Simultaneous Oral-Nasal Air Flow Measurements and Cinefluorographic Observations During Speech Production

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The function of the velopharyngeal mechanism has been studied by many investigators using a variety of observational techniques. These methods of observation may be divided into two general categories: a) direct techniques, such as cinefluorographic observations (*2, 4, 18, 19, 20*), which allow the experimenter to make relatively direct observations of the articulatory mechanism, and b) indirect techniques, such as the measurement of oral and nasal air pressures and flows (*1, 3, 5, 11, 14, 15, 17, 21, 23, 24, 26, 27*), that provide information from which the investigator can infer articulatory activities.

Examination of studies in which these techniques have been used suggests the following conclusions: a) There appears to be little, if any, empirical information concerning relationships between articulatory activities and measures of air flows or pressures. b) There appears to be little definitive information concerning the air flow or pressure characteristics of normal speech and the factors which bring about changes in such characteristics. c) The nasal and oral portions of the vocal tract must be considered together, since it has been shown that they produce interacting effects (*7*). Due to such interaction, nasal pressures and flows undoubtedly are related to various oral phenomena as well as to the activities of the velopharyngeal mechanism. d) Many of the techniques used to measure air flows and pressures during speech (for example, plugging the nostrils to create a closed system, placing tubes in the mouth, placing a face mask on the subject) place restrictions of varying, but unknown, degrees on the speech mechanism.

In view of the above conclusions, it is apparent that a technique designed to measure simultaneous oral and nasal air flows in conjunction

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with the direct observation of the articulatory processes would be useful in providing information about the nasal-oral air flow characteristics of speech and the relationship of those characteristics to articulatory variables. The purpose of the present study was to develop a method to measure oral and nasal air flows separately but simultaneously in conjunction with cinefluorographic measurements. Specific goals were a) to devise a face mask which effectively separates the oral and nasal air flows and to determine the effects of such a mask on articulatory positioning and b) to demonstrate a technique whereby such a mask can be used in synchrony with cinefluorographic techniques to investigate the relationships between oral and nasal air flows and various articulatory positions. It should be noted that the purposes of this study are methodological; the study was designed primarily to obtain specific data on the air flow characteristics of speech.

Equipment

CINEFLUOROGRAPHIC EQUIPMENT. The cinefluorographic equipment used in the present study consists basically of an x-ray tube with a .6 mm^2 focal spot, a nine-inch image intensifier tube, and a 16 mm motion picture camera which provides film speeds of 24 frames per second. An optical, unilateral sound track is obtained directly on the film in projection synchronization. More detailed descriptions of the cinefluorographic equipment used in this study are reported elsewhere (*16, 19, 25*).

FACE MASK. A face mask was divided into oral and nasal chambers to allow measurement of air flows from the nose and mouth separately but simultaneously (Figure 1). To obtain such cavity separation, a diaphragm was constructed from ⅜-inch plexiglass to fit tightly against the subject's upper lip so that passage of air between the two cavities was prevented. To provide a more effective seal, a bumper of ¼-inch rubber tubing was glued to the outer edge of the diaphragm.

AIR FLOW EQUIPMENT. A schematic diagram of the air flow instrumentation is shown in Figure 2. Two pneumotachographs were attached to the mask to provide measurement of air flow from each chamber (Figure 1). The pneumotachograph is a flow-metering device designed to offer a minimal amount of resistance to respiration (*6, 8, 9, 10, 22*). A fine wire mesh in the pneumotachograph causes small pressure drop which is linearly related to the rate of air flow. The pressure differentials across each wire mesh were delivered to Statham pressure transducers (Models PM 197 and PM 15) where the pressure variations were converted to electrical signals. The signals from each transducer were amplified (Ellis Associates Model BAM-1 bridge amplifiers) and fed to the two channels of an Offner, type 542, Dynograph paper-writer. The Dynograph provided air flow records on continuously moving paper, at a paper speed of 100 mm/second.

The air flow equipment was calibrated in such a manner that 2.22 mm

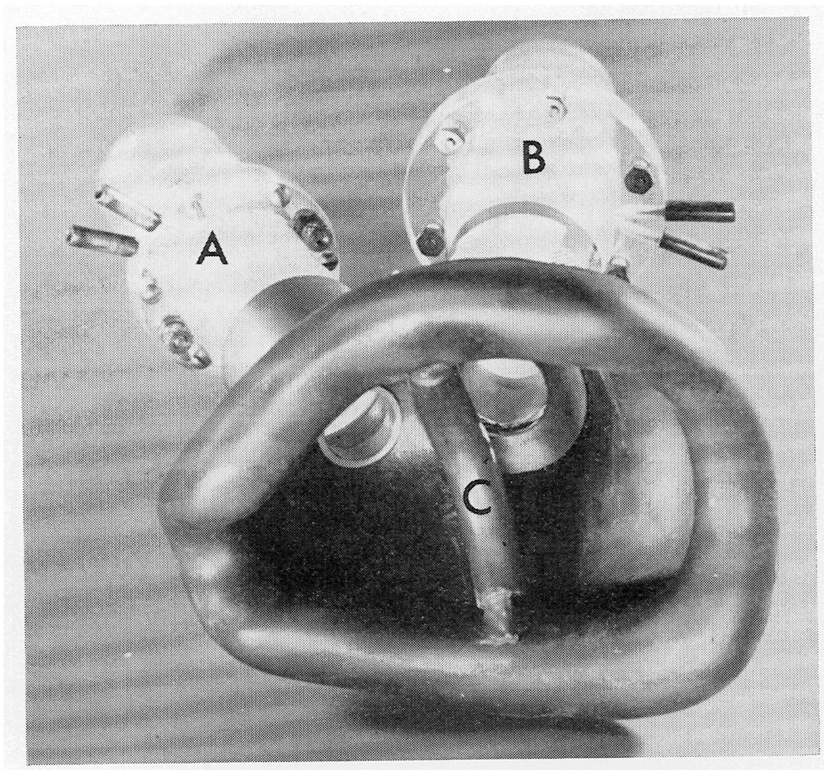

FIGURE 1. Face mask: a) nasal pneumotachograph, b) oral pneumotachograph, and c) diaphragm dividing the oral and nasal cavities.

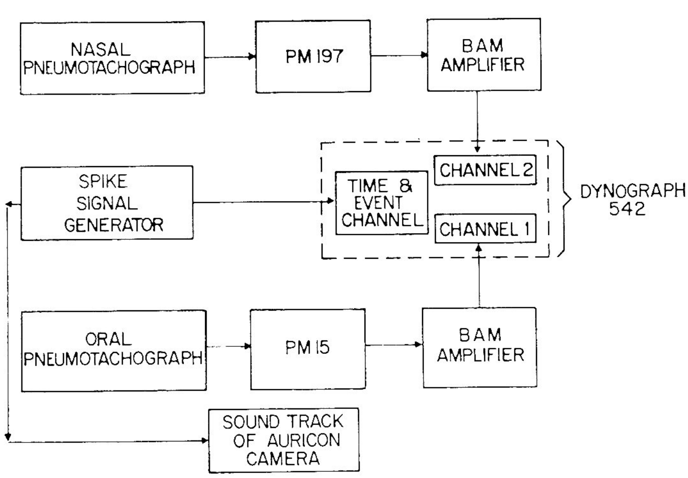

FIGURE 2. A schematic diagram of air flow measuring instrumentation and synchronization equipment.

of pen deflection in the nasal channel indicated a flow of one liter per minute. Due to characteristics of the calibration curves, the total air flow range for the oral channel was divided into three sections. In the first section, 1 mm of pen deflection equaled 4 liters per minute of air flow; for the second section, 1.18 mm of pen deflection equaled 4 liters per minute of flow; and in the third section, 1.68 mm of pen deflection equaled 4 liters per minute of air flow. From these calibration figures, a plastic template was constructed that could be placed directly over the air flow tracing for direct determination of the air flow rate without reference to the pneumotachograph calibration curves.

The effectiveness of the division of the mask chambers was determined by taping the subject's mouth closed, placing the mask in position, and asking the subject to breathe through his nose. A deflection of the pen on the oral channel of the Dynograph would indicate an inadequate chamber separation. A second test was conducted by plugging the subject's nostrils with vaseline-impregnated cotton and requiring him to breathe through his mouth. Again, deflections of the pen for the nasal channel would indicate inadequate division of the chambers. The effectiveness of the seal around the edges of the mask was determined by closing off the openings and instructing the subject to attempt inhalation. The seal was judged effective if inhalation was not possible. No leakage of air occurred under the above two conditions for the subjects in the present study.

Synchronization System. Synchronization between the cinefluorographic film and the air flow records was accomplished through the use of an Offner, type 709, spike generator. This system produced one spike signal per second which was delivered to the time-and-event marker of the Dynograph and to the sound track of the cinefluorographic film (Figure 2). The paper markings and the spike on the sound track provided reference points in time which permitted synchronization of the two systems.

Experiment I

Subjects. Two adult male subjects were used to investigate the effects of the divided face mask on articulatory positioning. Both subjects had normal hearing and articulation.

Speech Sample. The speech sample consisted of the syllables /pa/, /pi/, /ta/, and /ti/ and the sustained vowels /a/ and /i/. Each syllable was produced at a slow rate and at a rapid rate. The slow rate of syllable production was constant and was obtained by requiring the subject to produce each syllable in time with a metronome beat of 208 per minute, which resulted in a rate of 3.46 syllables per second. The rapid rate was defined as being the most rapid production of distinct syllables which the subject could achieve. The speech sample was designed to provide information concerning the effects of the face mask on four aspects of articulation: mouth opening, lip opening, tongue position, and rate of syllable production.

Experimental Procedures. Cinefluorographic films were taken with and without the face mask in position to determine the effects of the face mask on articulatory positioning. The without-mask condition was filmed twice to assess variations in articulatory positioning with repetition of the same task. The conditions occurred in the following order for both subjects: without-mask, with-mask, and without-mask. Vocal intensity was controlled through the use of a throat microphone and a VU meter so that the subjects produced the speech sample at the same intensity level with and without the face mask in position. Each subject was instructed to use his own normal inflectional pattern and pitch level. The order of production of the syllables comprising the speech sample was randomized within each condition for both subjects.

Cinefluorographic Film Analysis. The cinefluorographic films were projected to life size and measurements were made directly from the projected films. Measurements made to determine the effects of the mask on articulatory positioning are shown in Figure 3. These measurements were as follows: a) lip opening (L-O), the shortest distance between the lips; b) incisal opening (I-O), the distance between upper and lower central incisors; c) tongue-alveolar distance (T-A), measured from the tip of the tongue to the alveolar ridge; d) tongue height (T-H), the distance from the highest point on the tongue to the reference line AB; and e) tongue-pharynx distance (T-P), measured from the tongue to the posterior pharyngeal wall along line CD. The latter three measurements provided indices of tongue movement.

Reliability of the cinefluorographic measures was determined by repeated measurement of 50 randomly selected film frames. The product-moment correlation coefficients between the repeated measurements for L-O, I-O, T-H, T-P, and T-A were .98, .72, .99, .98, and .99, respectively. The mean discrepancies for these measures were .87, .58, .41, .50, and .39

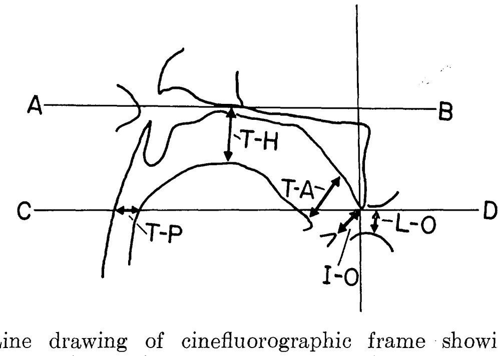

FIGURE 3. Line drawing of cinefluorographic frame showing measurements made to determine the effects of the face mask on articulatory positioning: L-O, lip opening ; I-O, incisal opening; T-A, tongue-alveolar distance; T-H, tongue height; T-P, tongue-pharynx.

mm, respectively. These values are in general agreement with cinefluorographic reliability data reported by Moll (*18*) and Powers (*20*). The reliability of the measures was adequate for the purposes of the present study.

RESULTS. The measures made to determine the effect of the face mask on articulatory positioning indicated that there were definite and consistent effects on lip and incisal opening. No consistent effects on tongue movement were noted. In both subjects lip opening decreased rather markedly and incisal opening increased. Such effects are not surprising since the mask may be expected to force soft tissue structures, such as the lips, together while the jaw tends to compensate for the pressure of the mask by opening farther than it would in unimpeded speech production.

The effect of the face mask on rate of syllable production is shown in Table 1. Examination of these data indicates that both subjects were unable to produce the bilabial /p/ as rapidly as the lingual-alveolar /t/ during the with-mask conditions. Such an effect is to be expected since the bilabials involve greater mandibular and lip movement than do the lingual-alveolar sounds. Further, Subject B appeared to have more difficulty with the rapid, with-mask production of syllables containing the low vowel /a/ than with those involving the high vowel /i/. Subject A, however, appeared to have more difficulty with the rapid, with-mask production of the high vowel /i/. In view of these conflicting data, the possibility exists that the effects of face mask on rate of syllable production is primarily determined by the consonant in the syllable rather than the vowel. It also may be noted that Subject A produced the syllable /ta/ more rapidly with the mask in place than without it. Finally, with

TABLE 1. Maximum rates of syllable production (in syllables per second) for different face-mask conditions. The difference value is the difference between the mean of the two without-mask conditions and the with-mask condition.

Syllable	*Subject*	*Mask Condition*			*Difference*
		With	*Without #1*	*Without #2*	
/pa/	A	4.95	5.61	6.62	1.16
	B	5.77	6.89	6.65	.99
/pi/	A	4.17	5.66	6.30	1.81
	B	5.60	5.94	6.34	.54
/ta/	A	6.82	5.82	6.89	−.47
	B	6.38	7.20	6.86	.65
/ti/	A	5.19	5.04	6.06	.36
	B	6.07	6.08	6.29	.10

the exception of Subject B on /pa/ and /ta/, the second without-mask production rate always exceeded that of the first without-mask production, suggesting that the subject's rate increased with practice. Thus, the mask appeared to have definite effects on maximum rate of syllable production, the extent of those effects appearing to be dependent upon the particular phoneme produced.

Experiment II

SUBJECT. One subject, an adult male, was used to demonstrate a method for measuring oral and nasal air flows synchronously with cinefluorographic observations.

SPEECH SAMPLE. The speech sample consisted of the nonsense syllables, /pin/, /pat/, /nap/, /pan/, /put/, /tap/, /pit/, /tup/, /nup/, /nip/, /pun/, /tip/, /næp/, /pæn/, /tæp/, and /pæt/, inserted in the carrier sentence, 'Say ________ again.' The sample was constructed so as to contain high and low vowels and nasal and non-nasal consonants. Cinefluorographic films were taken synchronously with oral and nasal air flow measures while the subject produced the speech sample. The subject was instructed to speak at a comfortable intensity and pitch level and at a conversational rate.

CINEFLUOROGRAPHIC FILM ANALYSIS. The projected cinefluorographic frames were traced, and measurements made from the tracings. The change from the direct measurement technique used in Experiment I was made because this technique was considerably more arduous than was the tracing method. Also, there appeared to be no significant differences in the reliabilities of the two procedures.

The measurements used to investigate the relationship between articulatory positioning and air flow rates appear in Figure 4. Two measures, incisal opening and lip opening, designed to provide an index of mouth opening, have been described previously in Experiment I. Three addi-

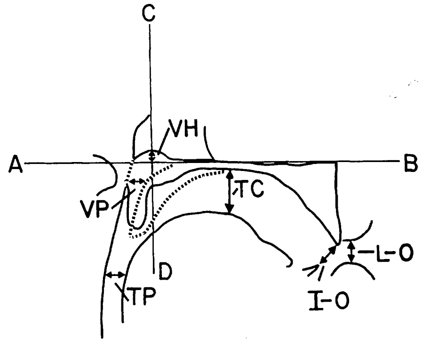

FIGURE 4. Line drawing of cinefluorographic frame showing measurements made in relating articulatory positioning to oral and nasal air flow rates: I-O, incisal opening; L-O, lip opening; T-C, tongue constriction; V-P, velo-pharyngeal distance; and V-H, velar height.

tional measures were made. Tongue constriction (T-C)[1] is a measure of the point of greatest constriction between the tongue and hard palate or alveolar ridge. Velum-pharyngeal distance (V-P) is the closest distance between the velum and posterior pharyngeal wall. Velar height (V-H) is the distance of the most superior point on the velum above reference line AB measured along the line CD drawn perpendicular to AB. Five mm were added to all measures of velar height to eliminate negative values.

Analysis of Air Flow Record. As described previously, the spike generator produced a signal at the rate of one per second which was applied to the time-and-event marker of the Dynograph and to the sound track of the cinefluorographic film. These synchronization marks on the air flow record corresponded in time to specific cinefluorographic frames exposed during the speech production. A detailed description of these synchronization procedures can be found elsewhere (*16*). Measures of nasal and oral air flow rates were made at each of these established points using the calibration template described previously. Measurement-remeasurement of 50 randomly selected 'frames' of the air flow record showed a mean discrepancy of .75 liters per minute for the oral channel and .18 liters per minute for the nasal channel. The magnitude of these measurement errors appears to be reasonably small.

Results

Evaluation of the Sampling Technique. Characteristics of the equipment used in the present study placed certain limitations on the assessment of the relationship between articulatory positioning and oral-nasal air flow. Since the air flow record is of a continuous nature, it is possible to sample an unlimited number of points along the time line. The present study, however, was concerned with the relationship between air flow and articulatory positioning, the latter being obtained from the measurement of cinefluorographic films. Therefore, when comparing air flow with articulatory positioning, only those points on the air flow record which corresponded to frames of cinefluorographic film exposed during the speech sample were used. For example, in a typical syllable such as /nip/, filmed at 24 frames per second, six cinefluorographic frames were exposed. Thus, only six sample points were located on the air flow record. To assess the adequacy of this sampling rate in describing the air flow curve, this record also was analyzed using 10, 15, and 20 sample points. The plotted curves changed appreciably as the number of points was increased to 15 with little change between curves for 15 and 20 sample points. This suggests that a minimum of 15 samples are necessary to provide an accurate description of the air flow record for the syllable /nip/. With fewer samples, the data do not reflect all of the peaks and valleys of the original flow curve. Assuming that all fluctua-

[1] The term *tongue constriction* is used here in the conventional sense to refer to a constriction of the oral cavity.

tions in the air flow record are of interest and that it is desirable to relate all such fluctuations to articulatory events, the need for higher film speeds becomes apparent. In order to provide an adequate number of sampling points for the syllable discussed above, film speeds of 60 to 80 frames per second would be necessary. This finding tends to corroborate the suggestions made elsewhere that a film speed of 24 frames per second is not adequate for describing articulatory events (*18*).

Another advantage in using faster film speeds concerns the effect of film speed on the width of the sampling space. At 24 frames per second, 4.1 mm along the air flow record is equal to one frame of cinefluorographic film. The camera shutter, however, is open to expose the film during only one-half of that time. The question then arises as to which half of the 4.1 mm space on the air flow record corresponds to the actual exposure of the cinefluorographic frame. Since this could not be determined in the present study, air flow was measured at the midpoint of each space. It is apparent that, at higher film speeds, corresponding distance along the air flow record would decrease. For example, if film speeds of 72 frames per second were used, 1.37 mm along the air flow record would be equivalent to one frame of cinefluorographic film. High film speeds decrease sampling error, thereby increasing the correspondence between measure of air flow and articulatory positioning.

IMPLICATIONS OF COMPARISONS OF AIR FLOWS AND ARTICULATORY POSITIONS. Figures 5, 6, and 7 present data concerning oral-nasal air flow and articulatory positions for various speech productions. Time is represented on the abscissa of each figure; the numbers refer to individual cinefluorographic frames. The distance between adjacent numbers on the abscissa represents approximately 42 milliseconds. The lower of the three graphs in each figure shows changes in velopharyngeal distance and velar height. The upper graph indicates variations in oral and nasal air flows with time. Changes in the articulatory positions are described in terms of distance in millimeters and air flow rate is noted in liters per minute. The data appearing in these figures represent those cinefluorographic frames immediately preceding the initiation of speech, as well as the phrase, 'say __________'.

In addition to the limitations concerning the adequacy of the sampling technique discussed above, it should be noted that there appears to be a time lag between the air flow and cinefluorographic systems. This time lag is especially noticeable in Figure 7 where it is seen that the oral air flow point directly coincidental with complete tongue constriction for the production of /t/ shows a maximum amount of air flow. Had the two systems been perfectly synchronized, little or no oral air flow would be expected, since the oral channel presumably is completely closed. This time lag also may be due to sampling errors resulting from an attempt to relate points on the continuous flow records to discrete cinefluorographic frames.

Due to these limitations, a point-by-point comparison of the air flow

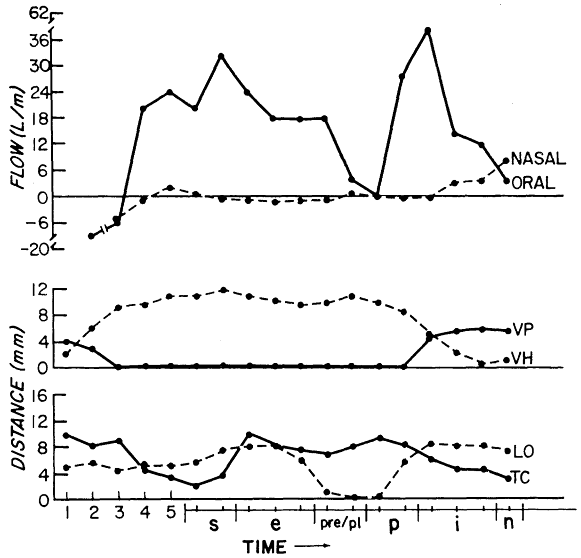

FIGURE 5. Oral and nasal air flow rates and articulatory positioning for the phrase /se pin/: V-P, velopharyngeal distance; V-H, velar height; L-O, lip opening; and T-C, tongue constriction.

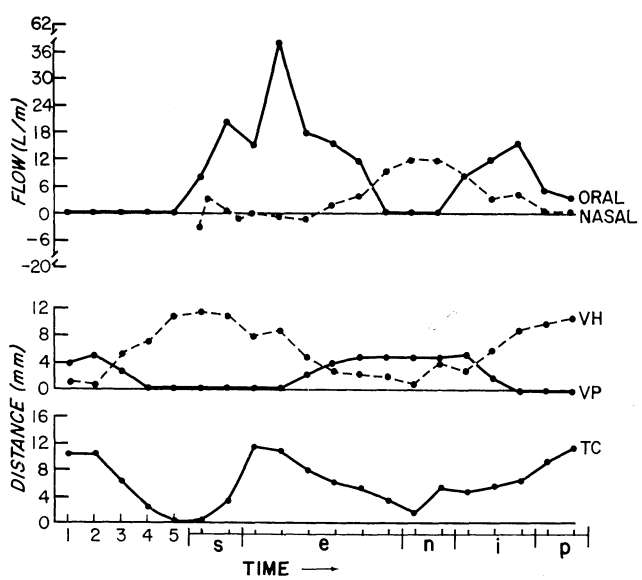

FIGURE 6. Oral and nasal air flow rates and articulatory positioning for the phrase /se nip/: V-H, velar height; V-P, velopharyngeal distance; and T-C, tongue constriction.

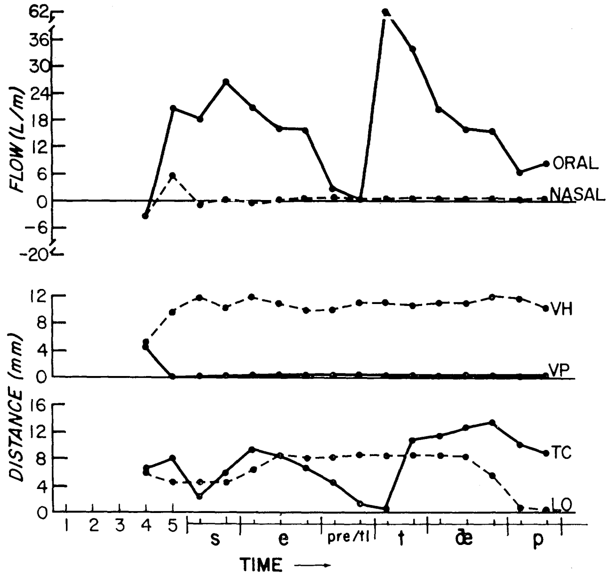

FIGURE 7. Oral and nasal air flow rates and articulatory positioning for the phrase /se tæp/: V-H, velar height; V-P, velopharyngeal distance; T-C, tongue constriction; and L-O, lip opening.

record and the articulatory measures was not attempted; however, general trends were noted. Since the data presented in the graphs represent only one subject, the statements made concerning these data should be taken only as implications for further study.

Figures 5, 6, and 7 show a small burst of nasal air flow just preceding or coincidental with the initiation of phonation. This finding supports data reported by Young (*27*). It also can be noted that this burst of nasal air flow occurs when the velopharyngeal distance is zero. The question arises as to how nasal flow of air can exist if the velopharyngeal orifice is closed. It is possible that the measure of velopharyngeal distance obtained from the cinefluorographic films is not an adequate index of velopharyngeal opening; that is, there may be closure at the midline, but there may be openings in the airway at the lateral borders of the velopharyngeal port which would allow air flow to continue. If this were true, nasal air flow would decrease as velar height increases, indicating tighter closure of the velopharyngeal port. Examination of the flow records indicates that such is not the case; air flow tends to increase as velar height increases. This latter observation gives rise to a second hypothesis. It is possible that the velopharyngeal port is completely closed when the cinefluorographic measure of V-P is zero but that the velum continues to rise as indicated in the V-H measure. An increase in velar elevation would decrease the size of the nasal chambers and force a small burst of air from the nose. It will be noted that immediately following the small burst of nasal air flow, nasal flow reverses direction and becomes slightly negative for several frames. Furthermore, slight lowering of the velum corresponds to this negative flow of air. Thus, it is possible that, with a closed velopharyngeal port, nasal flow of air may exist in either direction because of movements of the closed velum which create changes in nasal cavity size. The possibility that such small bursts of nasal flow are caused by velar movement is substantiated when air volume is computed. For example, in Figure 7 a total volume of approximately .0042 liters of air is expired from the nose as speech is initiated. A very small change in nasal cavity dimension could account for such an expiration.

Examination of the last two measures for /e/ and of both measures for /n/ in Figure 6, and of all measures for /i/ and /n/ in Figure 5 suggests that there is an increase in air flow from the nose while the amount of velopharyngeal opening remains constant and velar height decreases. There are at least two possible explanations for this increase in air flow while the orifice size appears to remain constant. First, velopharyngeal orifice area may be increasing even though velopharyngeal distance at the midline does not change; that is, the measures of velopharyngeal distance may not provide an adequate index of velopharyngeal opening. On the other hand, it is possible that an increase in nasal air flow is due to an increase in tongue constriction rather than to an increase in velopharyngeal orifice area. That there was an increase in nasal air flow as tongue constriction increased may be seen in Figures 5 and 6. Although the present data are insufficient to determine which of these alternatives, if either, is correct, it should be noted that the data obtained by House and Stevens (*12*) and Kaltenborn (*13*) suggest that sound transmission through the nose tends to increase as oral cavity constriction increases.

Examination of Figures 5, 6, and 7 indicates that oral air flow is correlated with the amount of oral constriction (tongue constriction and/or lip opening). As tongue constriction increases, oral air flow tends to decrease. Also, as lip opening decreases, oral air flow tends to decrease. Refined synchronization techniques and higher film speeds may provide a method for determining whether air flow variations are due entirely to valving of the air stream rather than, as has been suggested by Stetson (*24*), being partially due to pulses of flow from the respiratory system.

Discussion

The face mask was found to have definite effects on labial and mandibular movement and on maximum rate of syllable production. It is difficult to assess the significance of the mask's effect on maximum rate of syllable production, since this rate is not characteristic of normal speech production. The face mask did not appear to affect the conversation rate of syllable production, since the subjects could produce the syllables at the slow rate of 3.46 syllables per second with ease while wearing the mask. Although the presence of the face mask did not affect tongue movement, it is possible that such effects might occur with other types of speech samples than those studied. The mask may have altered the effort required to produce the speech samples, although both subjects reported that, while the mask was somewhat uncomfortable, it did not necessitate the use of extreme effort to produce speech.

Because of the restrictions which the presence of the face mask imposes on articulatory movements, the usefulness of this technique in describing the air flow characteristics of normal speech may be limited. However, if an investigator desires only to relate given amounts of oral and nasal air flow to given articulatory positions, even though these positions may not represent normal positions for the particular event, the restrictions of the face mask may be of less consequence. It may be possible to minimize such restrictions by developing a mask different from that used in the present study. For instance, a larger mask that fits over the mandible rather than directly on it may be used. Two major problems arise in attempts to use larger face masks. First, by enlarging the mask, a vast amount of dead space is added to the system. Comroe (*6*) points out that dead space must be kept to a minimum in order to make certain that the subject maintains normal breathing patterns. He found that the small, oronasal anesthesia masks produced suitably small amounts of dead space while the larger masks, such as the full-face gas mask, contained prohibitively large amounts of dead space. The question arises as to which factor is relatively more important, that is, the slight restriction to the articulators or a marked increase in dead space which could conceivably upset the patterns of inspiration and expiration normally used and thereby affect the air flow patterns for speech. Secondly, any increase in size of the face mask also will increase the amount of space that must be sealed off between the oral and nasal cavities and, therefore, will make it more difficult to achieve an air-tight seal between the cavities.

Further suggestions for reducing the restrictions imposed by the face mask include gluing the mask to the subject's face, coating the edges of the mask with a material such as vaseline, suspending the mask in such a manner that very little weight is borne by the subject, and combinations of these techniques. While it is recognized that such techniques may have merit and are worthy of closer examination, it appears that any mask which fits tightly enough to prevent air leaks around the mask edges and between the oral and nasal chambers is very likely to impose some restrictions upon labial and jaw movements.

Two other problems with the present technique are the inadequate number of sampling points obtained from the air flow record and the apparent lack of precise synchronization between the air flow records and cinefluorographic film. The number of sampling points can be increased adequately by increasing the film speed. Such an increase in film speed may also provide better synchronization of the two measurement systems, since the absolute size of the time involved in relating flow and articulatory measures would be decreased.

In spite of the limitations present in the technique, several interesting observations, which should be studied further, were made in Experiment II. The data indicate that changes in nasal air flow are not dependent solely on variations in velopharyngeal opening, but are related also to changes in oral constriction. This implies that one measure, such as velopharyngeal orifice distance, is not sufficient to describe the articulatory factors related to nasal air flow. This has been recognized by Warren (*26*) in his attempts to measure velopharyngeal orifice area. The present study emphasizes the complex nature of the speech production process and the need to make simultaneous observations of various parameters. Only by such observations can the interactive effects of articulatory movements on air flows be described fully.

Although the air flow measurement technique used in this study has certain limitations and can possibly be improved, it promises to provide a means whereby information concerning the relationships between oral-nasal air flow and articulatory positions may be obtained. At present there appear to be no better methods available for determining such relationships.

Summary

The present study was designed to develop a method to measure oral and nasal air flows separately but synchronously with cinefluorographic observations. The purpose of Experiment I was to develop a face mask that provided effective division of oral-nasal air flow and to determine the effects of the mask on articulatory positioning. Cinefluorographic films were taken of two subjects with and without the mask in position. Five measures of articulatory position were made from individual cinefluorographic frames to determine the effects of the divided face mask on the articulators.

Experiment II demonstrated a method whereby such a mask might be used to investigate relationships between oral-nasal air flows and various articulatory positions. Cinefluorographic films were taken synchronously with oral-nasal air flow measures for one subject. Measurements obtained from frame-by-frame analysis of the cinefluorographic film were compared with measures of oral-nasal air flow rates in liters per minute. Certain trends in the relationships between air flow rates and articulatory positioning were noted.

The following conclusions were made on the basis of the data obtained: a) The face mask used in the present study was found to have small but definite effects on labial and mandibular movement and on maximum rate of syllable production. For the speech sample used in the present study no effect on tongue movement was noted. b) Film speeds of 60 to 80 frames per second appear necessary to provide adequate sampling of air flow variations and, therefore, of the articulatory factors related to such variations. c) Positive or negative air flows may exist when the velopharyngeal port is closed because of fluctuations in the height of the

velum. d) The data indicate that nasal air flow is dependent not only upon the amount of velopharyngeal opening but also upon the amount of oral constriction. This suggests the need for multiple evaluation techniques in the study of speech physiology. e) In spite of the limitations of the observation technique used, the technique can provide important information on speech physiology. Further, there appears to be no better technique presently available for investigating the relationships between articulatory events and oral-nasal air flow.

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