimensions. As they were only measuring the volume of tongue protruding from the oral cavity, it is not surprising that their mean volume was less than ours, nor is it surprising that they found no correlation with arch dimensions.

Takada et al. (1980) used an impression technique similar to ours, trimming their casts to the first permanent molar instead of the last standing molar. However, despite this difference, their r value for tongue volume vs. oral cavity volume matches our female value. Despite the agreement of some of our findings, the shortcomings that we have encountered in the impression technique for recording tongue volumes leads us to conclude that we cannot share the confidence in the reliability of this method that Takada et al. seem to have adopted.

The apparent sex difference in the correlation between tongue dimensions and oral cavity dimensions cannot be confirmed in the literature, as one study (Bandy and Hunter 1969) measured males only, and another study (Takada et al. 1980) measured females only. Other workers (Eifert 1960, Cookson 1966/67), using lateral skull radiographs, note that females tend to hold their tongues higher in the oral cavity and thus one might expect a greater influence on oral dimensions.

Ratios of tongue area to intermaxillary area produced a value of 0.79 for males and 0.83 for females (Cohen and Vig 1976), supporting other work (Eifert 1960, Cookson 1966/67). Computed tomography (Roehm 1982) showed an overall ratio of 0.86. Our combined figures are 0.84, but in contrast to Cohen and Vig (1976), our male value was 0.86, and our female value was 0.80.

This difference may be related to technique, in that females already holding more tongue in their mouth have less reserve bulk to protrude into the impression, whereas males, with their lowered tongue position, can protrude a greater mass of tongue when required.

Fairbanks and Lintner (1951) examined palatal dimensions in a manner similar to our method. They found similar intercuspid widths. They could find no difference in oral dimensions between superior and poor articulators, in contrast to Fymbo (1957) and Lubit (1967), who both found a tendency for narrower and higher palates in poor articulators. Wardlaw (1962), using a younger sample, finds results in agreement with Fairbanks and Lintner (1951). Lubit (1967) also found a greater incidence of articulatory errors among males — a finding reinforced by larger epidemiological studies (Butler et al. 1973, Williams et al. 1980).

— Conclusions —

- Direct tongue measurements demonstrate significant inter-examiner differences.
- The impression technique for recording tongue morphology is subject to the limitations of the individual in tolerating an impression and the extension of the tongue into a viscous impression material.
- The dimensions of the tongue protruded into an impression are significantly different from dimensions in an unopposed protrusion.
- There are varying levels of correlation between tongue volume and oral cavity dimensions, with a generally lower correlation for males.
- There are significant sex differences in tongue and oral cavity dimensions, with males being generally larger.
- No relationship was found between incisor relationships and articulatory defects.
- Those speakers with noticeable articulatory defects showed a tendency toward smaller oral dimensions than normal articulators.

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