A Technique For Recording Velar Movement

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Soft palate or velar movement during speech has been studied using a variety of observational techniques. Lubker and Moll (*6*) have divided these methods of observation into two general categories, indirect and direct techniques. These authors point out that indirect methods, such as quantitative measurement of oral and nasal air pressures and flows, yield inferences about articulatory and physiological activities such as velar movement during speech. Direct techniques such as radiographic methods enable investigators to make direct quantitative measurements of the articulatory mechanism during speech. Both methods provide a considerable amount of knowledge concerning velopharyngeal function in general and velar movement in particular during normal and pathological speech.

However, if one is concerned with obtaining a quantitative continuous measure of velar movement instantaneously during speech for prolonged periods of time, then the traditional methods mentioned above have certain disadvantages. The indirect techniques infer velar movement as part of the more complex phenomenon of velopharyngeal closure. Radiographic techniques, such as cineradiography, provide quantitative information of velar movement, but this information is not immediately available during speech production. In addition to the lack of an instantaneous readout of velar movement during speech production, several investigators (Chase, *1;* Moll, *8;* Fletcher et al., *4;* Lubker and Moll, *6;* Lubker and Morris, *7*) have noted certain inherent concerns in the use of radiographic techniques. These concerns include quality and limited field of view of projection, laborious measurement procedures, expense and radiation exposure.

The present study involves the development of a new technique for recording velar movements during speech (*2, 3*). Basically, the technique employs resistance strain gage displacement transducers. Strain gage transducers are relatively simple in design and function, are relatively inexpensive to use, eliminate exposure hazard, provide for continuous and instantaneous recording of velar movement during speech production, and allow for observation of velar movement over extended periods of time.

The specific purposes of the study, in addition to the development of instrumentation for recording velar movement during speech were: 1) to assess the reliability of the instrumentation in recording velar movement during similar speech tasks over time, and 2) to determine the relationship between obtained measures of velar movement using a transducer technique and simultaneously obtained measures using lateral still radiography.

Method

Construction of Appliance. One of the authors (RLC) designed, constructed and positioned an initial displacement transducer appliance in a normal speaker (KTM). A plaster cast was prepared as a working model and an orthodontic band was fitted to a maxillary second molar. A four millimeter (mm) by 15 mm stainless steel beam (0.010 inch thick) was welded to the band. One standard grid resistance strain gage* was cemented to each side of the beam. A three-lead wire configuration connected to a Wheatstone bridge circuit was used for temperature compensation. A spring wire was welded to the free end of the beam. This wire was extended toward the midline of the hard palate, then looped and extended posteriorly to the middle third of the soft palate at the midline. At this location a small loop ("sensor tip") was constructed. Another wire (0.036 inch diameter) was welded to the band and shaped to extend the full length of the beam. This wire configuration served as a guard to prevent the tongue from making direct contact with the beam. The beam and strain gage were covered with a thin layer of epoxy resin. The strain gages were connected to a Sanborn 850 graphic recorder and amplifier unit. Figure 1 is a photograph of the transducer appliance.

The location of the appliance intraorally can be seen in Figure 2. In this figure the velum is elevated during the phonation of /a/. During "rest", the sensor tip is depressed, the transducer is in a loaded state and the output voltage is observed on the graphic recorder. With progressive velar elevation, the sensor tip follows movement at the midline, the transducer becomes progressively unloaded and the voltage changes are observed on the recorder. Figure 3 presents a radiographic tracing demonstrating movement of the velum and of the sensor tip from "rest" to the production of /s/.

Laboratory tests were conducted to determine the transducer output during static calibration under increments and decrements of micrometer-controlled deflection and gram-weight controlled deflection of the sensor tip. The results of these laboratory tests demonstrated a linear relationship between transducer output and sensor tip displacement, and between output and applied force.

The response characteristics of the initial appliance when positioned intraorally were assessed during the production of certain speech tasks. The tasks consisted of isolated vowels and consonants, consonant-vowel and consonant-vowel-consonant syllables, and sentences. Each task was

* Budd Company, Phoenixville, Pennsylvania.

produced five times in succession. A microphone was connected to another channel of the graphic recorder for sound pickup. Examples of the obtained graphic recording tracings are presented in Figures 4–8. In each figure the lower line gives the transducer output; the upper line shows the graphic recording of the sound pickup from the microphone. The vertical line indicates approximate onset of phonation for the first production in each series. The most striking feature of these recordings is the relative reproducibility of the transducer output during the production of similar speech tasks.

Subsequent to these procedures the following subjective judgments were made: 1) adaptation to the appliance was readily achieved, 2) the appliance, although "sensed" during many articulatory movements, did not restrict normal articulation, 3) there were no time restrictions related to physical discomfort.

On the basis of the information obtained above, the decision was made to construct appliances for additional subjects.

Subjects. Subjects were three normal adult speakers—two male and one female. All subjects were speech pathology graduate students who exhibited normal voice and articulation characteristics, and who had essentially normal dentition and occlusion. Subjects participated in three experimental sessions. Sessions took place on three consecutive days.

Speech Tasks. *Session one.* The speech tasks for session one consisted of the sustained sounds /i/, /u/, /a/, /æ/, /m/, and /z/, and the declarative sentence, "Sue roasted a duck for supper so ten men came in when Jane rang." Each task was produced twice for a total of 14 speech tasks.

FIGURE 1. Photograph of the displacement transducer appliance.

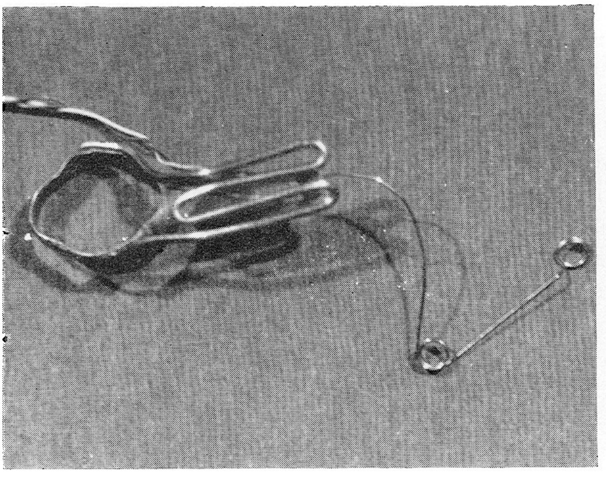
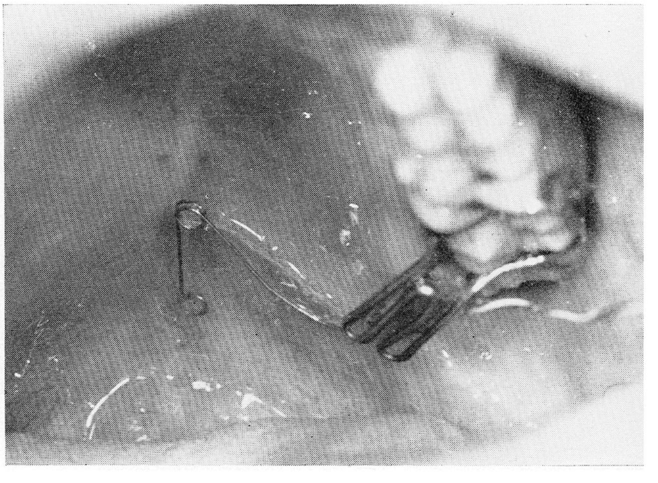


FIGURE 2. Intraoral photograph showing the position of the transducer appliance and sensor tip during phonation of /ɑ/.



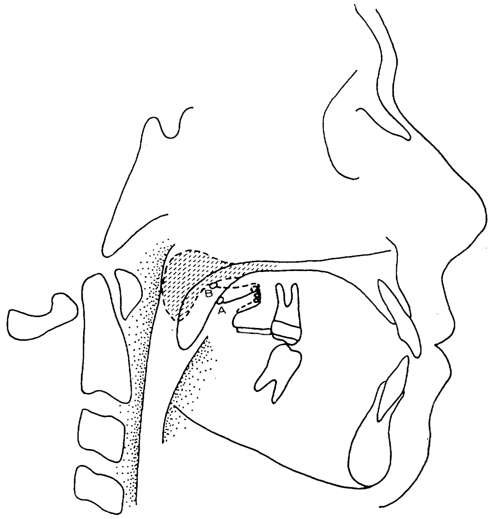


FIGURE 3. Radiographic tracing showing change in position of the sensor tip from "rest" (A) to production of /s/ (B).

The 14 tasks were randomized for order of presentation for each subject with the restriction that the same tasks could not appear in succession. The vowels were selected to represent two high (/i/, /u/) and two low (/a/, /æ/) vowels. The consonants were chosen to represent one nasal voiced (/m/) and one non-nasal voiced (/z/) consonant. The sentence, taken from Fairbanks (1960), included a non-nasal portion (first half) and a pro-nasal portion (second half).

Session two. The tasks for session two were identical to session one, but the order of presentation was re-randomized for each subject.

Session three. The tasks for session three consisted of the sustained sounds /i/, /a/, and /z/ presented twice each for a total of six tasks. The tasks were randomized for each subject.

APPARATUS. All three sessions were conducted in a room equipped for cephalometric radiography. The transducer appliance was connected to one channel of a Sanborn 150 graphic recorder and amplifier. A Uher M-15 microphone, connected to a Uher 4000 tape recorder, was used for sound recordings. An Ampex 702 microphone connected to a second channel of the recorder was used for graphic sound pickup.

A push-button located on a control box containing a three-poled single throw relay switch provided for the following simultaneous functions: 1) An event mark was placed on the graphic recording, 2) An acoustic signal was placed on the sound recording, and 3) The x-ray unit was activated.

Procedure

Prior to the experimental sessions a small tattoo mark was placed approximately on the middle third of the velum to aid in repositioning the sensor tip. Before each session the subject was fitted with the transducer

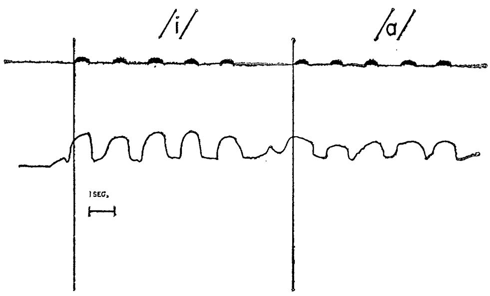


FIGURE 4. Photograph of the graphic recording tracing of five consecutive productions of /i/ and /ɑ/.

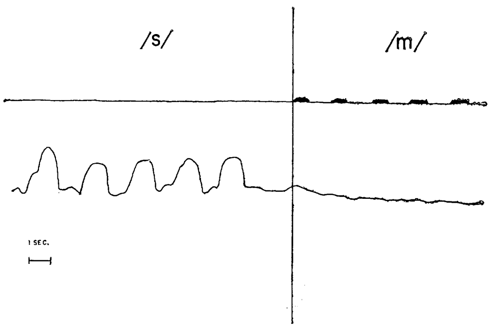


FIGURE 5. Photograph of the graphic recording tracing of five consecutive productions of /s/ and /m/.

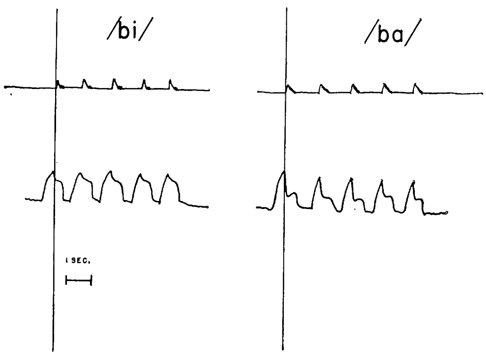


FIGURE 6. Photograph of the graphic recording tracing of five consecutive productions of /bi/ and /bɑ/.

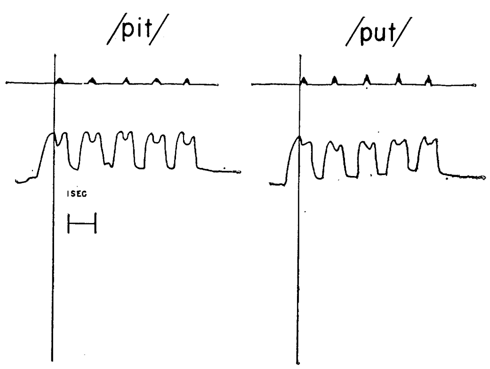


FIGURE 7. Photograph of the graphic recording tracing of five consecutive production of /pit/ and /put/.

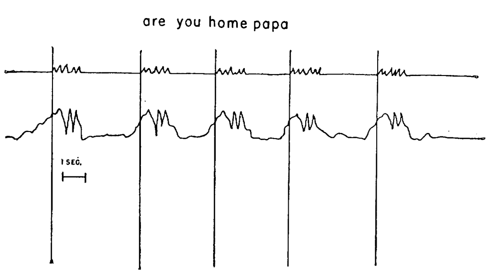


FIGURE 8. Photograph of the graphic recording tracing of five consecutive productions of "Are you home papa?"

appliance and was seated in a dental chair in the experimental room. Experimental sessions took place at approximately 24-hour intervals. For each session subjects were instructed to produce and sustain the sound displayed on the card in front of them. A card stating "relax" always preceded a speech task. The instructions included suggestions concerning velar relaxation. Subjects were told to sustain the isolated sound as long as a red light in front of them remained on (approximately five seconds). Subjects were told to produce the sentence task in a normal conversational manner.

Two experimenters, KTM (E_1) and RLC (E_2) were present in the room at all times. When the subject indicated readiness to begin, E_1 activated the tape recorder. When E_2 judged that the graphic recording line was stable during the "relax" period, E_1 cued the subject to produce the first speech task. When E_1 judged that the sound was being produced, he depressed the event pushbutton. Following production of the task, the subject was cued to relax and the above procedure was followed for the remaining tasks in the session. Only during session three were simultaneous radiographs taken.

CHART ANALYSIS AND MEASUREMENT PROCEDURE. *Graphic transducer recordings.* Although several parameters of the continuous graphic recordings were of interest, the most obvious was the extent or magnitude of displacement associated with the various sustained sounds. More specifically, an attempt was made to obtain a quantitative value for each of the sustained sounds at that point where the judgment was made that the sound was being produced.

In order to obtain these quantitative values for each sound, acetate tracing paper was placed over the graphic recording in such a way that the event mark was approximately in the center relative to the left-right dimension. Also, reference lines on the acetate paper and on the graphic recording were superimposed. The tracing of the transducer output included periods of time before production, during production, and after production. The event line and event mark also were traced between points before and after production. The graphic recording of the sound pickup was traced to indicate a pre-production period, initiation of production (i.e. an abrupt change in prior direction of the recording line), termination of production and a post-production period. A vertical line was constructed on the basis of the point at which the event mark was initiated and was extended down to the reference line on the acetate paper.

Using a Boley gauge graduated in tenths of a millimeter, a quantitative value was obtained from the tracings by measuring the length of the vertical line between the reference line on the acetate paper and the point at which the vertical line intersected the transducer recording line. The values obtained correspond to that point during the production of the sound where the perceptual judgment was made that the sound was being produced.

Radiographic measures. In order to obtain values concerning the movement of the sensor tip inside the oral cavity during the speech tasks produced in session three, each radiograph was traced in the following manner. A reference line was constructed on the basis of the most anterior visible portion of the anterior nasal spine and the most superior visible portion of the atlas. Another line was constructed from the sensor tip perpendicular to the reference line. Quantitative values were obtained for each projection by measuring the length of the perpendicular line.

Reliability of the measurement procedures was assessed by having an independent observer make tracings and obtain transducer recording and radiographic values for all sustained tasks produced during all sessions. The mean discrepancies between experimenter and independent observer for the transducer recordings and radiographs were 0.26 mm and 0.32 mm respectively.

Results and Discussion

SUSTAINED SOUND PRODUCTION. Table 1 presents the obtained values from the transducer recording tracings for each subject and each production of the sustained tasks during sessions one and two. In these sessions, the differences between values for similar sound productions were quite

TABLE 1. Graphic transducer recording values, in millimeters, for the two productions of each sound during sessions one and two for each subject.

Subject	Task	SESSION ONE			SESSION TWO		
		First Production	Second Production	Average	First Production	Second Production	Average
TL							
	/æ/	33.0	32.5	32.7	33.9	32.0	32.9
	/u/	35.1	35.0	35.0	34.9	34.2	34.5
	/i/	33.5	33.6	33.5	35.5	35.0	35.2
	/ɑ/	31.5	31.1	31.1	33.0	34.1	33.5
	/z/	33.8	34.3	34.0	35.7	35.3	35.5
	/m/	15.2	19.8	17.5	17.9	18.7	18.2
JG							
	/æ/	29.7	29.2	29.4	29.3	26.5	27.9
	/u/	34.0	33.5	33.7	32.9	32.8	32.8
	/i/	32.6	31.0	31.8	31.5	32.5	32.0
	/ɑ/	29.6	28.4	29.0	29.6	31.0	30.3
	/z/	31.2	33.0	32.1	32.6	33.9	33.2
	/m/	16.9	16.9	16.9	15.0	17.0	16.0
AF							
	/æ/	21.3	19.0	20.1	19.2	19.5	19.3
	/u/	29.0	27.3	28.1	27.3	29.1	28.2
	/i/	25.0	25.0	25.0	26.2	26.7	26.4
	/ɑ/	21.5	18.8	20.1	18.1	19.3	18.7
	/z/	23.0	23.5	23.2	24.0	25.0	24.5
	/m/	18.0	17.5	17.7	16.4	18.4	17.4

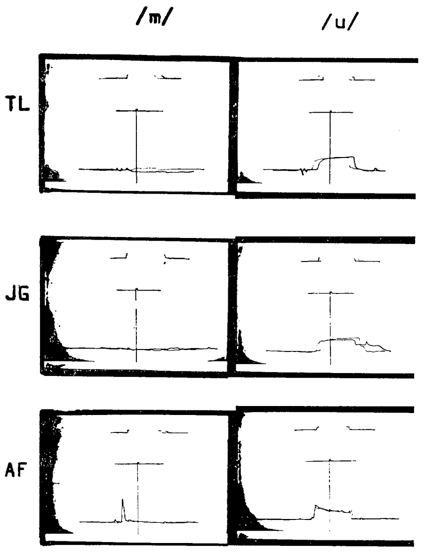


FIGURE 9. Photographs of the superimpositions of the graphic recording tracings for two productions of /m/ and /u/ during session one for each subject.

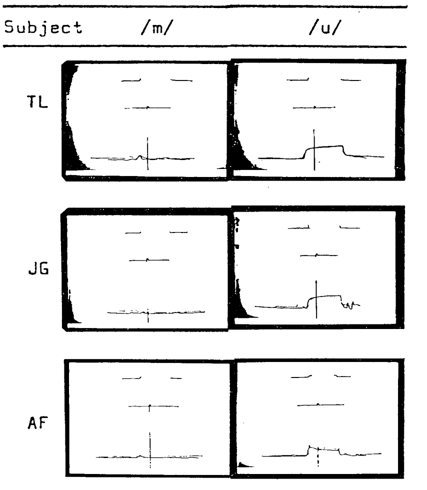


FIGURE 10. Photographs of the superimpositions of the graphic recording tracings for two productions of /m/ and /u/ during session two for each subject.

small. The mean differences across all subjects for session one and for session two were 1.06 mm and 1.10 mm, respectively. These results suggest that the transducer recording values obtained for perceptually similar sounds were consistent, both within and between sessions.

The transducer recording values presented in Table 1 only reflect the magnitude of displacement at one point during the production of a given sound. There were other points during the production of the sounds that similar judgments could have been made. Figures 9 and 10 present some examples of the superimpositions of the entire graphic recording tracings (/m/ and /u/ only) for each subject during session one and two, respectively. In order to obtain the superimpositions, the points at which the perceptual judgments were made (vertical line) were positioned coincident as were the constant horizontal reference lines (lower edge of acetate paper). It is quite obvious that the graphic recordings preceding, during and following productions of similar sounds are highly consistent. This consistency was true for other sounds as well. In some of the photographs in Figures 9 and 10, the apparent gross displacement before or after production results from swallow activity.

Sentence Production. No quantitative measures were obtained for the sentence tasks; however, the two recordings of the sentence task for each subject can be superimposed using approximate onsets of phonation as a coincident point. Obviously, duration of the task varied from production to production. Figures 11 and 12 present the superimposition of the

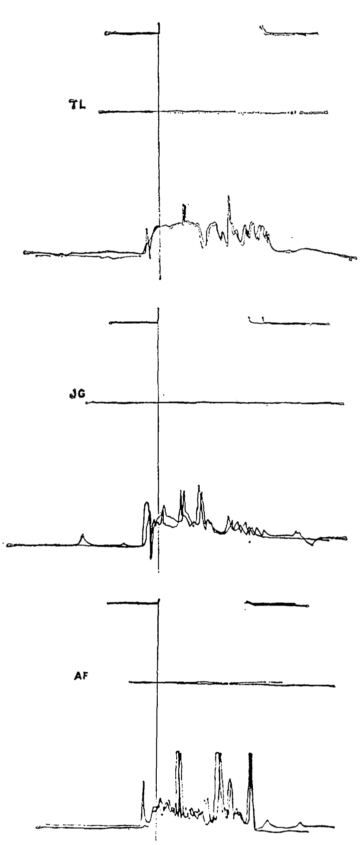


FIGURE 11. Photographs of the superimpositions of the graphic recording tracings for the two productions of the sentence "Sue roasted a duck for supper so ten men came in when Jane rang." during session one for each subject.

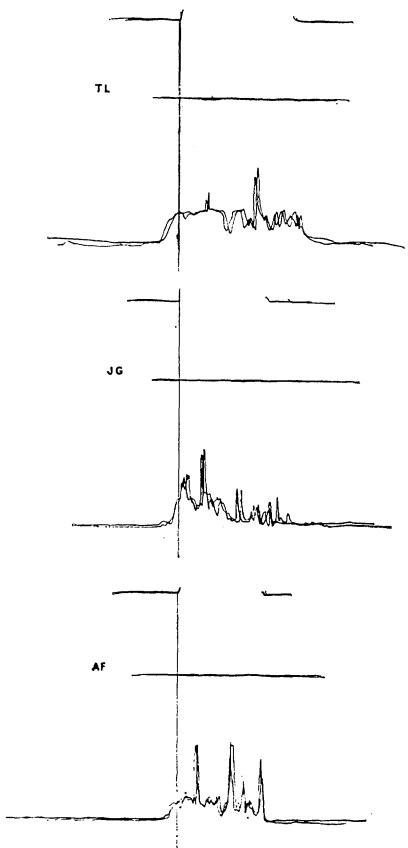


FIGURE 12. Photographs of the superimpositions of the graphic recording tracings for the two productions of the sentence "Sue roasted a duck for supper so ten men came in when Jane rang." during session two for each subject.

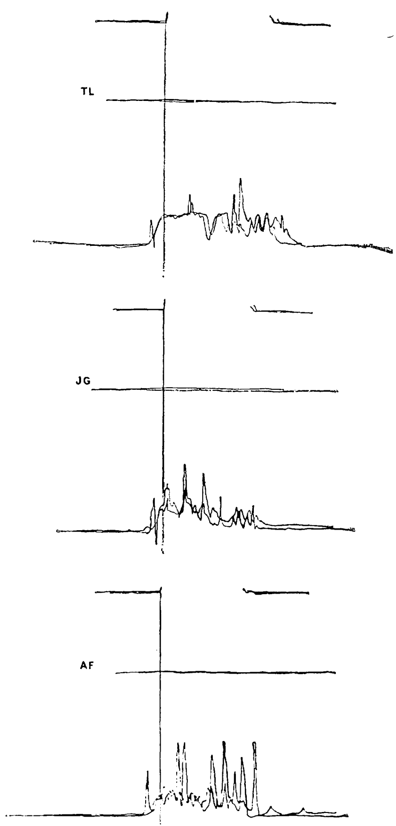


FIGURE 13. Photographs of the superimpositions of the graphic recording tracings for one sentence production during session one and one sentence production during session two for each subject.

graphic recording tracings for the two productions of the sentence for each subject during session one and session two, respectively. Figure 13 presents the superimpositions for one sentence production during session one and one sentence production during session two for each subject. In all these figures, the similarities of the recordings for each subject indicates consistent recording of similar productions of connected speech both within and between sessions.

Radiographic Data. During session three, radiographs were taken simultaneously with the event mark during the two productions of /i/, /a/, and /z/. In addition, two radiographs were taken during "relax" periods —one before and one after production of the sustained sounds. Table 2

TABLE 2. Graphic transducer recording and radiographic values, in millimeters, for the two productions of each task during session three for each subject.

Subject	Task	Transducer Value		Radiographic Value	
		First Production	Second Production	First Production	Second Production
TL					
	/i/	38.7	39.5	9.2	8.9
	/ɑ/	35.8	37.5	10.2	9.7
	/z/	38.3	38.3	9.9	9.1
	rest	18.0	19.1	17.3	16.5
JG	/i/	29.0	29.9	3.9	4.1
	/ɑ/	27.9	26.4	5.2	5.5
	/z/	29.1	30.8		4.4
	rest	18.8	11.7	8.4	11.4
AF					
	/i/	34.8	34.8		7.8
	/ɑ/	26.3	25.5	11.2	10.9
	/z/	35.5	35.5	7.0	6.6
	rest	18.2	17.9	16.0	16.3

presents values obtained from the radiographic tracings and the graphic recording tracings using the measurement procedure described previously. Two of the radiographs were over-exposed and consequently could not be measured. The average radiographic values and average graphic recording values across all subjects for the second production of each sound are plotted in Figure 14. It can be seen that the radiographic values are inversely proportional to the graphic recording values for the same task production; that is, beginning with the rest task, decreasing radiographic values were associated with increasing graphic recording values. The important aspect is that, defined by the measurement procedures used, increased values from the transducer recordings and decreased values from the radiographs both reflect velar elevation. This predictable, linear relationship between the two measures indicates that the transducer technique was assessing velar elevation during the tasks produced in session three at least as well as the more traditional radiographs.

Previous research (Moll, *10;* Moll and Shriner, *11;* Lubker, *5*) has demonstrated that velar elevation varies with different sounds. Generally, high vowels have greater velar elevation than low vowels, and nasal consonants display relatively little velar elevation as compared with non-nasal consonants. In the present study, information concerning relative velar movement or elevation among different sounds was obtained from

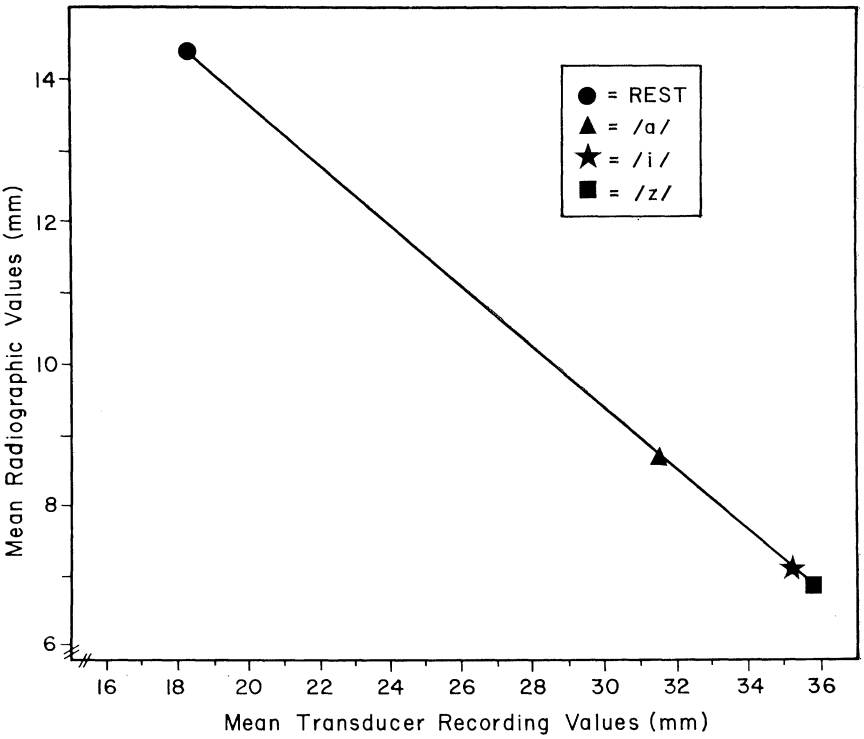


FIGURE 14. Graph showing the relationship of the mean transducer recording values and the mean radiographic values for the second production of each sound for all subjects.

the graphic transducer recordings. For each sound, a mean value over all productions by all subjects was computed and the results are shown graphically in Figure 15. Inspection reveals virtually no difference in velar elevation between conditions of rest and the production of /m/. The low vowel (/æ/, /a/) have similar levels of velar elevation, but considerably more elevation than rest or /m/. The high vowels (/i/ and /u/) and the non-nasal consonant /z/ all have approximately the same level of velar elevation, but are considerably higher than the low vowels. These results are consistent with the cinefluorographic findings of Moll (1963) to the extent that low vowels exhibit less velar elevation than high vowels, and that velar elevation is similar between low vowels or between high vowels.

The graphic recordings obtained during the production of the sentence task also yield information relative to the validity of the transducer appliance in recording velar movement. Figure 16 is a graphic recording of one subject's production of the sentence. In the sentence, "Sue roasted a duck for supper so ten men came in when Jane rang," the words "Sue roasted a duck for supper so" are non-nasal and are associated with a

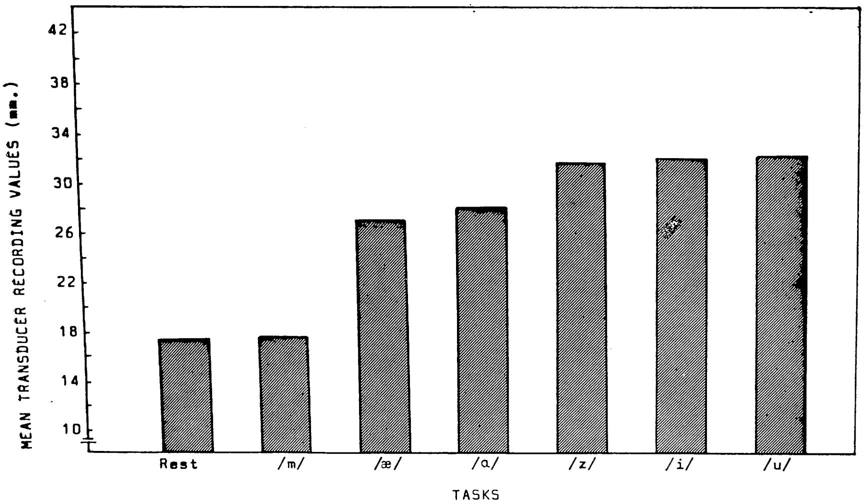


FIGURE 15. Bar graph representing the mean transducer recording values for each task during all sessions for all subjects.

high level of velar elevation. The remaining words in the sentence are pro-nasal, that is, each word contains at least one nasal consonant. However, in the pro-nasal portion of the sentence, four non-nasal consonants are also included, /t/ in ten, /k/ in came, /dʒ/ in Jane, and /r/ in rang. Based on previous knowledge about velar elevation in nasal versus non-nasal sound contexts, the following speculations relative to the observable characteristics of the graphic recording seem pertinent: 1) More observable overall curve height (displacement) associated with the first half of the sentence as compared to the second half, and 2) More peaks in the recording during the second half of the sentence due to the presence of the non-nasal consonants.

Summary and Conclusions

Intraoral appliances utilizing resistance strain gage transducers were constructed and positioned for normal speakers in order to 1) obtain measures of velar movement instantaneously during the production of certain speech tasks, 2) assess the reliability of the instrumentation in measuring velar movement during similar speech tasks over time, and 3) determine the relationship between the obtained transducer measures and simultaneous radiographic measures.

On the basis of the obtained results the following conclusions appear warranted: 1) The response characteristics of the transducer appliances are linear as a function of displacement of the sensor tip. 2) The consistency with which the transducer appliance assesses velar movement and position during similar speech tasks within and between sessions is high. 3) The relationship between obtained transducer measures and radi-

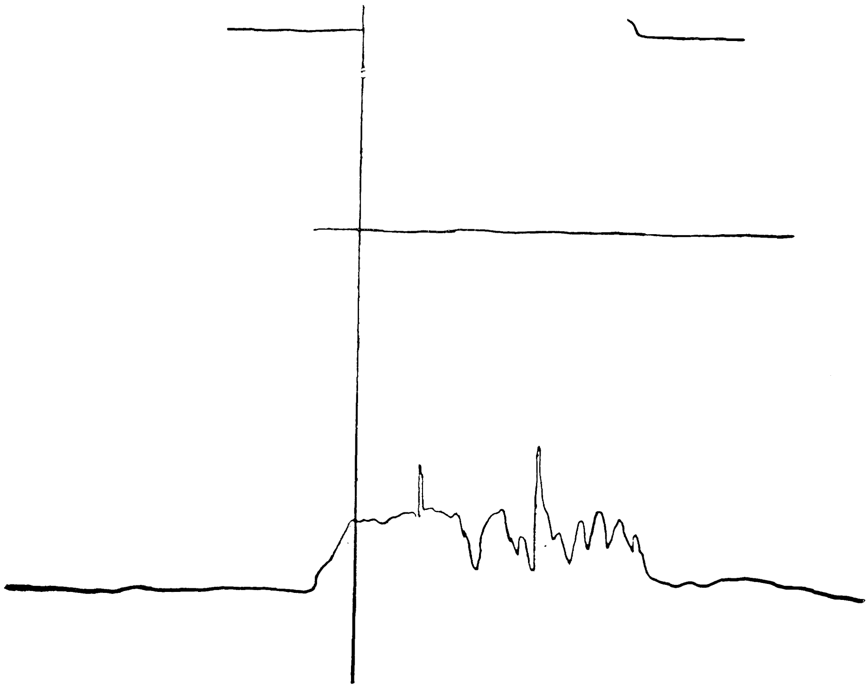


FIGURE 16. Photograph of the graphic recording tracing of one production of the sentence during session one for Subject TL.

ographic measures is high. 4) In general, the transducer appliance appears to be an easily constructed, relatively inexpensive, and unobstructive intraoral device to record velar movement continuously during speech production.

Relationship of the transducer recordings of velar elevation during certain speech tasks with previous knowledge of velar elevation using another technique was discussed.

References

1. Chase, R., An objective evaluation of palatopharyngeal competence. *Plastic Reconstruct. Surg., 26:* 23–39, 1960.
2. Christiansen, R., Moller, K., Wilkes, C., Instrumentation for recording velar movement. Paper presented at I.A.D.R. Convention, Houston, Texas, April, 1969.
3. Christiansen, R., and Moller, K., Instrumentation for recording velar movement. *Amer. J. Orth.* (in press).
4. Fletcher, S., Shelton, R., Smith, C. and Bosma, J., Radiography in speech pathology. *J. Speech Hearing Dis., 25,* 135–144, 1960.
5. Lubker, J., An electromyographic-cinefluorographic investigation of velar function during normal speech production. *Cleft Palate J. 5,* 1–18, 1968.
6. Lubker, J., and Moll, K., Simultaneous oral-nasal air flow measurements and cinefluorographic observations during speech production. *Cleft Palate J., 2,* 257–272, 1965.
7. Lubker, J., and Morris, H., Predicting cinefluorgraphic measures of velo-

pharyngeal opening from lateral still X-ray films. *J. Speech Hearing Res., 11,* 747–753, 1968.

8. MOLL, K., Cinefluorographic techniques in speech research. *J. Speech Hearing Res., 3,* 227–241, 1960.
9. MOLL, K., Photographic and radiographic procedures in speech research. In Proceedings of the Conference: Communicative Problems in Cleft Palate. *ASHA Reports, 1,* 129–139, 1965.
10. MOLL, K., Velopharyngeal closure on vowels. *J. Speech Hearing Res. 5,* 30–37, 1962.
11. MOLL, K., and SHRINER, T., Preliminary investigation of a new concept of velar activity during speech. *Cleft Palate J., 4,* 58–69, 1967.