CEPHALOMETRIC ANALYSIS OF TONGUE POSTURE AND STRUCTURAL POSITION DURING ACCEPTABLE AND UNACCEPTABLE PRODUCTION OF THE [S] SOUND

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ABSTRACT

CEPHALOMETRIC ANALYSIS OF TONGUE POSTURE AND STRUCTURAL POSITION DURING ACCEPTABLE AND UNACCEPTABLE PRODUCTION OF THE [S] SOUND

By Eleanor Harger Burgess

There is still much to be known about the production of consonants. Much has been written concerning the apparent physiological production of consonant sounds, but this information generally has been determined from casual inspection rather than precise measurement. The [s] sound is one of the most frequently employed and misarticulated consonant sounds in American English. It has been described phonetically as a surd, lingua-alveolar continuant fricative, but there are considerable variations in the physiologic descriptions of acceptable [s] sound production. Investigation of [s] sound production as related to tongue posture and dental occlusion has been indicated. This study proposed to determine objectively the differences in tongue posture and structural position during the acceptable and the unacceptable production of the [s] sound by means of cephalometric analysis.

Eleanor Harger Burgess

The study was conducted in the Department of Orthodontia, Eastman Dental Dispensary, Rochester, New York, and was supported in part by a United States Public Health Service Grant (# D-1071). A group of thirty adult and adolescent speakers having acceptable [s] sound production and normal occlusion and a group of thirty adolescent speakers having unacceptable [s] sound production were examined. Cephalometric roentgenograms were taken of each subject during the production of the [s] sound. Tantalum powder was used as a radio-opaque media in order to define the anterior regions of the tongue. Tracings of these roentgenograms were made by a qualified orthodontist. Measurements designed to specify the exact posture of the tongue in relation to the anterior structures were made. A statistical test was employed with these measurements to determine if there were significant differences between the two groups.

Statistically significant differences were found between the anterior structural position and the antero-posterior tongue posture during the production of the [s] sound by subjects who produced the sound acceptably and subjects who produced the sound unacceptably. The physiologic differences were described, and implications for the correction of defective [s] sound production were discussed.

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CHAPTER I

STATEMENT OF THE PROBLEM

I. INTRODUCTION

There is still much to be known about the production of consonants. Consonant sounds comprise the majority of sounds in American English. Among all speech problems, the misarticulations of consonant sounds are the most prevalent. Much has been written concerning the apparent physiological production of consonant sounds, but this information generally has been determined from casual inspection rather than precise measurement. Exactly what occurs in the production of some consonants is not fully known. It is vital to the field of Speech Therapy that finer measures be made in the area of consonant sound production. This is indicated by Peterson[1] in his statement:

> The physiological articulations of the consonants have long been described in terms of organic position and manner of production. In general, however, these descriptions are at the level of casual observation and personal opinion. The concept of speech production as a combined mechanical and acoustical process, in which there is a balance between articulatory

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[1]G. E. Peterson, "Speech and Hearing Research," *Journal of Speech and Hearing Research*, I (March, 1958), p. 9.

> (muscle) tension and driving breath pressure, needs much further emphasis . . . . Devices are available which can be applied to the study of many aspects of the articulatory processes, but at present this area of research is essentially undeveloped.

Although the [s] is but one sound, it is one of the most frequently employed and misarticulated consonant sounds in American English. The [s] sound has been described phonetically as a surd, lingua-alveolar continuant fricative,[2] but there are considerable variations in the descriptions of correct [s] sound production. Judson and Weaver[3] state:

> The velar-pharyngeal closure is complete. The air coming from the lungs under pressure is forced by the tongue to pass through a relatively constricted aperture to be released over the cutting edge of one or more of the teeth. (Usually the air follows a narrow groove along the mid-line of the dorsum of the tongue and is directed against the sharp edge of the lower incisors. However, the sound may be made in numerous positions between the tongue and the hard palate.) This produces a high frequency friction sound.

Berry and Eisenson[4] seem to concur with this description. They conclude their statements concerning [s] sound production with the comment that a good [s] sound "can vary from the stated position. Some have their tongues

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[2]L. S. Judson and A. T. Weaver, Voice Science (New York: Appleton-Century-Crofts, Inc., 1942), p. 377.

[3]Ibid.

[4]M. Berry and J. Eisenson, Speech Disorders Principles and Practices of Therapy (New York: Appleton-Century-Crofts, Inc., 1956), p. 164.

close to the lower gum ridge. Others have a fairly flat tongue . . . . , the phonetic descriptions are suggestive and not prescriptive." Bloomer[5] supports this rationale concerning [s] sound production. He adds:

> The phoneme [s] is ordinarily produced with the tongue grooved and in contact with the alveolar ridge of the maxilla as far forward as the incisors. It is possible to produce an acoustically acceptable [s] in other ways. One variant form is to bring the tongue tip in contact with the lingual surface of the lower incisors and the grooved blade into contact with the maxillary alveolar ridge (Kanter and West, 1941; Froeschels, 1933) . . . . It is quite possible, of course, that every speaker uses each method to some extent depending on the sound which immediately precedes or follows the [s] sound. Individual preference may also be related to general tongue posture and dental occlusion, but this has not yet been determined objectively.

It should be noted that each of the forementioned descriptions state that it is possible to produce an acoustically acceptable [s] sound in a variety of ways. Exactly which kind of variation can be made in acceptable [s] sound production needs extensive investigation. It also should be noted that further investigation of [s] sound production as related to tongue posture and dental occlusion has been recommended. It is hoped that this study will contribute toward a more objective explanation of the differences between acceptable and defective [s] sound production, and that in so doing, it will aid

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[5]H. H. Bloomer, "Speech Defects Associated with Dental Abnormalities and Malocclusions," Handbook of Speech Pathology, ed. L. Travis (New York: Appleton-Century-Crofts, Inc., 1957), p. 612.

therapists in correcting the most frequently misarticulated consonant sound in American English.

II. STATEMENT OF THE PROBLEM AND PURPOSE OF THE STUDY

The purpose of this study was to compare the oral structural positions and tongue posture of two groups of speakers during the production of the [s] sound. One group of speakers was judged to have made the [s] sound acceptably, whereas the other group was judged to have made the [s] sound unacceptably. The following question was proposed: 1. What differences are there between the two groups as regards relationship of oral structures of the subjects during the production of an acceptable and an unacceptable [s] sound?

III. NULL HYPOTHESES

In view of the question proposed, the following null hypotheses were developed:

1. There is no significant difference in the distance between the maxillary and mandibular incisal edges during the production of the [s] sound as evidenced on the cephalometric roentgenograms of the subjects who produce the [s] sound acceptably and the subjects who produce the [s] sound unacceptably.
2. There is no significant difference in the distance between the maxillary permanent first molar and the mandibular permanent first molar during the pro-

duction of the [s] sound as evidenced on the cephalometric roentgenograms of the subjects who produce the [s] sound acceptably and the subjects who produce the [s] sound unacceptably.

3. There is no significant difference in the distance between the anterior, inferior portion of the tip of the tongue and the anterior mandibular incisal edge during the production of the [s] sound as evidenced on the cephalometric roentgenograms of the subjects who produce the [s] sound acceptably and the subjects who produce the [s] sound unacceptably.
4. There is no significant difference in the distance between the lingual reference line and the anterior mandibular incisal edge during the production of the [s] sound as evidenced on the cephalometric roentgenograms of the subjects who produce the [s] sound acceptably and the subjects who produce the [s] sound unacceptably.
5. There is no significant difference in the distance between the anterior, inferior portion of the tip of the tongue and the palatal plane during the production of the [s] sound as evidenced on the cephalometric roentgenograms of the subjects who produce the [s] sound acceptably and the subjects who produce the [s] sound unacceptably.
6. There is no significant difference in the shortest distance between the highest point of the tongue and

palatal plane during the production of the [s] sound as evidenced on the cephalometric roentgenograms of the subjects who produce the [s] sound acceptably and the subjects who produce the [s] sound unacceptably.

7. There is no significant difference in the distance between the highest point of the tongue and the pterygo-maxillary fissure line during the production of the [s] sound as evidenced on the cephalometric roentgenograms of the subjects who produce the [s] sound acceptably and the subjects who produce the [s] sound unacceptably.

8. There is no significant difference in the distance between the posterior aspect of the tongue and the pharyngeal wall during the production of the [s] sound as evidenced on the cephalometric roentgenograms of the subjects who produce the [s] sound acceptably and the subjects who produce the [s] sound unacceptably.

9. There is no difference in the velar-pharyngeal closure during the production of the [s] sound as evidenced on the cephalometric roentgenograms of the subjects who produce the [s] sound acceptably and the subjects who produce the [s] sound unacceptably.

10. There is no significant difference in the size of the angle formed at sella turcica by the sella-nasion line and the sella-pogonian line during the production

of the [s] sound as evidenced on the cephalometric roentgenograms of the subjects who produce the [s] sound acceptably and the subjects who produce the [s] sound unacceptably.

11. There is no significant difference in the size of the angle formed at nasion by the sella-nasion line and the nasion-pogonian line during the production of the [s] sound as evidenced on the cephalometric roentgenograms of the subjects who produce the [s] sound acceptably and the subjects who produce the [s] sound unacceptably.

IV. IMPORTANCE OF THE STUDY

The [s] sound is one of the most frequently employed and misarticulated consonant sounds in the English language. Fairbanks[6] states that the [s] sound ranks sixth in frequency of use among the consonants of English. Travis[7] found the [s] sound fourth in frequency of occurrence in the conversational speech of children. West, Kennedy, and Carr[8] suggest, "Since the sound occurs frequently in our speech (comprising about seven per cent

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[6] G. Fairbanks, Voice and Articulation Drillbook (New York: Harper and Brothers, Publishers, 1940), p. 85.

[7] L. E. Travis, Speech Pathology (New York: D. Appleton-Century and Company, 1931), p. 223.

[8] R. West, L. Kennedy, and A. Carr, The Rehabilitation of Speech (New York: Harper and Brothers, Publishers, 1947), p. 209.

of our spoken sounds) its importance is further apparent." In eight years of experience as a public high school speech therapist, the investigator found that approximately two-thirds of the speech cases had difficulty in articulating the [s] sound. Many investigators in the field of Speech Therapy have noted that the [s] sound ranks high in frequency of error. Powers,[9] in a discussion of functional articulatory disorders, states, "The [s] and [z] sounds are among the most frequently misarticulated of all speech sounds." She supports this statement by citing a number of studies directed toward this problem. Roe and Milisen[10] studied the articulation of children in grades one through six in 1941. They found the [θ] and the [s] sounds most frequently in error. Sayler[11] studied the articulation of children in grades seven through twelve in 1949. In this study the [θ] and the [s] sounds were also the most frequently mispronounced. Van Riper[12] observed that the most frequently

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[9]M. H. Powers, "Functional Disorders of Articulation-Symptomatology and Etiology," Handbook of Speech Pathology, ed. L. Travis (New York: Appleton-Century-Crofts, Inc., 1957), p. 718.

[10]V. Roe and R. Milisen, "The Effect of Maturation upon Defective Articulation in Elementary Grades," Journal of Speech Disorders, VII (1942), pp. 37-50.

[11]H. K. Sayler, "The Effect of Maturation upon Defective Articulation in Grades Seven through Twelve," Journal of Speech and Hearing Disorders, CIV (1949), pp. 202-207.

[12]C. Van Riper, Speech Correction Principles and Methods, (New York: Prentice-Hall, Inc., 1947), p. 152.

mispronounced sounds were the [s], [z], [θ], [ð], [r], and [l] in a study in 1947. In a study of school children and college freshmen made by Hall[13] in 1938, she found that the [s] and [z] sounds were the most frequently misarticulated. Fairbanks and Spriestersbach[14] made the same observation in their study of college students in 1950. Fairbanks[15] further states that 90% of all clinical articulatory cases have difficulty with [s]. He says that it is much more frequently misarticulated by both children and adults than any other sound. West, Kennedy, and Carr[16] agree that the [s] sound is the most frequently misarticulated consonant sound by stating that, "From one-third to one-half of the cases in a school speech clinic lisp." Since the [s] sound seems to be the consonant sound most frequently misarticulated, there appears to be adequate justification in exploring its normal production as well as its production when it is judged to be defective. It is hoped that the information

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[13] M. E. Hall, "Auditory Factors in Functional Articulatory Speech Defects," Journal of Exceptional Education, VII, (1938), pp. 110-138.

[14] G. Fairbanks and D. Spriestersbach, "A Study of Minor Organic Deviation in 'Functional' Disorders of Articulation: 1. Rate of Movement of Oral Structures," Journal of Speech and Hearing Disorders, XV (January, 1950), pp. 60-69.

[15] Fairbanks, loc. cit.

[16] West, Kennedy, and Carr, loc. cit.

derived from this investigation will be more specific and more objective due to the employment of cephalometric roentgenography.

V. DEFINITION OF TERMS

1. Unacceptable [s] sound production: in the context of this study, [s] sound production which is not acoustically acceptable as judged by three trained listeners.

2. Oral structures: lips, teeth, tongue, maxilla, mandible, hard palate, soft palate, and pharyngeal wall.

3. Tongue position: the posture of the tongue.

4. Occlusion: the natural and normal fitting together of the teeth.

5. Normal occlusion: the dental arches are arranged in concentric, parabolic curves in which the outline of the maxillary arch is slightly larger than the mandibular arch. The mesio-buccal cusp of the maxillary permanent first molar occludes in the buccal groove of the mandibular permanent first molar. The teeth of the maxillary arch overhang the teeth in the mandibular arch labially and buccally. The incisal ridges of the maxillary incisors extend below the incisal ridges of the mandibular incisors by one-third of the mandibular incisal crowns.[17]

6. Malocclusion: failure of the teeth to assume a normal

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[17]Bloomer, _op. cit._, pp. 626-627.

antero-posterior relationship.

7. Angle Classification: class of malocclusion of molars as defined by Edward H. Angle.[18] The following is a description of the classes.

(1) Class I (Neutrocclusion)--normal antero-posterior relationship of the molars, but anterior malocclusions of various types are present.

(2) Class II (Distocclusion)--the mesio-buccal cusp of the maxillary permanent first molar articulates anterior to the buccal groove of the mandibular permanent first molar.

(a) Division I--distocclusion accompanied by extreme protrusion of the maxillary incisors.

(b) Division II--distocclusion accompanied by retrusion of the maxillary central incisors and tipping of the maxillary lateral incisors labially and mesially.

(c) Subdivisions--distocclusion occurs on only one side of the dental arch.

(3) Class III (Mesiocclusion)--the mesio-buccal cusp of the maxillary permanent first molar articulates posterior to the buccal groove of the mandibular permanent first molar, the lower

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[18]Edward H. Angle, Malocclusion of the Teeth (7th ed.; Philadelphia: S. S. White Dental Manufacturing Company, 1907).

incisors protruding.

8. Overjet: the overhanging of the maxillary teeth over the mandibular teeth labially and buccally.

9. Linguaversion: toward the tongue.

10. Labially: toward the lips.

11. Buccally: toward the cheek.

12. Distally: posterior to the normal position.

13. Mesially: anterior to the normal position.

14. Lingual reference line: a line drawn from the anterior, inferior point of the tip of the tongue through the pharyngeal wall that is parallel to the palatal plane and perpendicular to the pterygo-maxillary fissure line.

15. Palatal plane: a line drawn from the anterior nasal spine through the posterior nasal spine which bisects both.

16. Pterygo-maxillary fissure line: a line drawn perpendicular to the palatal plane which bisects the pterygo-maxillary fissure.

17. Posterior aspect of the tongue: point on the lingual reference line where the lingual reference line crosses the posterior portion of the tongue.

18. Velar-pharyngeal closure: the closing of the velum against the pharyngeal wall.

19. Sella-nasion line: a line drawn from the center of sella turcica to the juncture of the nasal bone and the frontal bone.

20. Sella-pogonian line: a line drawn from the center of sella turcica to the anterior most point on the skeletal chin.

21. Nasion-pogonian line: a line drawn from the juncture of the nasal bone and the frontal bone to the anterior most point on the skeletal chin.

22. Cephalometric roentgenogram: x-ray photograph of the head from which exact measurements of the structures of the head can be made.

23. Sweep check: an audiometric method of screening out possible hearing-loss cases by testing for auditory response to the following frequencies presented at a constant intensity level of fifteen decibels of sound: 500 cps, 1000 cps, 2000 cps, 3000 cps, 4000 cps, 6000 cps, and 8000 cps.[19]

VI. ORGANIZATION OF THESIS

Chapter I has contained a discussion of the problem under study, the purpose of the study, the null hypotheses that will be tested, the importance of the study, the definition of terms, and the organization of the thesis.

Chapter II will contain a survey of the literature on the use of roentgenography in the study of consonant sound production and defective /s/ sound production and occlusion.

Chapter III will describe the subjects, equipment, and testing procedures used in this study.

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[19] K. S. Wood, "Terminology and Nomenclature," Handbook of Speech Pathology, ed. L. Travis (New York: Appleton-Century-Crofts, Inc., 1957), p. 54.

Chapter IV will discuss the analysis and results of the study.

Chapter V will contain the summary of the study and the conclusions.

CHAPTER II

SURVEY OF THE LITERATURE

Speech scientists have been concerned for many years with the production of speech sounds. In 1922, Barclay and Nelson[1] made an x-ray analysis of the sounds of speech. This was a radiographic study of two different speakers saying eighteen different sounds. For a clearer picture of tongue position, a paste of bismuth carbonate and vaseline was applied to the mid-line of the tongue and frenum. The two sets of radiographs were compared for each sound, and there was practically no difference in the positions of the oral structures. The study gave a description of how an [s] sound was produced. No information was given concerning the occlusion of the subjects. The study was limited in the number of subjects photographed, and specific measurements were taken from the x-rays. In 1934, Russell[2] examined the production of speech sounds with an x-ray study of selected consonant sounds. He determined that

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[1] A. Barclay and W. Nelson, "X-Ray Analyses of the Sounds of Speech," Journal of Radiography, III (July, 1922), pp. 277-280.

[2] G. Russell, "First Preliminary X-Ray Consonant Study," Journal of the Acoustical Society of America, V (April, 1934), pp. 247-251.

the position of the tongue for the /z/ sound changed depending upon the changing of the sounds on either side of it. A significant finding was that the diameter of the aperture between the tongue and the alveolar ridge remained fairly constant. However, no specific measurements of the diameter or of the oral structures were made. This study was done with x-ray motion pictures, but there was no information concerning the selection of subjects, the speech of the subjects, or the occlusion of the subjects. X-ray was employed by Holbrook[3] in a study of speech articulations in the early 1930's. Unfortunately, he died before a thorough analysis of the study was made. Carmody completed the analyses. This study investigated the differences in the articulations of vowels and some consonants of English, French, Spanish, and Russian. Holbrook primarily studied the movement of the hyoid bone, the length of the vocal cords, and the pharynx, but measurements in millimeters were taken of the distance between the jaws, the lips, the projection of the lower lip, the diameter of the pharynx (top, mid., base), the distance from the molars to the cords, and the distance from the vertebra to the base of the pharynx. These measurements were taken for each sound studied. The study was made with ten speakers and did not include defective

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[3]R. Holbrook and F. Carmody, "X-Ray Studies of Speech Articulations," Modern Philology, XX (December, 1937), pp. 187-238.

production. No mention was made of the occlusion of the subjects, and no definite conclusions were drawn concerning the [s] sound.

During the 1930's, speech scientists and dentists became interested in the relationship of dentition and speech. Several studies were published on this problem. From the Spring of 1935 to June of 1937, Frowine and Moser[4] studied seven cases with severe malocclusions to determine the influence of dentition on speech. They studied the following areas: (1) dental case histories, (2) dental casts, (3) intra-oral photographs, (4) facial photographs, (5) speech case histories, (6) phonographic recordings of speech, (7) speech analyses. Of the cases studied, there was only one who had unsatisfactory speech. The other cases had excellent or satisfactory speech. Each tended to compensate for his dentofacial anomaly. No specific conclusions were drawn. A definite outcome of the study was that the psychological factor was prominent in each case. The investigators recommended that a separate study be made of the psychological factor.

Fymbo[5] made a contribution to the knowledge of

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[4] V. Frowine and H. Moser, "Relationship of Dentition and Speech," Journal of the American Dental Association, XXXI (July, 1944), pp. 1081-1090.

[5] L. H. Fymbo, "The Relation of Malocclusion of the Teeth to Defects of Speech," Archives of Speech, I (June, 1936), pp. 204-216.

the relationship of malocclusion to defects of speech in his study of 410 male and female university students in 1936. Evaluations of the subjects' speech were made by the members of the Department of Speech, State University of Iowa. Each subject's speech was classified as superior, average, or defective. The following results were determined by Fymbo: (1) 70% of the cases with normal occlusion had satisfactory speech. Going from defective to superior speakers, there was a decrease of dental anomalies and facial deformities. Of the defective speakers, 87.3% had malocclusions, 62% of the average speakers had malocclusions, and 35% of the superior speakers had malocclusions, (2) females were more able to produce good speech in the face of handicaps than were males, (3) intelligence became higher going from defective speakers to superior speakers, (4) malocclusion cases had more difficulty with [s], [z], [θ], [ð], [ʃ], [ʒ], [tʃ], [dʒ], (5) with normal vertical relationships, 58% had satisfactory speech, with closed-bite only 29% had satisfactory speech, and with open-bite 21% had satisfactory speech, (6) of the total number of anterior teeth missing from the subjects' mouths, 52% were missing from defective speakers, 38% were missing from average speakers, and 10% were missing from superior speakers. The absence of posterior is not as important as absence of any of the upper eight anterior teeth, (7) defective speakers had more spaces between their teeth, (8) unusually high or low palates operated to produce faulty sounds, particularly the [s] and [z], (9) there was a progressive increase in the size of the palate in the cuspid region going from defective to superior male and female speakers.

Fymbo concluded that there was a definite relationship between malocclusion and speech defects. In the same year, Van Thal[6] reported a high percentage of lispers among orthodontic patients of the Royal Dental Hospital in London; although she modified this with the statement that many of them exhibited faulty tongue control. Wolf[7] tended to support this statement in his study of malocclusion and its relation to sigmatism. He stated that there were two forms of sigmatism: (1) position of the tongue normal, and (2) position of the tongue faulty. When the position of the tongue was normal, the sigmatism was due to mechanical defects of the organs of speech such as missing teeth, open-bite or cleft palate. When the tongue position was faulty, the sigmatism was due to motor ineptness, congenital word deafness, impaired hearing, mental retardation, or some defect of the organs of speech. Although he gave no means of selection of the

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[6] J. Van Thal, "The Relationship between Faults of Dentition and Defects of Speech," Proceedings of the Second International Congress of Phonetic Sciences, London, 1936, pp. 254-255.

[7] I. J. Wolf, "Relation of Malocclusion to Sigmatism," American Journal of Diseases of Children, LIV (September, 1937), pp. 520-528.

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subjects, no methods of execution of the study, no norms established for comparison, and no specific measurements, he did state that 74% of the lispers had malocclusions. Of the 74%, only 28% had a definite relationship between the /s/ sound and the malocclusion. He concluded:

> Although it is reasonable to assume that malocclusion may interfere with the normal action of the tongue so that sigmatism results, such correlation is often difficult to establish. In this group, therefore, that relationship between malocclusion and sigmatism is obscure and controversial.

Green[8] was more positive in the conclusions of a study he did in 1937 on speech defects and oral anomalies. Although he observed that compensatory movements can be made for the production of most sounds, he concluded:

> . . . when teeth are out of alinement, they generally impede the motion and formations of the tongue, especially when there is a high palate. The sounds of the second and third articulation sphere are more or less strongly impeded, the /s/ sound more so than the other sounds.

The influence of the palate on lisping was the object of a statistical investigation done by Herman[9] in 1943. Palatopography was employed in this study. The study resulted in the following conclusion:

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[8] J. S. Green, "Speech Defects and Related Oral Anomalies," <u>Journal of the American Dental Association and the Dental Cosmos</u>, XXIV (December, 1937), p. 1972.

[9] G. Herman, "A Study of Palate Shape and Its Characteristics in Lispers," (unpublished Master's thesis, University of Michigan, May, 1943), p. 55.

> In general, no difference has been established between the palates of lispers and the palates of the general population (as represented by the control group). In almost every aspect of palate shape considered, it was possible to demonstrate that no significant difference existed between the two groups. This does not indicate that palate shape never operates as an influence in the etiology of lisping; but it suggests that, in general, palate shape is not a factor which may be considered as responsible for the development of the lisp. It certainly never operates as an independent cause of lisping and probably not as a prime factor in a complex of causes.

Palmer[10] studied the influence of dental anomalies on speech in 1948. He stated, "While speech is primarily a function of the central nervous system, abnormalities in the peripheral speech organs, of course, militate against the development of normal language." He outlined normal [s] sound production and followed his outline with a discussion of the influence of malocclusions on normal [s] sound production. He found that the movement of the mandible forward or backward from its normal position made it difficult to hit the lower teeth with a blast of air. This impeded the ability of the tongue to make proper contact with the alveolus. A medial open-bite contributed to tongue protrusion. Cross-bites or lateral open-bites contributed to lateral [s] sounds. He reasoned that the process of learning a good [s] sound was a chance system greatly aided by normal occlusion. "The point is that malocclusions prevent normal

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[10] J. F. Palmer, "Orthodontics and the Disorders of Speech," American Journal of Orthodontics, XXXIV (July, 1948), p. 579.

movements from developing by the usual chance system."

The factor of chance was not considered by Gardner[11] in his study of dental, oral, and general causes of articulatory defects in 1949.

> Articulatory defects are those caused by dental defects and cleft palate. Articulation includes the movements during speech of the organs that modify the stream of breath into meaningful sounds largely through movements of the mandible, lips, tongue and the soft palate.

He suggested five oral anomalies that caused defective [s] sound production. They were (1) retrusive mandible, (2) prognathous mandible, (3) open-bite, (4) cleft palate, and (5) high palatal arch. Concerning the fifth cause he concluded:

> Directly it interferes with the formation of a lingual groove along the median raphe of the tongue in the production of [s] and [z] sounds. In order to follow the anatomy of the hard palate of the mouth, the dorsum of the tongue has to be so sharply arched that the groove is impossible.

A cephalometric study was conducted at Lynn, Massachusetts, by Murray Bernstein[12] in 1954. This study involved 437 children with defective speech and 446 children with normal speech. The children with defective

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[11] A. F. Gardner, "Dental, Oral, and General Causes of Speech Pathology," Oral Surgery, Oral Medicine, and Oral Pathology, II (June, 1949), p. 745.

[12] M. Bernstein, "Relation of Speech Defects and Malocclusion," American Journal of Orthodontia, XL (February, 1954), pp. 149-150.

speech were divided into two groups, those having normal occlusion and defective speech and those having malocclusions and defective speech. The latter group was investigated by lateral head x-rays with the Margolis Cephalostat and speech recordings. The following conclusions were drawn:

1. Children with speech defects did not have greater amounts of malocclusion than children with normal speech.
2. Speech defects were not related to malocclusion generally except in the case of open-bite.
3. The open-bite was strongly related to lisping.
4. In the case of open-bite, the severity of the lisp did not vary with the amount the bite was open or the amount of overjet or over-bite.

In a study of ten cases with marked speech problems and malocclusions, Rathbone and Snidecor[13] found that many defective dental sounds were corrected by orthodontia. Only [s], [z], [θ], [ʃ], and [ʒ] were not corrected, but they improved. They stated that the following dental anomalies were associated with defects of the following sounds: (1) spaces--all dental sounds except [n] and [y]; (2) high palate-- [s], [z], [θ],

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[13]J. S. Rathbone and J. C. Snidecor, "Appraisal of Speech in Dental Anomalies with Reference to Speech Improvement," The Angle Orthodontist, XXIX (January, 1959), pp. 54-58.

[r], [l]; (3) width of arch-- [s], [z], and [θ]; (4) open-bite-- [s], [ʃ], [ʒ], [θ], [tʃ], and [dʒ]; (5) degree of protrusion-- [s], [z], [ʃ], [ʒ]; (6) thickness of the alveolar ridge-- [s], [z], [ʃ]; (7) severity of rotated teeth--all dental sounds but [n] and [y]. They concluded that, "Improvement of speech can be predicted with improved structural factors, and any residual errors can be reduced or eliminated by the process of learning."[14]

Bloomer[15] found a limited and qualified relationship between the form of oral structures and speech defects in his investigations. He suggested that a functional relationship might exist between speech articulation and malocclusion in a particular individual. He listed the following malocclusions that might contribute to defective speech: (1) extreme distocclusion, (2) extreme mesiocclusion, (3) open-bite, (4) lingually malposed teeth (especially in the maxillary anterior teeth), (5) maxillary teeth in labioversion (especially when associated with distocclusion), (6) asymmetry of the dental arches (especially of the maxillary teeth), (7) absence of teeth, (8) extreme contraction of the maxillary arch. In connection with palate height he stated:

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[14] Ibid., p. 59.

[15] H. Bloomer, "Speech as Related to Dentistry," Journal of The Michigan State Dental Association, XL (November, 1958), p. 264.

> Palate height probably has little effect on consonant articulation. Its significance lies in the fact that it usually accompanies a narrow maxillary arch and palate height is usually associated with nasal constriction. A high maxillary vault should not interfere with speech.

He concluded that malocclusions often contributed to but were not the primary cause of speech defects.

A roentgenologic investigation was conducted with 246 patients, 143 male and 103 female, at the Orthodontic Department of the Royal Dental College, Copenhagen, Denmark, by Benediktsson[16] in 1958. The study examined the relations of the tongue and jaws during [s] sound production in cases with normal and abnormal incisal occlusion. The subjects were placed into nine groups according to combinations of overjet and overbite. The group with normal incisal occlusion was used as the control group. The roentgenograms were identical profile exposures; they were taken of the jaws in occlusion, in rest position, and in [s] sound position. Tantalum powder was used to bring out the position of the tongue in occlusion and in [s] sound production. For this study, a normal [s] sound was either a tongue tip [s] sound or a tongue blade [s] sound, the tongue blade [s] sound being more frequent in the Danish language. There was no acoustical evaluation of the [s] sounds produced by

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[16] E. Benediktsson, "Variation in Tongue and Jaw Position in a Sound Production in Relation to Front Teeth Occlusion," Acta Odontologica Scandinavica, XV (January, 1958), pp. 275-297.

the subjects. The subjects were grouped in the following classes: (1) normal overjet and normal overbite, (2) mandibular overjet and deep bite, (3) normal overjet and deep bite, (4) maxillary overjet and deep bite, (5) mandibular overjet and normal overbite, (6) maxillary overjet and normal overbite, (7) mandibular overjet and open-bite, (8) normal overjet and open-bite, (9) maxillary overjet and open-bite. Measurements in millimeters were taken of the changes in jaw position in occlusion, in rest position and in /s/ sound position. No exact measurements were taken of the tongue in any position; however, descriptions were given of the tongue posture of each of the positions. The investigator gave the following results of her study:

> The investigation demonstrates a certain relationship between malocclusions and jaw and tongue positions. Abnormal overjet or overbite of the incisors or combinations of both cause deviation from the normal function both as regards the position of the tongue and that of the jaw. The degree of this deviation and its direction depend upon the type of malocclusion.
>
> Whether normal /s/ sound production is achieved by means of these compensatory movements of tongue and jaw cannot be concluded from this investigation as there has been no acoustical registration. The distinct tendency to variation of the compensatory movements according to the incisal occlusion, however, might indicate that these movements are necessary for normal speech. It is concievable that certain speech anomalies are caused by failure of functional adaptation due to lack of ability of adaptation or to too extreme deviation from normal incisal occlusion.

The investigator found a marked influence of incisal occlusion on the movements and the position of the tongue and the lower jaw in /s/ sound production. In cases of malocclusion a compensatory tendency was found. The main features of the compensatory movements were summarized as follows:

> Jaw position: In cases with extreme maxillary overjet and normal or extreme overbite the general tendency is towards a more pronounced frontal translation of the lower jaw than in the normal group, whereas in cases with mandibular overjet the translation of the lower jaw is less pronounced, in some cases even dorsal. In cases with open bite, however, the translation of the lower jaw during /s/ sound production is generally very slight within all groups. Regardless of the degree of overjet the lowering of the mandible is pronounced in cases with extreme overbite, whereas in cases with openbite the lowering of the mandible is slighter than in the normal group apart from cases which also have extreme maxillary overjet. In such cases the lowering of the mandible is the same as in the normal group.
>
> Tongue position: Various movements of the tongue from rest position to /s/ sound position were demonstrated, indicating various means of achieving normal tongue position during /s/ sound production. This appears especially obvious in the cases in which the translation of the lower jaw does not fully compensate for the extreme overjet as in group 9. In these cases a very marked protrusion of the tongue is found. On the other hand, in cases with mandibular overjet usually no protrusion of the tongue is found. Such compensatory variations of the tongue movements frequently result in a normal tongue position in relation to the front teeth.[17]

The most recently published cephalometric study was conducted in the Department of Orthodontia, Eastman Dental Hospital, University of London, by Peter Blyth[18]

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[17] *Ibid.*, pp. 298-299.

[18] Peter Blyth, "The Relationship between Speech, Tongue Behaviour, and Occlusal Abnormalities," *Dental Practitioner and Dental Record*, X (September, 1959), pp. 11-22. (Institute of Dental Surgery, University of London, Eastman Dental Hospital).

in 1959. Two hundred children attending the orthodontia clinic were examined for the relationship between speech, tongue behavior and occlusal abnormalities. Conversion tracings were prepared from lateral head plates, and cephalometric measurements were made. The speech was evaluated by a speech therapist; 52 of the children were found to have interdental sigmatism and 10 were found to have lateral sigmatism. In essence, the conclusions were as follows:

1. Skeletal base discrepency in an antero-posterior direction does not produce an actual increase in sigmatisms and compensations take place both by the tongue and mandibular movements.
2. The cause and effect relationship between a high maxillary-mandibular plane angle and an interdental sigmatism cannot be assessed. There is an association between high angles and Class II, division 1 malocclusion. There is an association between high angles and low tongue position. There is also an association between Class II, division 1 malocclusion and interdental sigmatism.
3. The importance of the tongue in relation to the occlusal plane cannot be resolved.
4. Some form of tongue thrusting behavior accompanies most of the interdental sigmatism. Where there is a substitution of [e] for [s], there is less likely to be atypical swallowing.

5. Tongue behavior improves when finger or thumb sucking is brought under control.
6. Persistence of thumb-finger sucking habit may serve to perpetuate the other disorders.
7. The cause of interdental sigmatism not accompanied by secondary sucking mechanisms is not definite. Deafness and intelligence are also important as well as other etiological factors.
8. Lateral sigmatism may or may not be associated with tooth apart swallowing. When lateral sigmatism is associated with Class II, division I malocclusion, the cause of the incisor relationship must be ascribed to some other factor than forward tongue thrusting, unless the two co-exist.
9. Lateral sigmatism is often associated with Class II, division II malocclusion.
10. Cases should be subject to a period of observation before beginning orthodontic treatment.

Many and varied investigations concerning the [s] sound have been conducted. Each has contributed some new information, and each has brought forth new questions about [s] sound production. The relationship of malocclusion, tongue posture, palate height, and jaw position to defective [s] sound production are just a few problems which call for further study. Specific differences between normal and defective [s] sound production have yet to be determined.

yet to be determined.

CHAPTER III

SUBJECTS, EQUIPMENT, AND PROCEDURES

I. SUBJECTS

Number and source of subject population. Sixty subjects participated in this study. Twenty of them were students at the Eastman Dental Dispensary, Rochester, New York. Forty were public high school students from Benjamin Franklin High School, Edison Technical and Industrial High School, and East High School, Rochester, New York. Participation in the study was voluntary. The parents of each participating high school student were contacted by letter (see Appendix, page 78.) The letter briefly explained the study and contained a form which the parents were asked to sign if they approved of having their child participate in the study. The signed form was then returned to the investigator. No student under eighteen years of age participated in this study without the written permission of his parent or parents. The high school students were from grades nine through twelve, with ages ranging from thirteen years to nineteen years. The Dental Dispensary students were dental hygienists and interning dentists whose ages ranged from eighteen years to twenty-five years.

Selection of Subjects. Thirty-seven male and twenty-three female subjects participated in the study. The primary criterion employed in the selection of all subjects was the acceptability or unacceptability of the production of the /s/ sound. The group of thirty with unacceptable /s/ sound production were high school students selected from the speech therapy classes of the investigator. Each of these subjects was judged to have a moderately severe or severe distortion or substitution of the /s/ and /z/ sounds. A second criterion was employed in the selection of the group of thirty with acceptable /s/ sound production. Each subject in this group was required to have acceptable /s/ sound production and normal occlusion. The judgements on occlusion were made by a qualified orthodontist. The judgements of the acceptability or unacceptability of the /s/ sound production of each subject were made by a panel of three experienced, practicing speech therapists. All of the subjects were tested with articulation-testing sentences and words from Voice and Articulation Drillbook (see Appendix, page 77 .)[1]

II. EQUIPMENT

The equipment employed in this study was:

1. A Sonotone audiometer. (Model 91)

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[1]Fairbanks, op. cit., pp. xii-xx.

2. A Margolis cephalostat.

3. A Broadbent Bolton cephalostat.

III. PROCEDURES

Hearing examinations. In order to determine whether any subject with defective [s] sound production had a hearing loss, each subject with defective [s] sound production was given an individual audiometric examination by the investigator. These examinations were administered in the speech therapy rooms in Benjamin Franklin High School and Edison Technical and Industrial High School. The speech therapy rooms were not sound treated. A puretone audiometer, (Sonotone, model 91), was employed in the administration of the hearing examinations. Each subject with defective [s] sound production was given a sweep check at fifteen decibels in each ear at the following frequencies: 500 cps, 1000 cps, 2000 cps, 3000 cps, 4000 cps, 6000 cps, and 8000 cps. Two of the subjects had losses at 4000 cps in the left ear only. One of those two subjects had a loss of forty decibels at 4000 cps in the left ear, and the other subject had a loss of thirty decibels at 4000 cps in the left ear.

Evaluation of occlusion. An evaluation of the occlusion of each subject was made by an orthodontist. This evaluation was made in the Department of Orthodontia, Eastman Dental Dispensary. The orthodontist completed an examination sheet on each subject (see Appendix, page 79).

The occlusion was evaluated to determine the Angle classification, open-bite, closed-bite, overjet, spacing, crowding, teeth in linguaversion, rotations, missing teeth, palate contour, ability to elevate and groove the tongue, the appearance and function of the lips during swallowing, and the pattern of swallowing. These evaluations were later analyzed and compared.

Cephalometric roentgenography. The cephalometric roentgenograms were made at the Eastman Dental Dispensary, Rochester, New York, Department of Orthodontia, under the direction of Dr. J. Daniel Subtelny. An orthodontist and an x-ray technician were responsible for taking and developing the roentgenograms. A set of three cephalometric roentgenograms per subject was taken. The investigator was present each time to evaluate [s] sound production when the roentgenogram was taken. The first forty-three sets of cephalometric roentgenograms were made with a Margolis cephalostat, and the last seventeen sets were made with a Broadbent Bolton cephalostat. The reason two different cephalostats were employed was due to the fact that a new Broadbent Bolton cephalostat was purchased by the Dental Dispensary as a replacement for the Margolis unit during the investigation. The x-ray head of both cephalostats was positioned four feet, ten inches from the mid-line of the skull of the subject being x-rayed. Only lateral cephalometric roentgenograms were taken. The amount of enlargement and distortion was the same for all of the roentgenograms. Each subject was seated in the stationary chair which was adjustable in height. The chair was then raised so that the subject's head was directly anterior to the cassette holder. The head was stabilized and positioned by ear rods and a nose piece. The ear rods and nose piece were graduated and adjustable. Because of this the head of each subject was positioned identically anterior to the cassette. Immediately prior to taking the first roentgenogram, the orthodontist painted the mid-line and tip of the subject's tongue with tantalum powder paste. This paste was composed of tantalum powder, gum Arabic, and water. Tantalum was used as a radio-opaque media to assure a clear outline of the tongue posture during the production of the [s] sound in the roentgenogram. The first roentgenogram was taken as the subject produced a sustained [s] sound. The roentgenogram was actually taken one to two seconds after the subject initiated the [s] sound. This was done to allow the investigator time to make a judgment as to whether the [s] sound was either acceptable or unacceptable at the moment the roentgenogram was taken. The second roentgenogram was taken of the subject's mandible at rest. This was the position assumed by the mandible when it was relaxed. The third roentgenogram was taken of the subject's teeth occluded. All three roentgenograms were lateral head-plates and limited to two planes. Tracings of the roentgenograms showing oral structures during sustained [s] sound production were made by a qualified orthodontist. Structures traced were as follows:

1. nose
2. lips
3. chin
4. nasal bone
5. nasion
6. anterior portion of the maxilla
7. maxillary central incisor
8. anterior portion of the mandible
9. mandibular central incisor
10. alveolar ridge
11. anterior and posterior nasal spines
12. hard palate
13. soft palate
14. velar-pharyngeal closure
15. maxillary permanent first molar
16. mandibular permanent first molar
17. tongue posture at midline aspect of the tongue
18. hyoid bone
19. epiglottis
20. pterygo-maxillary fissure
21. sella turcica
22. pharyngeal wall

Cephalometric measurements of these structures were made from the tracings. The following measurements were made for this study:

1. the distance between the incisal edge of the maxillary central incisor and the anterior incisal edge of the mandibular central incisor during the production of the [s] sound.
2. the distance between the maxillary permanent first molar and the mandibular permanent first molar during the production of the [s] sound.
3. the distance between the anterior, inferior portion of the tip of the tongue and the anterior mandibular incisal edge during the production of the [s] sound.
4. the distance between the lingual reference line and the anterior mandibular incisal edge during the production of the [s] sound.
5. the distance between the anterior, inferior portion of the tip of the tongue and the palatal plane during the production of the [s] sound.
6. the distance between the highest point of the tongue and the palatal plane during the production of the [s] sound.
7. the distance between the highest point of the tongue and the pterygo-maxillary fissure line during the production of the [s] sound.
8. the distance between the posterior aspect of the tongue and the pharyngeal wall during the production of the [s] sound.
9. the velar-pharyngeal closure during the production of the [s] sound.

10. the size of the angle formed at sella turcica by the sella-nasion line and the sella-pogonian line during the production of the [s] sound.

11. the size of the angle formed at nasion by the sella-nasion line and the nasion-pogonian line during the production of the [s] sound.

The portion of the study which was conducted at Eastman Dental Dispensary was supported in part by a United States Public Health Service Grant (#D-1071).

CHAPTER IV

ANALYSIS AND DISCUSSION

An analysis was made of the data obtained from the tracings of the cephalometric roentgenograms taken during the production of the [s] sound. See Figure 1 for drawing of a tracing of a cephalometric roentgenogram taken during the production of an acceptable [s] sound. See Figure 2 for drawing of a tracing of a cephalometric roentgenogram taken during the production of an unacceptable [s] sound. On each tracing base lines were drawn on the structures of the head. By using the same points on the skeletal structure of each subject's tracing, comparable angular and linear measurements could be made with the elimination of the factors of distortion from the x-ray and differences in head size. The first line drawn was the sella-nasion line. Using a transparent plastic ruler, this line was drawn from the center of the sella turcica to the juncture of the nasal bone and the frontal bone. The second line drawn was the nasion-pogonian line. This line was drawn from the juncture of the nasal bone and the frontal bone to the anterior most portion of the skeletal chin. The third line drawn was the sella-pogonian line. This line

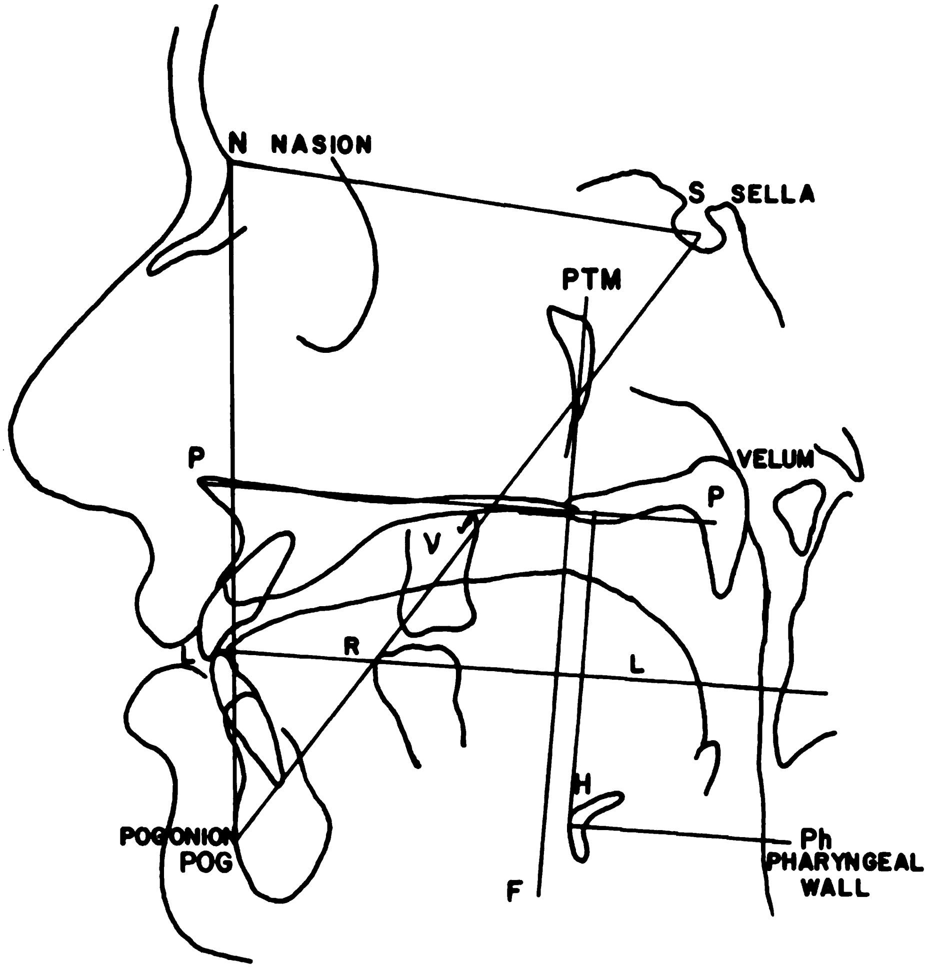

FIGURE I. MASTER TRACING OF ACCEPTABLE [S] SOUND PRODUCTION SHOWING REFERENCE POINT AND LOCATION OF MEASUREMENTS.

S–N SELLA-NASION LINE
S-POG SELLA-POGONION LINE
N–POG NASION-POGONION LINE
P-P PALATAL PLANE
Pt-M-F PTERYGO-MAXILLARY FISSURE LINE
L-R-L LINGUAL REFERENCE LINE
Ph–H PHARYNGEAL-HYOID LINE
P-P-H PALATAL PLANE-HYOID LINE

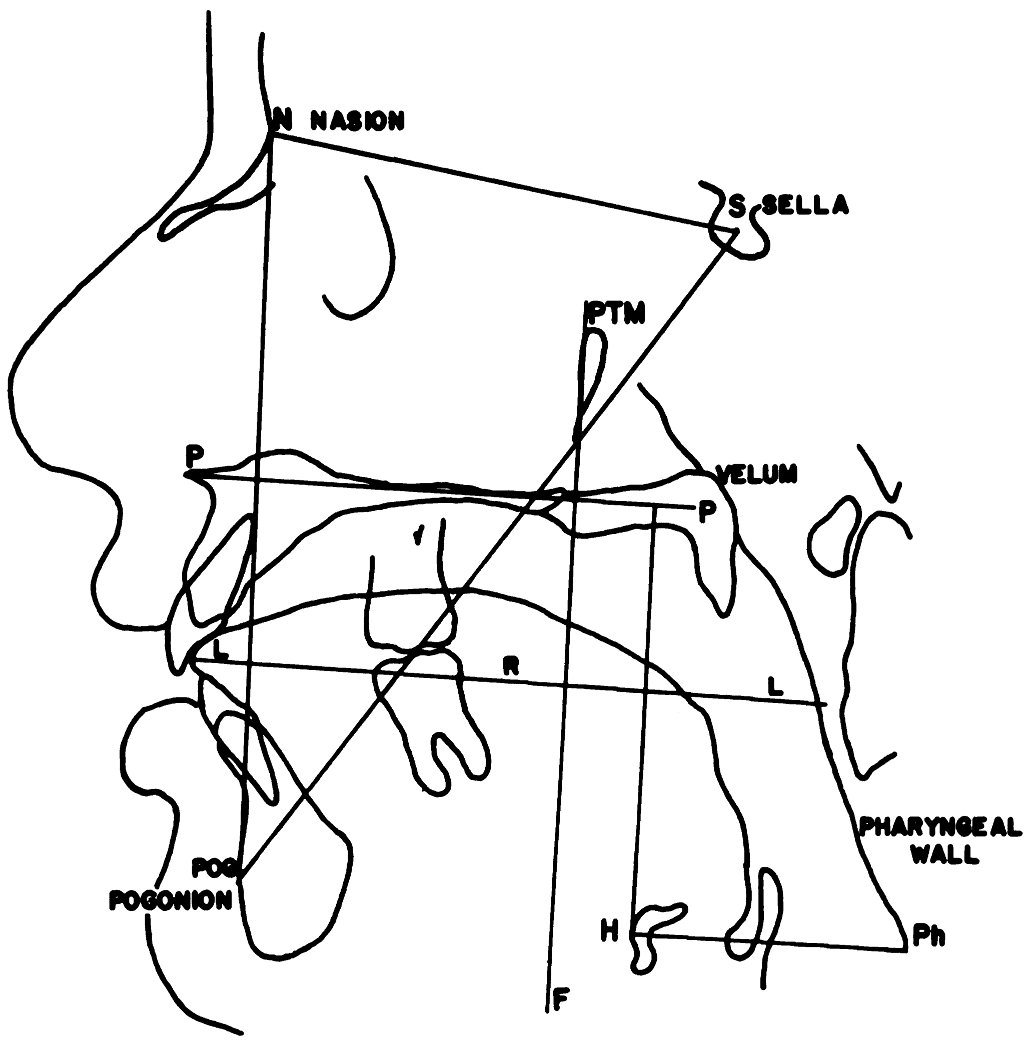

FIGURE 2. MASTER TRACING OF UNACCEPTABLE [S] SOUND PRODUCTION SHOWING REFERENCE POINTS AND LOCATION OF MEASUREMENTS.

S-N SELLA-NASION LINE
S-POG SELLA-POGONION LINE
N-POG NASION-POGONION LINE
P-P PALATAL PLANE
Pt-M-F PTERYGO-MAXILLARY FISSURE LINE
L-R-L LINGUAL REFERENCE LINE
H-Ph HYOID PHARYNGEAL WALL LINE
P-P-H PALATAL PLANE-HYOID LINE

was drawn from the same center point of the sella turcica to a point on the nasion-pogonian line where that line contacted the anterior most portion of the skeletal chin. The sella-pogonian line also bisected that anterior most portion of the skeletal chin. The next line drawn was the palatal plane. This line was drawn from the anterior nasal spine through the posterior nasal spine and bisected both spines. All of the above lines were drawn with a transparent plastic ruler whereas all other lines were drawn with a transparent plastic protractor. The pterygo-maxillary line was drawn perpendicular to the palatal plane and bisected the pterygo-maxillary fissure. The lingual reference line was drawn from the anterior, inferior portion of the tip of the tongue through the pharyngeal wall. This line was parallel to the palatal plane and perpendicular to the pterygo-maxillary fissure line. A line was drawn from the anterior, superior most point of the hyoid to the palatal plane. This line was parallel to the pterygo-maxillary fissure line and perpendicular to the palatal plane. A line was drawn from that same anterior, superior point of the hyoid through the pharyngeal wall. This line was parallel to the lingual reference line and perpendicular to the hyoid-palatal plane line. Upon completion of the base lines, the cephalometric measurements were made and recorded. With the completion of all of the cephalometric measurements, _t_ tests were employed to determine the significance of the differences in the variances between the two small sample groups.[1] The following symbolization was used in the employment of the t test:

X_1 -- each score of the population with acceptable /s/ sound production

X_2 -- each score of the population with unacceptable /s/ sound production

$\bar{X}_1$ -- the mean of the scores of the population with acceptable /s/ sound production

$\bar{X}_2$ -- the mean of the scores of the population with unacceptable /s/ sound production

N -- the number in each sample

s^2 -- the variances estimated from sample data

Σ -- the sign for the process of adding.

The mean for each particular measurement for each group was calculated by the following formula:

$$\bar{X} = \frac{\Sigma X}{N}$$

The variance for each particular measurement was calculated by the following formula:

$$s^2 = \frac{\Sigma X_1^2 + \Sigma X_2^2 - \frac{(\Sigma X_1)^2}{N} + \frac{(\Sigma X_2)^2}{N}}{N_1 + N_2 - 2}$$

To obtain the value of t for each particular measurement, the following formula was used:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{s^2 \left(\frac{1}{N_1} + \frac{1}{N_2}\right)}}$$

[1]Quinn McNemar, Psychological Statistics (New York: John Wiley and Sons, Inc., 1949), p. 224.

By using a .01 and a .05 level of confidence, it was possible to determine which measurements showed a significant difference.

The measurements made and tested for this study were:

1. <u>the distance between the maxillary and mandibular incisal edges during the production of the /s/ sound as evidenced on the tracings of the cephalometric roentgenograms of the subjects who produce the /s/ sound acceptably and the subjects who produce the /s/ sound unacceptably</u>. To determine the distance between the maxillary and mandibular incisal edges during the production of the /s/ sound, one point of the compass was placed on the anterior point of the mandibular incisal edge and the other point of the compass was placed on the anterior point of the maxillary incisal edge. This distance was then transposed from the compass to a metric ruler and the exact measurement of the distance in millimeters was recorded on the data sheet. When the measurements for all subjects were complete, the *t* test was employed. Results of the statistical test are presented in Table 1.

TABLE 1.--The Difference in the Distance between the Maxillary and Mandibular Incisal Edges during the Production of the /s/ Sound by Subjects who Produce the /s/ Sound Acceptably and the Subjects who Produce the /s/ Sound Unacceptably

$\bar{X}_1$	$\bar{X}_2$	t*	degrees of freedom
1.72 mm.	4.77 mm.	6.17	58

*at .01 level of confidence t = 2.75
at .05 level of confidence t = 2.00

There is a significant difference at the .01 level of confidence in the distance between the maxillary and mandibular incisal edges during the production of the /s/ sound by subjects who produce the /s/ sound acceptably and subjects who produce the /s/ sound unacceptably. Subjects who produce the /s/ sound acceptably have a much closer antero-posterior relationship of the incisal edges during the production of the /s/ sound than do subjects who produce the /s/ sound unacceptably. In general, subjects who produced the /s/ sound acceptably had the mandibular incisal edge slightly above and posterior to the maxillary incisal edge. Of this group, three had an edge to edge anterior incisal relationship. The greatest antero-posterior distance between incisal edges was 4.0 mm. while the mean for this group was 1.72 mm. Of the subjects who produced the /s/ sound unacceptably, only one had an edge to edge anterior incisal relationship. In this group the greatest antero-posterior distance between incisal edges during the production of the /s/ sound was 10.5 mm. while the mean for the group was 4.77 mm. Because there is a significant difference in the distance between the maxillary and mandibular incisal edges during the production of the /s/ sound, it can be concluded that the antero-posterior relationship of the maxillary and mandibular incisal edges is a significant factor in the production of an acceptable /s/ sound.

2. <u>the shortest distance between the maxillary permanent first molar and the mandibular permanent first molar during the production of the /s/ sound</u>.

To determine the distance between the maxillary permanent first molar and the mandibular permanent first molar, one point of the compass was placed on the point of the mandibular molar that appeared to be nearest to the maxillary permanent first molar. The other point of the compass was placed on the nearest point of the maxillary permanent first molar. This distance was then transposed from the compass to the metric ruler, and the exact distance in millimeters was recorded on the data sheet. Other distances between the permanent first molars were measured in the same manner to assure that the shortest distance was the one measured and recorded. If the molars were completely occluded, the distance was recorded as zero. When all of the measurements for all subjects were complete, the *t* test was employed. Table 2 presents the statistical results of the *t* test.

TABLE 2.--The Difference in the Shortest Distance between the Maxillary Permanent First Molar and the Mandibular Permanent First Molar during the Production of the [s] Sound by Subjects who Produce the [s] Sound Acceptably and the Subjects who Produce the [s] Sound Unacceptably

$\bar{X}_1$	$\bar{X}_2$	*t**	degrees of freedom
1.03 mm.	1.08 mm.	.1765	58

*at .01 level of confidence t = 2.75
at .05 level of confidence *t* = 2.00

There is no significant difference in the shortest distance between the maxillary permanent first molar and the mandibular permanent first molar during the production of the [s] sound by subjects who produce the [s] sound acceptably and subjects who produce the [s] sound unacceptably. Both groups had practically the same molar relationship during the production of the [s] sound. Of the subjects who produced the [s] sound acceptably, seven had the permanent first molars occluded during the production of the [s] sound. In this group the greatest distance between the permanent first molars was 3.5 mm. while the mean was 1.03 mm. Of the subjects who produced the [s] sound unacceptably, twelve had the molars occluded during the production of the [s] sound. In this group the greatest distance between the permanent first molars was 4.0 mm. while the mean was 1.08 mm. Because there is no significant difference in the distance between mandibular and maxillary permanent first molars during the production of the [s] sound, it can be concluded that this posterior molar relationship is not a significant factor during the production of an acceptable [s] sound.

3. <u>the distance between the anterior, inferior point of the tip of the tongue and the anterior mandibular incisal edge during the production of the [s] sound</u>. To determine the distance between the anterior, inferior point of the tip of the tongue and the anterior mandibular incisal edge, one point of the compass was placed on the anterior mandibular incisal edge. The other point of the compass was placed on the point of the tip of the tongue where the lingual reference line crossed the tip of the tongue. This distance was then transposed from the compass to the metric ruler, and the exact distance in millimeters was recorded on the data sheet. If the anterior,

inferior point of the tip of the tongue was anterior to the anterior mandibular incisal edge, the distance was recorded as plus millimeters. If the anterior, inferior point of the tip of the tongue was neither anterior nor posterior to the anterior mandibular incisal edge but exactly perpendicular to the anterior mandibular incisal edge, the distance was recorded as zero millimeters. If the anterior, inferior point of the tip of the tongue was posterior to the anterior mandibular incisal edge, the distance was recorded as minus millimeters. When all of the measurements were complete, the scores were transposed to eliminate the pluses and minuses. The raw and transposed scores can be found in the Appendix, page 84 . The *t* test was employed with the transposed scores. Table 3 presents the results of the statistical test.

TABLE 3.--The Difference in the Distance between the Anterior, Inferior Point of the Tip of the Tongue and the Anterior Mandibular Incisal Edge during the Production of the /s/ Sound by Subjects who Produce the /s/ Sound Acceptably and Subjects who Produce the /s/ Sound Unacceptably

$\bar{X}_1$	$\bar{X}_2$	*t**	degrees of freedom
5.47	9.28	4.28	58

*at .01 level of confidence $t = 2.75$
at .05 level of confidence $t = 2.00$

There is a significant difference at the .01 level of confidence in the distance between the anterior, inferior point of the tip of the tongue and the anterior mandibular incisal edge during the production of the [s] sound by subjects who produce the [s] sound acceptably and subjects who produce the [s] sound unacceptably. All the subjects who produced the [s] sound acceptably had the tip of the tongue posterior to the anterior mandibular incisal edge. The distances ranged from 2.0 mm. to 9.0 mm. posterior to the anterior mandibular incisal edge while the mean distance for the group was 4.5 mm. posterior to the anterior mandibular incisal edge. Of the subjects who produced the [s] sound unacceptably, the tip of the tongue was placed anywhere from 7.0 mm. anterior to the anterior mandibular incisal edge to 8.5 mm. posterior to the anterior mandibular incisal edge. The mean for this group was .7 mm. posterior to the anterior mandibular incisal edge. It is interesting to note that the subjects who produced the [s] sound unacceptably had an antero-posterior tongue tip position that was considerably farther forward than that of the subjects who produced the [s] sound acceptably. Because there is a significant difference in the distance between the anterior, inferior point of the tip of the tongue and the anterior mandibular incisal edge during the production of the [s] sound by subjects who produce the [s] sound acceptably and subjects who produce the [s] sound unacceptably, it can be concluded that the antero-posterior distance of the tongue tip from the anterior mandibular incisal edge is a significant factor during the production of the [s] sound.

4. <u>the distance between the lingual reference line and the anterior mandibular incisal edge during the production of the [s] sound.</u> To determine the distance between the lingual reference line and the anterior mandibular incisal edge, one point of the compass was placed on the anterior point of the mandibular incisal edge. The other point of the compass was placed perpendicular to the anterior mandibular incisal edge on the lingual reference line. This distance was then transposed from the compass to the metric ruler, and the exact distance in millimeters was recorded on the data sheet. If the lingual reference line was below the anterior mandibular incisal edge, the distance was recorded as minus millimeters. If the lingual reference line exactly crossed the anterior mandibular incisal edge, the distance was recorded as zero millimeters because the lingual reference line was neither above nor below the anterior mandibular incisal edge. If the lingual reference line was above the anterior

mandibular incisal edge, the distance was recorded as plus millimeters. When all of the measurements were complete, the scores were transposed to eliminate the pluses and minuses. These scores and transposed figures are found in the Appendix, page 86. A *t* test was employed with the transposed scores. Table 4 gives the results of the statistical test.

TABLE 4.--The Difference in the Distance between the Lingual Reference Line and the Anterior Mandibular Incisal Edge during the Production of the /s/ Sound by Subjects who Produce the /s/ Sound Acceptably and Subjects who Produce the /s/ Sound Unacceptably

$\bar{X}_1$	$\bar{X}_2$	*t**	degrees of freedom
4.73	5.93	2.83	58

*at .01 level of confidence *t* = 2.75
at .05 level of confidence *t* = 2.00

There is a significant difference at the .01 level of confidence in the distance between the lingual reference line and the anterior mandibular incisal edge during the production of the /s/ sound by subjects who produce the /s/ sound acceptably and subjects who produce the /s/ sound unacceptably. Of the subjects who produced the /s/ sound acceptably, the distances of the lingual reference line from the anterior mandibular incisal edge ranged from 1.0 mm.

below the anterior mandibular incisal edge to 2.5 mm. above the anterior mandibular incisal edge. The mean for this group was .73 mm. above the mandibular incisal edge. Of the subjects who produced the [s] sound unacceptably, the distances of the lingual reference line from the anterior mandibular incisal edge ranged from 3.0 mm. below the anterior mandibular incisal edge to 5.0 mm. above the anterior mandibular incisal edge. The mean for this group was 1.93 mm. above the anterior mandibular incisal edge. The subjects who produced the [s] sound unacceptably did not relate the tip of the tongue to the anterior mandibular incisal edge in either the vertical or antero-posterior aspects of tongue tip position. All of the subjects who produced the [s] sound acceptably related the tip of the tongue to the mandibular incisal edge rather than the alveolar ridge. This was true in both the antero-posterior and vertical aspects of tongue tip position. It must be reiterated that the subjects who produced the [s] sound acceptably also had normal occlusion. It is quite possible that the tip of the tongue relates with the mandibular incisal edge during the production of the [s] sound when the subjects producing the [s] sound acceptably have normal occlusion. It may be that the much discussed tongue tip-alveolar ridge relationship during the production of an acceptable [s] sound is an adaptive movement rather than a normal movement depending on normalcy of the occlusion. Since all of the subjects who produced the [s] sound acceptably had the same tongue tip-mandibular incisal edge relationship, this investigation would support the idea that the lower tongue tip position during the production of an acceptable [s] sound is normal for subjects who have normal occlusion. At any rate, because there is a significant difference in the distance between the lingual reference line and the anterior mandibular incisal edge during the production of the [s] sound by subjects who produce the [s] sound acceptably and subjects who produce the [s] sound unacceptably, it can be concluded that the vertical distance of the tongue tip from the mandibular incisal edge is a significant factor during the production of an acceptable [s] sound.

5. <u>the distance between the anterior, inferior point of the tip of the tongue and the palatal plane during the production of the [s] sound</u>. To determine the distance between the anterior, inferior point of the tip of the tongue and the palatal plane during the production of the [s] sound, one point of the compass was placed on the point of the tip of the tongue where the lingual reference line crossed the tip of the tongue. The other point of the compass was placed

perpendicular to the anterior, inferior point of the tip of the tongue on the palatal plane. This distance was then transposed from the compass to the metric ruler, and the exact measurement in millimeters was recorded on the data sheet. When all of the measurements were complete, a t test was employed. Table 5 gives the results of this test.

TABLE 5.--The Difference in the Distance between the Anterior, Inferior Point of the Tip of the Tongue and the Palatal Plane during the Production of the [s] Sound by Subjects who Produce the [s] Sound Acceptably and Subjects who Produce the [s] Sound Unacceptably

$\bar{X}_1$	$\bar{X}_2$	t*	degrees of freedom
30.4 mm.	28.83 mm.	1.38	58

*at .01 level of confidence t = 2.75
at .05 level of confidence t = 2.00

There is no significant difference in the distance between the anterior, inferior point of the tip of the tongue and the palatal plane during the production of the [s] sound by subjects who produce the [s] sound acceptably and subjects who produce the [s] sound unacceptably. Of the subjects who produced the [s] sound acceptably, the distances between the anterior, inferior point of the tip of the tongue and the palatal plane ranged from 23.0 mm.

to 41.5 mm. The mean for this group was 30.48 mm. Of the subjects who produced the /s/ sound unacceptably, the distances between the anterior, inferior point of the tip of the tongue and the palatal plane ranged from 21.0 mm. to 38.0 mm. The mean for this group was 28.83 mm. The relationship of the tongue tip to the palatal plane was approximately the same for both groups. Because there is no significant difference in the distance between the anterior, inferior point of the tip of the tongue and the palatal plane during the production of the /s/ sound by subjects who produce the /s/ sound acceptably and subjects who produce the /s/ sound unacceptably, it can be concluded that the distance of the tongue tip from the palatal plane is not a significant factor in the production of an acceptable /s/ sound.

6. <u>the distance between the highest portion of the tongue and the palatal plane</u>. To determine the distance between the highest portion of the tongue and the palatal plane, it was first necessary to determine which was the highest portion of the tongue. To do this, the transparent ruler was placed on the tracing with the first line superimposed upon the palatal plane. The ruler was then moved along the palatal plane. The distance between the palatal plane and the tongue was continuously noted. When

it was determined what portion of the tongue was closest to the palatal plane, the length of this portion was marked and measured in millimeters. This distance was then bisected on the tracing. One point of the compass was placed on the point of bisection. The other point of the compass was placed on the palatal plane perpendicular to the point of bisection. This distance was then transposed from the compass to a metric ruler, and the exact measurement in millimeters was recorded on the data sheet. When all of the measurements were complete, a $\underline{t}$ test was employed.

TABLE 6.--The Difference in the Distance between the Highest Portion of the Tongue and the Palatal Plane during the Production of the [s] Sound by Subjects who Produce the [s] Sound Acceptably and Subjects who Produce the [s] Sound Unacceptably

$\bar{X}_1$	$\bar{X}_2$	$\underline{t}$*	degrees of freedom
15.16 mm.	12.97 mm.	2.02	58

*at .01 level of confidence t = 2.75
at .05 level of confidence $\underline{t}$ = 2.00

There is no significant difference at the one per cent level of confidence, but there is a significant difference at the five per cent level of confidence in the distance between the highest portion of the tongue and the palatal plane during the production of the [s] sound by subjects who produce the [s] sound acceptably and subjects who produce the [s] sound unacceptably. Of the subjects who produced the [s] sound acceptably, the distances between the highest portion of the tongue and the palatal plane ranged from 26.0 mm. to 10.0 mm. The mean for this group was 15.16 mm. Of the subjects who produced the [s] sound unacceptably, the distances between the highest portion of the tongue and the palatal plane ranged from 19.5 mm. to 6.5 mm. The mean for this group was 12.97 mm. There was a greater distance between the highest portion of the tongue and the palatal plane during the production of the [s] sound by subjects who produced the [s] sound acceptably. This supports the previous finding that generally the tongue posture during the production of the [s] sound is lower in the oral cavity for subjects who produce the [s] sound acceptably. Because there is a significant difference at the five per cent level in the distance between the highest portion of the tongue and the palatal plane during the production of the [s] sound by subjects who produce the [s] sound acceptably and subjects who produce the [s] sound unacceptably, it can be concluded that the distance of the highest portion of the tongue from the palatal plane is a somewhat significant factor in the production of an acceptable [s] sound.

7. <u>the distance between the highest portion of the tongue and the pterygo-maxillary fissure line</u>. To determine the distance between the highest portion of the tongue and the pterygo-maxillary fissure line during the production of the [s] sound, one point of the compass was placed on the bisected point of the highest portion of the tongue which was discussed in the previous measurement. The other point of the compass was placed on the pterygo-maxillary fissure line perpendicular to the point of bisection. This distance was then transposed from the compass to a metric ruler, and the exact distance in millimeters was recorded on the data sheet. When all of the measurements for all subjects had been completed, a <u>t</u> test was employed. Table 7 gives the results of this test. There is no significant difference in the distance between the highest portion of the tongue and the pterygo-maxillary fissure line during the production of the [s] sound by subjects who produce the [s] sound acceptably and subjects who produce the [s] sound unacceptably. Of the subjects who produced the [s] sound acceptably, the distances between the highest portion of the tongue and the pterygo-maxillary fissure line ranged from 40.0 mm. to 0.0 mm. The mean for this group was 8.72 mm. Of the subjects who produced the [s] sound unacceptably, the distances between the highest

portion of the tongue and the pterygo-maxillary fissure line ranged from 52.5 mm. to 1.0 mm. The mean for this group was 13.6 mm. Both groups had a large variation in the distances of the highest portion of the tongue from the pterygo-maxillary fissure line. Because there is no significant difference in the distance between the highest portion of the tongue and the pterygo-maxillary fissure line during the production of the [s] sound by subjects who produce the [s] sound acceptably and subjects who produce the [s] sound unacceptably, it can be concluded that the distance of the highest portion of the tongue from the pterygo-maxillary fissure line is not a significant factor in the production of an acceptable [s] sound.

TABLE 7.--The Difference in the Distance between the Highest Portion of the Tongue and the Pterygo-Maxillary Fissure Line during the Production of the [s] Sound by Subjects who Produce the [s] Sound Acceptably and Subjects who Produce the [s] Sound Unacceptably

$\bar{X}_1$	$\bar{X}_2$	t*	degrees of freedom
8.72 mm.	13.6 mm.	1.79	58

*at .01 level of confidence t = 2.75
at .05 level of confidence t = 2.00

8. <u>the distance between the posterior aspect of the tongue and the pharyngeal wall.</u> To determine the

distance between the posterior aspect of the tongue and the pharyngeal during the production of the [s] sound, one point of the compass was placed on the point of the tongue where the lingual reference line crossed the posterior aspect of the tongue. The other point of the compass was placed on the point of the pharyngeal wall where the lingual reference line crossed the pharyngeal wall. This distance was then transposed from the compass to a metric ruler, and the exact distance in millimeters was recorded on the data sheet. When all of the measurements for all subjects were complete, a t test was employed. Table 8 gives the results of this statistical test.

TABLE 8.--The Difference in the Distance between the Posterior Aspect of the Tongue and the Pharyngeal Wall during the Production of the [s] Sound by Subjects who Produce the [s] Sound Acceptably and Subjects who Produce the [s] Sound Unacceptably

$\bar{X}_1$	$\bar{X}_2$	t*	degrees of freedom
14.27 mm.	20.54 mm.	3.73	58

*at .01 level of confidence t = 2.75
at .05 level of confidence t = 2.00

There is a significant difference at the .01 level of confidence in the distance between the posterior aspect of the tongue and the pharyngeal wall during the production of the [s] sound by subjects who produce the [s] sound acceptably and subjects who produce the [s] sound unacceptably. Of the subjects who produced the [s] sound acceptably, the distances between the posterior aspect of the tongue and the pharyngeal ranged from 28.0 mm. to 5.0 mm. The mean for this group was 14.27 mm. Of the subjects who produced the [s] sound unacceptably, the distances between the posterior aspect of the tongue and the pharyngeal wall ranged from 32.5 mm. to 8.0 mm. The mean for this group was 20.54 mm. The fact that the distance between the posterior aspect of the tongue and the pharyngeal wall is much less for subjects who produce the [s] sound acceptably gives further support to the previous findings of this study regarding the antero-posterior aspects of tongue posture. All subjects who produced the [s] sound acceptably retracted the whole tongue in the oral cavity further than did subjects who produced the [s] sound unacceptably. It would appear that the antero-posterior tongue posture is extremely important in acceptable [s] sound production. Because there is a significant difference in the distance between the posterior aspect of the tongue and the pharyngeal wall during the production of the [s] sound by subjects who produce the [s] sound acceptably and subjects who produce the [s] sound unacceptably, it can be concluded that the relationship and the distance of the posterior aspect of the tongue to the pharyngeal wall is a significant factor in the production of an acceptable [s] sound.

9. <u>the velar-pharyngeal closure</u>. No statistical measurement was made of the velar-pharyngeal closure because the velar-pharyngeal closure was complete for all subjects regardless of the type of [s] sound production. There is no difference in the velar-pharyngeal closure for both groups of subjects. This can be seen very clearly on all of the tracings. Because there is no difference in the velar-pharyngeal closure during the production of the [s] sound by subjects who produce the [s] sound acceptably and subjects who produce the [s] sound unacceptably, it can be concluded that the velar-pharyngeal closure is not a factor in the production of an acceptable [s] sound.

10. <u>the size of the angle formed at sella turcica by the sella-nasion line and the sella-pogonian line</u>. To determine the size of the angle formed at sella turcica by the sella-nasion line and the sella-pogonian line during the production of the [s] sound, a protractor was employed to measure the number of degrees in the angle. After measuring the angle, the exact number of degrees was recorded on the data sheet. When all of the measurements for all subjects were complete, a <u>t</u> test was employed.

Table 9 gives the results of this test.

TABLE 9.--The Difference in the Size of the Angle Formed at Sella Turcica by the Sella-Nasion Line and the Sella-Pogonian Line during the Production of the [s] Sound by Subjects who Produce the [s] sound Acceptably and Subjects who Produce the [s] Sound Unacceptably

$\bar{X}_1$	$\bar{X}_2$	t*	degrees of freedom
64.51°	65.57°	1.12	58

*at .01 level of confidence t = 2.75
at .05 level of confidence t = 2.00

There is no significant difference in the size of the angle formed at sella turcica by the sella-nasion line and the sella-pogonian line during the production of the [s] sound by subjects who produce the [s] sound acceptably and subjects who produce the [s] sound unacceptably. Of the subjects who produced the [s] sound acceptably, the size of the angle formed at sella turcica varied from 57.0 degrees to 69.5 degrees. The mean for this group was 64.51 degrees. Of the subjects who produced the [s] sound unacceptably, the size of the angle formed at sella turcica varied from 57.5 degrees to 74.0 degrees. The mean for this group was 65.57 degrees. The fact that there is no significant difference in the size of the angle formed at sella turcica during the production of the /s/ sound by both groups indicates that the downward movement of the mandible during the production of the /s/ sound is approximately the same for both groups. Because there is no significant difference in the size of the angle formed at sella turcica during the production of the /s/ sound by subjects who produce the /s/ sound acceptably and subjects who produce the /s/ sound unacceptably, it can be concluded that the size of the angle formed at sella turcica is not a significant factor in the production of an acceptable /s/ sound.

11. _the size of the angle formed at nasion by the sella-nasion line and the nasion-pogonian line._ To determine the size of the angle formed at nasion by the sella-nasion line and the nasion-pogonian line during the production of the /s/ sound, a protractor again was employed to measure the number of degrees in the angle. After measuring the angle, the exact number of degrees in the angle was recorded on the data sheet. When all of the measurements for all subjects were complete, a _t_ test was employed. Table 10 gives the results of this test.

TABLE 10.--The Difference in the Size of the Angle formed at Nasion by the Sella-Nasion Line and the Nasion-Pogonian Line during the Production of the /s/ Sound by Subjects who Produce the /s/ Sound Acceptably and Subjects who Produce the /s/ Sound Unacceptably

$\bar{X}_1$	$\bar{X}_2$	t*	degrees of freedom
81.95°	80.28°	1.56	58

*at .01 level of confidence $t = 2.75$
at .05 level of confidence $t = 2.00$

There is no significant difference in the size of the angle formed at nasion by the sella-nasion line and the nasion-pogonian line during the production of the /s/ sound by subjects who produce the /s/ sound acceptably and subjects who produce the /s/ sound unacceptably. Of the subjects who produced the /s/ sound acceptably, the size of the angle formed at nasion varied from 89.0 degrees to 76.0 degrees. The mean for this group was 81.95 degrees. Of the subjects who produced the /s/ sound unacceptably, the size of the angle formed at nasion varied from 88.0 degrees to 72.0 degrees. The fact that there is no significant difference in the size of the angle formed at nasion during the production of the /s/ sound by both groups indicates that the forward movement of the mandible during the production of the /s/ sound is approximately the same for both groups.

Because there is no significant difference in the size of the angle formed at nasion by the sella-nasion line and the nasion-pogonian line during the production of the [s] sound by subjects who produce the [s] sound acceptably and subjects who produce the [s] sound unacceptably, it can be concluded that the size of the angle formed at nasion is not a significant factor in acceptable [s] sound production.

Of the total measurements made for this study, only five proved to be statistically different between subjects who produce the [s] sound acceptably and subjects who produce the [s] sound unacceptably. These were:

1. the distance between the maxillary and mandibular incisal edges during the production of the [s] sound.
2. the distance between the anterior, inferior point of the tip of the tongue and the anterior mandibular incisal edge during the production of the [s] sound.
3. the distance between the lingual reference line and the anterior mandibular incisal edge during the production of the [s] sound.
4. the distance between the highest portion of the tongue and the palatal plane during the production of the [s] sound.

5. the distance between the posterior aspect of the tongue and the pharyngeal wall during the production of the [s] sound.

The statistical significance of these differences suggests certain clinical implications.

The relationship of the mandibular incisal edge to the maxillary incisal edge of the subjects who produced the [s] sound acceptably was slightly posterior to and slightly above the maxillary incisal edge. Clinically this would suggest that it would be necessary to obtain a comparable antero-posterior maxillary and mandibular incisal relationship for acceptable [s] sound production. In order to obtain this closer antero-posterior relationship of the maxillary and mandibular incisal edges for acceptable [s] sound production, the group with unacceptable [s] sound production probably would have to have greater mandibular movement. It is doubtful that this increased mandibular movement would greatly affect the size of the angles at sella turcica or at nasion. It would appear that clinically a closer antero-posterior relationship of the maxillary and mandibular incisal edges should be effected for acceptable [s] sound production.

The relationship of the anterior, inferior point of the tip of the tongue to the anterior mandibular incisal edge of the subjects who produced the [s] sound acceptably was posterior to and slightly above the mandibular incisal edge. The relationship of the highest portion of the tongue to the palatal plane of the subjects who produced the [s] sound acceptably was lower than that of the subjects who produced the [s] sound unacceptably. The relationship of the posterior aspect of the tongue to the pharyngeal wall of the subjects who produced the [s] sound acceptably was considerably narrower than that of the subjects who produced the [s] sound unacceptably. Clinically these relationships must be considered together because they all are concerned with tongue posture. All of these relationships indicate that the tongue should be farther back in the mouth for acceptable [s] sound production. This would indicate that, if the proper incisal relationship is effected, it would be plausable to relate the tip of the tongue to the mandibular incisal edge for acceptable [s] sound production. It would appear that a more retracted antero-posterior tongue posture should be effected for acceptable [s] sound production.

The other aspects of tongue posture and structural positions investigated in this study proved to be comparable for both groups of subjects. It would appear that the relationship of the permanent first molars, the relationship of the anterior, inferior point of the tip of the tongue to the palatal plane, the relationship of the highest portion of the tongue to the pterygomaxillary fissure line, the velar-pharyngeal closure, the angle formed at sella turcica indicating the vertical movement of the mandible, and the angle formed at nasion indicating the horizontal movement of the mandible would not be significant factors in the production of an acceptable [s] sound because these relationships were approximately the same for both groups of speakers.

CHAPTER V

SUMMARY AND CONCLUSIONS

I. SUMMARY

The [s] sound is one of the most frequently misarticulated consonant sounds in American English. In public school speech therapy programs, approximately two-thirds of the speech cases have difficulty articulating the [s] sound. Much has been written concerning the apparent physiological production of the [s] sound, but this information generally has been determined from casual observation. Exactly what occurs in the production of the [s] sound is not fully known. The purpose of this study was to determine objectively the differences in tongue posture and structural position during the acceptable and the unacceptable production of the [s] sound through cephalometric analysis. The study was conducted in the Department of Orthodontia, Eastman Dental Dispensary, Rochester, New York, and was supported in part by a United States Public Health Service Grant (# D-1071.) A group of thirty adult and adolescent speakers having acceptable [s] sound production and normal occlusion and a group of thirty adolescent speakers having unacceptable [s] sound production were examined. Cephalometric roentgenograms were taken of each subject during the production of the [s] sound. Tantalum powder was used as a radio-opaque media in order to define the anterior regions of the tongue. Tracings of these roentgenograms were made by a qualified orthodontist. Measurements designed to specify the exact posture of the tongue in relation to the anterior structures were made. Statistically significant differences in the measurements of tongue posture and structural position of speakers who produce the [s] sound acceptably and speakers who produce the [s] sound unacceptably were found. The physiologic differences were described, and clinical implications for the correction of defective [s] sound production were discussed.

II. CONCLUSIONS

This study has investigated objectively the differences in tongue posture and structural position between speakers who were judged as producing the [s] sound acceptably and other speakers with unacceptable [s] sound production. A method of cephalometric analysis was employed. The results of this investigation lead to the following conclusions:

1. There is a significant difference in the relationship between the maxillary and mandibular incisal edges during acceptable and unacceptable

production of the [s] sound. During acceptable [s] sound production, the mandibular incisal edge is placed posterior to and slightly above the maxillary incisal edge. These two incisal edges relate very closely. During unacceptable [s] sound production, there are wide discrepancies from the forementioned anterior structural position. In many cases, the maxillary and mandibular incisal edges do not relate at all.

2. There is a significant difference in the horizontal relationship of the tip of the tongue to the mandibular incisal edge during the acceptable and unacceptable production of the [s] sound. During the acceptable [s] sound production, the tip of the tongue was constantly posterior to the mandibular incisal edge. During the unacceptable [s] sound production, the tip of the tongue was considerably farther forward in the mouth. In many cases, the tip of the tongue was anterior to the mandibular incisal edge.

3. There is a significant difference in the vertical relationship of the tip of the tongue to the mandibular incisal edge during the acceptable and unacceptable production of the [s] sound. During acceptable [s] sound production, the

height of the tip of the tongue was closely related to the mandibular incisal edge. In every case, the tip of the tongue was related to the mandibular incisal edge. During unacceptable [s] sound production, the tip of the tongue was higher in the mouth. In most cases, the tip of the tongue was related to anterior structures other than the mandibular incisal edge.

4. There is a significant difference in the relationship of the highest portion of the tongue to the palatal plane during the production of the acceptable and unacceptable [s] sound. During acceptable [s] sound production, the tongue is lower in the mouth. It is interesting to note that the highest portion of the tongue is generally in the area of the pterygomaxillary fissure line for both acceptable and unacceptable [s] sound production. The highest part of the tongue is the dorsum of the tongue, not the tip.

5. There is a significant difference in the relationship of the posterior aspect of the tongue to the pharyngeal wall during acceptable and unacceptable [s] sound production. During acceptable [s] sound production, the posterior aspect of the tongue is much closer to the

pharyngeal wall. This relationship gives further proof that the whole tongue is drawn farther back in the oral cavity during the production of an acceptable [s] sound.

6. The following aspects of tongue posture and structural position are approximately the same for both acceptable and unacceptable [s] sound production:
   a. the relationship of the tip of the tongue to the palatal plane.
   b. the relationship of the maxillary and mandibular permanent first molars to each other.
   c. the relationship of the highest portion of the tongue to the pterygo-maxillary fissure line.
   d. the complete velar-pharyngeal closure.
   e. the forward movement of the mandible.
   f. the downward movement of the mandible.

The findings of this investigation indicate that the antero-posterior tongue posture and the anterior structural relationship are factors with which the therapist must be primarily concerned in order to obtain acceptable [s] sound production.

These findings indicate a need for greater objective research on this subject. More objective information is needed concerning tongue posture and structural position during acceptable /s/ sound production by subjects who have malocclusions. More objective research is needed concerning tongue posture and structural position during unacceptable /s/ sound production by subjects who have normal occlusion. More objective research is needed concerning tongue habits and /s/ sound production. This investigation in conjunction with correlated research could lead to new methods for correction of defective /s/ sound production.

APPENDIX

1. Sentences used for articulation testing.

   a. We hasten the boys off my garage path to show which edge young owls could view.

   b. Sister eats soup and ice-cream with a spoon. She also likes to sew her dress.

   c. The trees are thick on both sides of the path. Do you think you can see anything?

   d. Little girls like to play with dolls. Little boys like to play ball.

   e. Harry read a story about a rabbit. A bird who had no feathers was in the same story.

   f. The bees are always buzzing in my ears. Their music makes me lazy.

   g. While she washed the dishes the men fished. Then she looked for shells along the shore.

2. Words used for articulation testing.

race	buzz	sin	thing	thumb
lice	fuzz	sank	fish	truce
bus	Jews	sing	some	pass
fuss	zink	fizz	truth	miss
juice	zeal	ship	path	leash
sink	shag	shine	myth	lash
seal	sip	shave	lease	shown
zag	sign	theme	lass	wish
raise	save	thin	zone	sheaf
lies	seem	thank	with	thief

3. Permission letter to parents.

Dear Mr. and Mrs. :

I am doing a research study on why children produce the "s" sound incorrectly. The results of the study should give us increased knowledge of this problem and should help us to meet the needs of our children in an improved manner. I would like to have your written permission to have your son, daughter ______________________ participate in this study with me. This will involve approximately one hour of class time. If you have any questions or wish to talk with me about this study, please call me at Benjamin Franklin High School on Tuesdays, Thursdays, or Fridays or at Edison Technical and Industrial High School on Mondays and Wednesdays. Thank you so much for your cooperation in this matter.

Very truly yours,

(Mrs.) Eleanor H. Burgess
Speech and Hearing Therapist

Please fill out the attached form and return it immediately to:

Mrs. Eleanor H. Burgess
Speech and Hearing Therapist
Benjamin Franklin High School
950 Norton Street
Rochester 21, New York

I hereby freely give my permission for my son, daughter ______________________________ to participate in a study by Mrs. Eleanor H. Burgess on defective "s" sound production.

Signed ______________________________ Date ____________
(Parent or Guardian)

4. Occlusal evaluation sheet.

Date ____________

Name ____________________ Age ____________

Case Number ______________ R.O. ____________

Angle Classification: Class I ___ Class II ___ Class III ___

Open Bite: Present ___ Absent ___

Approximate dimension between incisal edges in mm _____

Closed Bite: Present ___ Absent ___

Mild ___ Moderate ___ Severe ___

Over-jet: Present ____ Absent ___

Approximate a-p dimension between incisors in mm _______

Spacing: Present ____ Absent ____

Located between Upper Centrals Yes ___ No ___

Upper R. Central and Lateral Yes ___ No ___

Upper L. Central and Lateral Yes ___ No ___

Located between Lower Centrals Yes ___ No ___

Lower R. Central and Lateral Yes ___ No ___

Lower L. Central and Lateral Yes ___ No ___

Spacing in Buccal Segments Yes ___ No ___

Located in Upper ______________________________

Located in Lower ______________________________

Crowding in Upper Anterior Region: Present ____ Absent ___

Crowding in Lower Anterior Region Present ___ Absent ___

Crowding in Upper Buccal Segments: Present __ Absent ___

One side ___ Both sides ___

Crowding in Lower Buccal Segments: Present __ Absent __

One side ___ Both sides ___

Number of Teeth in Linguaversion in Upper Arch ________

Identify Upper Teeth in Linguaversion ________________

Estimated Degree of Linguaversion of upper teeth in mms ________

Number of Teeth in Linguaversion in Lower Arch ________

Identify Lower Teeth in Linguaversion ________________

Estimated Degree of Linguaversion of lower teeth in mms ________

Rotations in Upper Anteriors: Present ____ Absent ____

Identify Rotations in Upper Anteriors ________________

Rotation in Lower Anteriors: Present ___ Absent ___
Identify Rotations in Lower Anteriors ______________
Number of Missing Teeth in Upper Arch ______________
Identify Missing upper Teeth ______________________
Number of Missing Teeth in Lower Arch ______________
Identify Missing Teeth in Lower Arch _______________

Palate Contour: Normal ____ Low and Broad ___________
High and Narrow _______ Irregular in Contour ____

Tongue: Can elevate tip to touch outer margin of upper lip Yes ___ No ___
Can groove easily ___ with difficulty __ Not at all___

Lips: Normal in appearance ___ Do not approximate in repose ____
Normal in Function ______ Hypo tonic upper
Hypo tonic lower
Evidence of perverted swallow Yes ___ No ___
Evidence of adverse habit patterns observed Yes ___
No ____

5. Distance in millimeters between maxillary and and mandibular incisal edges during the production of the [s] sound.

Case Number	Acceptable [s] sound	Unacceptable [s] sound
1	1.0 mm.	2.75 mm.
2	4.0 mm.	2.0 mm.
3	2.0 mm.	6.0 mm.
4	4.0 mm.	4.0 mm.
5	4.0 mm.	6.75 mm.
6	0.0 mm.	0.0 mm.
7	2.0 mm.	5.5 mm.
8	2.0 mm.	6.0 mm.
9	1.0 mm.	4.0 mm.
10	2.0 mm.	10.5 mm.
11	1.0 mm.	4.5 mm.
12	3.5 mm.	6.25 mm.
13	2.75 mm.	2.5 mm.
14	3.5 mm.	5.0 mm.
15	1.5 mm.	10.0 mm.
16	2.0 mm.	2.0 mm.
17	1.0 mm.	4.5 mm.
18	3.0 mm.	2.0 mm.
19	0.0 mm.	6.5 mm.
20	0.75 mm.	6.0 mm.
21	1.0 mm.	4.0 mm.
22	1.0 mm.	1.75 mm.
23	0.5 mm.	2.5 mm.
24	1.0 mm.	8.5 mm.
25	0.5 mm.	5.0 mm.
26	2.5 mm.	2.5 mm.
27	1.7 mm.	3.0 mm.
28	1.5 mm.	6.5 mm.
29	1.0 mm.	5.5 mm.
30	0.0 mm.	7.0 mm.

6. Distance in millimeters between the maxillary and mandibular permanent first molars during the production of the /s/ sound.

Case Number	Acceptable /s/ sound	Unacceptable /s/ sound
1	2.0 mm.	0.0 mm.
2	1.0 mm.	3.0 mm.
3	1.0 mm.	2.0 mm.
4	0.0 mm.	1.0 mm.
5	1.0 mm.	2.5 mm.
6	2.5 mm.	0.0 mm.
7	0.0 mm.	1.0 mm.
8	1.0 mm.	0.0 mm.
9	1.0 mm.	3.75 mm.
10	2.0 mm.	0.0 mm.
11	2.5 mm.	1.0 mm.
12	0.0 mm.	0.0 mm.
13	0.0 mm.	0.5 mm.
14	0.5 mm.	3.0 mm.
15	1.5 mm.	3.0 mm.
16	2.0 mm.	0.0 mm.
17	0.5 mm.	1.5 mm.
18	0.5 mm.	0.5 mm.
19	0.0 mm.	4.0 mm.
20	0.5 mm.	0.5 mm.
21	0.5 mm.	0.5 mm.
22	0.0 mm.	0.0 mm.
23	1.5 mm.	0.0 mm.
24	0.5 mm.	0.0 mm.
25	2.5 mm.	3.0 mm.
26	1.5 mm.	0.0 mm.
27	1.5 mm.	0.0 mm.
28	0.0 mm.	0.5 mm.
29	1.0 mm.	0.0 mm.
30	2.25 mm.	1.0 mm.

7. Distance in millimeters between the anterior, inferior point of the tip of the tongue and the anterior mandibular incisal edge during the production of the [s] sound.

Case Number	Acceptable [s] sound	Unacceptable [s] sound
1	-5.0 mm.	+1.0 mm.
2	-3.5 mm.	-5.0 mm.
3	-5.0 mm.	+3.0 mm.
4	-5.0 mm.	+3.5 mm.
5	-9.0 mm.	+7.0 mm.
6	-4.5 mm.	-4.0 mm.
7	-5.0 mm.	+4.5 mm.
8	-5.0 mm.	-5.5 mm.
9	-5.5 mm.	+4.5 mm.
10	-3.0 mm.	-4.0 mm.
11	-4.25 mm.	0.0 mm.
12	-5.75 mm.	0.0 mm.
13	-4.0 mm.	0.0 mm.
14	-2.0 mm.	-2.5 mm.
15	-4.5 mm.	+2.5 mm.
16	-3.5 mm.	-2.0 mm.
17	-4.5 mm.	-5.5 mm.
18	-5.0 mm.	-1.5 mm.
19	-8.0 mm.	+6.5 mm.
20	-6.5 mm.	-4.0 mm.
21	-3.5 mm.	-4.0 mm.
22	-3.5 mm.	-5.5 mm.
23	-7.0 mm.	-6.0 mm.
24	-3.0 mm.	+6.5 mm.
25	-3.0 mm.	+4.5 mm.
26	-3.5 mm.	-4.0 mm.
27	-2.0 mm.	-8.0 mm.
28	-6.0 mm.	+5.5 mm.
29	-2.0 mm.	-8.5 mm.
30	-6.0 mm.	0.0 mm.

8. Transposed scores of the measurement of the distance in millimeters between the anterior, inferior point of the tip of the tongue and the anterior mandibular incisal edge during the production of the [s] sound

Case Number	Acceptable [s] sound	Unacceptable [s] sound
1	5.0	11.0
2	6.5	5.0
3	5.0	13.0
4	5.0	13.5
5	1.0	17.0
6	5.5	6.0
7	5.0	14.5
8	5.0	4.5
9	4.5	14.5
10	7.0	6.0
11	5.25	10.0
12	4.75	10.0
13	6.0	10.0
14	8.0	7.5
15	5.5	12.5
16	6.5	8.0
17	5.5	4.5
18	5.0	8.5
19	2.0	16.5
20	3.5	6.0
21	6.5	6.0
22	6.5	4.5
23	3.0	4.0
24	7.0	16.5
25	7.0	14.5
26	6.5	6.0
27	8.0	2.0
28	4.0	15.0
29	8.0	1.5
30	6.0	10.0

9. **Distance in millimeters between the lingual reference line and the anterior mandibular edge during the production of the [s] sound.**

Case Number	Acceptable [s] sound	Unacceptable [s] sound
1	+2.0 mm.	+0.5 mm.
2	+1.0 mm.	-0.5 mm.
3	+1.0 mm.	+2.5 mm.
4	+1.0 mm.	+2.0 mm.
5	0.0 mm.	+4.0 mm.
6	+0.5 mm.	-1.0 mm.
7	0.0 mm.	+2.0 mm.
8	+1.0 mm.	-2.0 mm.
9	+2.0 mm.	0.0 mm.
10	0.0 mm.	+2.0 mm.
11	+1.5 mm.	+3.5 mm.
12	+2.0 mm.	+4.25 mm.
13	-1.0 mm.	+2.0 mm.
14	+1.0 mm.	+2.5 mm.
15	+3.0 mm.	+2.0 mm.
16	-2.0 mm.	+0.5 mm.
17	0.0 mm.	+4.0 mm.
18	-1.0 mm.	+0.75 mm.
19	-1.0 mm.	+1.75 mm.
20	+2.0 mm.	-1.0 mm.
21	+1.5 mm.	-3.0 mm.
22	+2.0 mm.	+3.0 mm.
23	+2.5 mm.	+4.0 mm.
24	+1.0 mm.	+5.0 mm.
25	+0.75 mm.	+4.5 mm.
26	0.0 mm.	+3.0 mm.
27	+1.0 mm.	+4.0 mm.
28	0.0 mm.	+2.0 mm.
29	0.0 mm.	+3.5 mm.
30	0.0 mm.	+ 2.0 mm.

10. The transposed scores for the distance in millimeters between the lingual reference line and the anterior mandibular incisal edge during the production of the /s/ sound.

Case Number	Acceptable /s/ sound	Unacceptable /s/ sound
1	6.0	4.5
2	5.0	3.5
3	5.0	6.5
4	5.0	6.0
5	4.0	8.0
6	4.5	3.0
7	4.0	6.0
8	5.0	2.0
9	6.0	4.0
10	4.0	6.0
11	5.5	7.5
12	6.0	8.25
13	3.0	6.0
14	5.0	6.5
15	7.0	6.0
16	2.0	4.5
17	4.0	8.0
18	3.0	4.75
19	3.0	5.75
20	6.0	3.0
21	5.5	1.0
22	6.0	7.0
23	6.5	8.0
24	5.0	9.0
25	4.75	8.5
26	4.0	7.0
27	5.0	8.0
28	4.0	6.0
29	4.0	7.5
30	4.0	6.0

11. Measurements in millimeters of the anterior, inferior point of the tip of the tongue to the palatal plane during the production of the /s/ sound.

Case Number	Acceptable /s/ sound	Unacceptable /s/ sound
1	30.0 mm.	25.0 mm.
2	28.0 mm.	32.0 mm.
3	33.0 mm.	24.0 mm.
4	24.0 mm.	27.75 mm.
5	30.0 mm.	30.5 mm.
6	32.5 mm.	29.0 mm.
7	33.0 mm.	28.75 mm.
8	23.0 mm.	25.5 mm.
9	34.0 mm.	30.0 mm.
10	26.0 mm.	21.0 mm.
11	31.0 mm.	30.0 mm.
12	37.0 mm.	25.0 mm.
13	33.5 mm.	30.5 mm.
14	32.0 mm.	33.5 mm.
15	27.0 mm.	29.0 mm.
16	32.5 mm.	32.5 mm.
17	32.0 mm.	33.75 mm.
18	41.5 mm.	31.0 mm.
19	36.0 mm.	37.5 mm.
20	33.0 mm.	24.0 mm.
21	28.0 mm.	25.0 mm.
22	29.5 mm.	28.5 mm.
23	32.0 mm.	24.5 mm.
24	25.0 mm.	35.5 mm.
25	31.5 mm.	26.5 mm.
26	27.0 mm.	29.75 mm.
27	23.0 mm.	20.5 mm.
28	32.5 mm.	38.0 mm.
29	29.0 mm.	22.0 mm.
30	28.0 mm.	34.0 mm.

12. Measurements in millimeters of the highest portion of the tongue to the palatal plane during the production of the [s] sound.

Case Number	Acceptable [s] sound	Unacceptable [s] sound
1	12.2 mm.	9.0 mm.
2	13.7 mm.	18.5 mm.
3	13.5 mm.	18.5 mm.
4	10.0 mm.	15.0 mm.
5	16.2 mm.	8.75 mm.
6	15.0 mm.	12.0 mm.
7	21.0 mm.	16.0 mm.
8	13.0 mm.	12.5 mm.
9	18.0 mm.	14.5 mm.
10	10.5 mm.	9.5 mm.
11	12.0 mm.	8.5 mm.
12	17.7 mm.	13.5 mm.
13	17.0 mm.	13.0 mm.
14	15.0 mm.	13.75 mm.
15	13.5 mm.	19.5 mm.
16	11.0 mm.	11.5 mm.
17	10.8 mm.	8.5 mm.
18	14.0 mm.	18.2 mm.
19	21.0 mm.	14.5 mm.
20	21.5 mm.	9.0 mm.
21	11.5 mm.	15.0 mm.
22	16.0 mm.	16.5 mm.
23	26.0 mm.	12.5 mm.
24	11.5 mm.	15.5 mm.
25	10.0 mm.	17.0 mm.
26	23.0 mm.	6.5 mm.
27	16.0 mm.	11.0 mm.
28	15.0 mm.	14.0 mm.
29	16.0 mm.	17.0 mm.
30	14.0 mm.	

13. Measurements in millimeters of the distance between the highest portion of the tongue and the pterygo-maxillary fissure line during the production of the /s/ sound.

Case Number	Acceptable /s/ sound	Unacceptable /s/ sound
1	10.0 mm.	19.0 mm.
2	6.0 mm.	12.0 mm.
3	0.5 mm.	52.5 mm.
4	6.5 mm.	16.5 mm.
5	13.0 mm.	8.0 mm.
6	15.2 mm.	14.5 mm.
7	39.5 mm.	10.0 mm.
8	16.0 mm.	8.5 mm.
9	1.5 mm.	7.5 mm.
10	2.0 mm.	18.5 mm.
11	4.0 mm.	11.0 mm.
12	6.0 mm.	12.5 mm.
13	7.0 mm.	1.0 mm.
14	7.5 mm.	6.0 mm.
15	8.0 mm.	4.5 mm.
16	15.0 mm.	22.5 mm.
17	14.0 mm.	12.5 mm.
18	3.0 mm.	28.0 mm.
19	1.0 mm.	14.0 mm.
20	0.75 mm.	8.0 mm.
21	0.0 mm.	38.0 mm.
22	2.0 mm.	6.0 mm.
23	1.2 mm.	5.0 mm.
24	14.0 mm.	8.5 mm.
25	2.0 mm.	4.0 mm.
26	10.0 mm.	
27	40.0 mm.	15.5 mm.
28	2.0 mm.	3.0 mm.
29	4.0 mm.	24.5 mm.
30	10.0 mm.	3.0 mm.

14. Measurements in millimeters of the distance between the posterior aspect of the tongue and the pharyngeal wall during the production of the /s/ sound.

Case Number	Acceptable /s/ sound	Unacceptable /s/ sound
1	14.5 mm.	32.0 mm.
2	13.5 mm.	21.0 mm.
3	10.0 mm.	32.0 mm.
4	19.0 mm.	22.5 mm.
5	19.5 mm.	28.5 mm.
6	19.0 mm.	16.0 mm.
7	26.5 mm.	18.5 mm.
8	19.0 mm.	19.5 mm.
9	18.0 mm.	28.0 mm.
10	9.0 mm.	23.5 mm.
11	6.0 mm.	13.5 mm.
12	5.0 mm.	23.0 mm.
13	12.5 mm.	21.75 mm.
14	7.0 mm.	10.0 mm.
15	8.0 mm.	21.5 mm.
16	15.0 mm.	17.5 mm.
17	10.0 mm.	32.5 mm.
18	15.0 mm.	13.5 mm.
19	9.0 mm.	17.5 mm.
20	11.0 mm.	16.0 mm.
21	18.0 mm.	36.0 mm.
22	11.0 mm.	14.0 mm.
23	13.5 mm.	15.0 mm.
24	19.0 mm.	11.5 mm.
25	7.0 mm.	17.0 mm.
26	23.0 mm.	27.5 mm.
27	28.0 mm.	15.0 mm.
28	13.5 mm.	8.0 mm.
29	14.5 mm.	24.5 mm.
30	14.0 mm.	19.5 mm.

15. Scores for the completeness of the velar-pharyngeal closure during the production of the [s] sound. If the closure was complete, it was recorded as zero.

Case Number	Acceptable [s] sound	Unacceptable [s] sound
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
14	0	0
15	0	0
16	0	0
17	0	0
18	0	0
19	0	0
20	0	0
21	0	0
22	0	0
23	0	0
24	0	0
25	0	0
26	0	0
27	0	0
28	0	0
29	0	0
30	0	0

16. Measurement in degrees of the size of the angle formed at sella turcica during the production of the /s/ sound.

Case Number	Acceptable /s/ sound	Unacceptable /s/ sound
1	69.0 °	65.5 °
2	66.0 °	65.2 °
3	67.0 °	57.5 °
4	68.0 °	65.0 °
5	68.0 °	66.0 °
6	65.0 °	61.0 °
7	65.0 °	72.5 °
8	62.0 °	62.0 °
9	67.0 °	64.25°
10	63.0 °	62.0 °
11	67.0 °	69.0 °
12	68.25°	63.5 °
13	64.5 °	64.75°
14	69.5 °	59.0 °
15	62.0 °	66.0 °
16	60.0 °	68.0 °
17	63.0 °	65.0 °
18	63.0 °	65.0 °
19	60.5 °	68.5 °
20	63.0 °	65.5 °
21	61.5 °	58.5 °
22	67.0 °	70.0 °
23	62.5 °	61.0 °
24	62.0 °	67.0 °
25	64.0 °	65.0 °
26	63.5 °	68.0 °
27	57.0 °	65.0 °
28	68.0 °	74.0 °
29	68.0 °	74.0 °
30	61.0 °	69.5 °

16. Measurement in degrees of the size of the angle formed at sella turcica during the production of the /s/ sound.

Case Number	Acceptable /s/ sound	Unacceptable /s/ sound
1	69.0 °	65.5 °
2	66.0 °	65.2 °
3	67.0 °	57.5 °
4	68.0 °	65.0 °
5	68.0 °	66.0 °
6	65.0 °	61.0 °
7	65.0 °	72.5 °
8	62.0 °	62.0 °
9	67.0 °	64.25°
10	63.0 °	62.0 °
11	67.0 °	69.0 °
12	68.25°	63.5 °
13	64.5 °	64.75°
14	69.5 °	59.0 °
15	62.0 °	66.0 °
16	60.0 °	68.0 °
17	63.0 °	65.0 °
18	63.0 °	65.0 °
19	60.5 °	68.5 °
20	63.0 °	65.5 °
21	61.5 °	58.5 °
22	67.0 °	70.0 °
23	62.5 °	61.0 °
24	62.0 °	67.0 °
25	64.0 °	65.0 °
26	63.5 °	68.0 °
27	57.0 °	65.0 °
28	68.0 °	74.0 °
29	68.0 °	74.0 °
30	61.0 °	69.5 °

17. Raw scores for the measurement of the size of the angle formed at nasion during the acceptable and unacceptable production of the /s/ sound.

Case Number	Acceptable /s/ sound	Unacceptable /s/ sound
1	79.0°	78.0°
2	81.0°	79.0°
3	80.0°	88.0°
4	79.0°	80.5°
5	79.0°	83.0°
6	79.0°	82.5°
7	83.0°	72.0°
8	87.0°	85.0°
9	77.0°	81.0°
10	81.0°	83.0°
11	78.0°	81.0°
12	80.25°	79.25°
13	83.0°	83.5°
14	76.0°	87.5°
15	84.5°	79.5°
16	86.0°	78.0°
17	80.0°	81.5°
18	84.5°	81.0°
19	85.0°	77.5°
20	85.0°	77.0°
21	84.0°	86.0°
22	79.0°	75.5°
23	86.0°	86.0°
24	85.0°	79.0°
25	84.0°	83.5°
26	83.0°	77.0°
27	89.0°	81.5°
28	77.0°	74.0°
29	79.0°	72.0°
30	86.0°	76.0°

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