SUMMARY

The purpose of this investigation was to study certain aspects of velar dynamics among normals. Two adult subjects, one male and one female, were filmed using high-speed (100 fps) lateral-view cineradiography. Small radiopaque cups were attached to the surface of the soft palate and other articulators for tracking purposes. Trajectories of the velar fleshpoint in the midsagittal plane were demonstrated. Measures of velar velocity, velar displacement, and duration of transitional movements were studied in relation to the effects of phonetic context and speaking rate variation and were compared to the activity of other articulators. Velar positioning also was studied during nasal consonant production in relation to the effects of vowel context.

A Cineradiographic Investigation of Velar Movement Variables in Two Normals

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A familiar question asked in the cleft palate clinic is whether or not a particular patient achieves velopharyngeal closure for speech and, if not, how large is the space during palatal elevation. If a patient exhibits a large velopharyngeal space during palatal elevation, it is likely that this patient will produce speech that is characterized by hypernasality and excessive nasal emission of air. On the other hand, as suggested previously (Yules and Chase, 1968), if a speaker exhibits little or no velopharyngeal space during palatal elevation as determined by lateral-view x-rays, for example, this speaker may not necessarily be perceived as a normal speaker. Carney and Morris (1971) have shown that adult speakers judged to be hypernasal frequently exhibit velopharyngeal closure at least in the midsagittal plane during vowel production. Such closure was also reported by McWilliams, et al, (1968); but they noted loss of contact when certain patients were placed in an extended position.

The results of these studies suggest that factors other than lack of velopharyngeal closure in the midsagittal plane may be related to hypernasality in some cases. One possible factor may be that, in some patients, velopharyngeal open-

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ings persist during velar elevation lateral to midline which would not be detected using traditional lateral-view x-ray techniques. Another factor may be poor timing of velopharyngeal closure in relation to other articulatory activity. Although numerous studies have been reported concerning velar positioning and patterning of movement (see Dickson, et al., 1974) for a comprehensive bibliography), few investigators have studied the timing of velar movements in relation to other articulatory activity (Kent, et al., 1974; Moll and Daniloff, 1971; Subtelny, et al, 1969).

Closely involved in the timing of articulatory events is the speed with which articulatory movements are accomplished. The data of Blackfield, et al., (1962) and Nylen (1961) suggest that the time required for velar elevating or lowering gestures is similar for normals, cleft palate subjects, and velopharyngeal incompetent patients without cleft palate. Data from two other studies (Hoopes, et al, 1970; Yules and Chase, 1968) suggest that the actual speed of velar movement during speech is greater for normals than for cleft palate and velopharyngeal incompetent subjects. It is difficult to determine the compatibility of the results of these two pairs of studies since measures of velar displacements were provided in only one of them (Hoopes et al., 1970). If the normal and clinical groups exhibited articulatory transitions that were similar with regard to *time* intervals, it follows that these groups would exhibit articulatory *velocities* that would differ only if corresponding differences in *displacements* also occurred.

Compared with other articulators, the soft palate is sometimes considered to be "sluggish" in its movement (Hudgins, and Stetson, 1937). This appears to be especially true in some cleft palate individuals, but data substantiating such a claim are lacking. It would appear that future investigations should provide more complete information regarding movement of the soft palate as a single articulator but also in relation to the dynamics of other articulators. For example, a certain patient might move his palate much more slowly than normal. However, if adequate closure is achieved within the time domain dictated by movement of the other articulators, this might explain the normally oral instead of hypernasal speech for this patient.

The purpose of the present investigation was to study velar elevating and lowering movements with regard to velocities, displacements, and time required for such movements in relation to changes in phonetic context, to speaking rate variation, and to the behavior of other articulators. Normal speaking adult subjects were utilized, and the experimental technique involved lateral-view high-speed cineradiography. The results of this study, along with those of other similar studies, should serve as a basis for comparison with velar movement measures of cleft palate individuals.

Procedure

SUBJECTS. Two young adults, one male (Subject RS) and one female (Subject HK), served as subjects. Neither had a history of orofacial pathology, and both were judged to produce speech normally, including appropriate oral-nasal resonance balances.

Speech Sample. The speech sample is shown in Table 1. Two different speaking rates, normal and more rapid than normal, were utilized. Various consonants were selected to provide different places and manners of articulation as well as different voicing conditions. The different vowels were chosen to provide contrastive tongue positioning. It can be seen that the "vowel-oral consonant-nasal consonant-vowel" (VCNV) and the "vowel-nasal consonant-oral consonant-vowel" (VNCV) columns for both speaking rate conditions involve the same speech sounds but that the oral and nasal consonant sequence is reversed in one column compared to the other. The purpose of this was to study both velar elevating and velar lowering gestures in a comparable phonemic environment.

In the normal speaking rate condition, each subject produced each VCNV and VNCV utterance embedded in the carrier phrase, "Say —— again." In the rapid speaking rate condition, the VCNV and VNCV utterances listed were each spoken three times in quick succession. The size of the speech sample was necessarily restricted to keep the radiation dosage well within safe limits (less than 2.0 R for each subject).

Filming Procedure. Just prior to filming, radiopaque markers (thin metal cups approximately 3.5 mm in diameter) were attached to the midline of soft tissue structures including the depression on the elevated soft palate. Figure 1 shows a tracing of a cineradiograph for each subject. The tongue and lip markers were attached using a dental adhesive (Durelon), and the velar marker was sutured to the mucosa following application of a topical anesthetic. This technique had been used successfully previously (Kent, et al., 1974) and resulted in only minor subject discomfort during initial application. The subjects were allowed to adapt to the fleshpoint markers prior to filming.

The cineradiographic equipment used has been described previously (Kent and Moll, 1969). The filming speed was 100 frames-per-second resulting

TABLE 1. Speech sample.

1. Normal speaking rate condition; Carrier phrase: "Say _____ again."

VCNV	*VNCV*
/atna/	/anta/
/adna/	/anda/
/itni/	/inti/
/utnu/	/untu/
/asna/	/ansa/
/alna/	/anla/
/apma/	/ampa/
/ipmi/	/impi/
/apna/	/anpa/

2. Rapid speaking rate condition; Spoken three times each:

VCNV	*VNCV*
/atna/	/anta/
/apma/	/ampa/

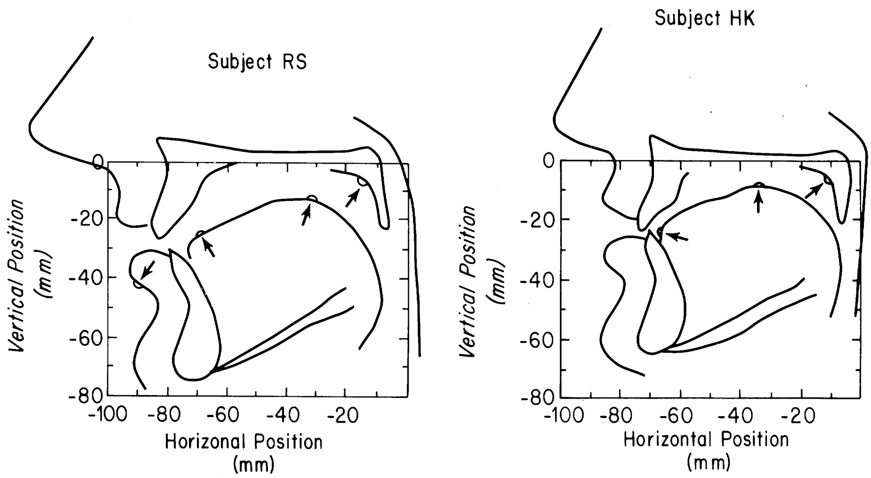

FIGURE 1. Tracing of a cineradiograph for each subject. Arrows indicate the fleshpoint markers. Instantaneous marker positions relative to the maxilla were determined within the coordinate system shown for each subject. A = Subject RS; B = Subject HK

in an interframe sampling period of 10 msec. A tape recording of the speech sample was obtained synchronously with the film to verify the intended utterance production and to aid in subsequent segmentation of movement sequences observed on the film.

Film Analysis. To aid in film analysis, two templates were drawn on millimeter-ruled grids for each subject. One template for each subject consisted of a tracing of easily observable maxillary structures and the other was a tracing of mandibular structures. The films were analyzed on a frame-by-frame basis by projecting the image to life-size, superimposing a template on the corresponding maxillary or mandibular image, and reading off the instantaneous position of the center of each marker on the grid to the nearest half-millimeter. Repeated measurements by the experimenter indicated a standard error of less than 1.0 mm for each marker. The mandibular template (coordinate system) was used to determine lingual and labial movement independent of the jaw component motion (Kent and Moll, 1972). Instantaneous velar positions were determined only within the maxillary coordinate system which is shown for each subject in Figures 1a and 1b.

With the aid of computer processing, the x-y coordinate points were utilized to reconstruct movement paths in the mid-sagittal plane for each of the fleshpoint markers (Kuehn, 1973). Measures of velocity were determined for the transitional movement of fleshpoint markers from one steady-state (zero velocity) position to the next. This was accomplished by computing a running total of the distance moved (cumulative displacement) of each marker from one film frame to the next throughout a transitional movement and plotting these cumulative displacement values as a function of time (10 msec. intervals). This resulted in characteristically S-shaped curves with an elongated linear (constant velocity) middle portion. The slope of this relatively linear portion of the cumulative displacement-versus-time curve was used as an index of velocity. In addition to the velocity measures described, the total cumulative displacement moved by a marker during a transition also was recorded along with the time involved in the movement from the first observable (half-millimeter or greater) movement away from a steady-state to the last observable movement into the following steady-state. Repeated measurements by the experimenter of these starting and ending points of articulatory movements indicated a standard error of less than two film frames (less than 20 msecs.).

In summary, measures of velocity, displacement, and time were determined for transitional movement of each fleshpoint marker including that of the soft palate. In addition, beginning and ending time points were recorded for various articulatory maneuvers.

Results

TRAJECTORIES OF THE VELAR FLESHPOINT. Figures 2a and 2b show the path of movement in the midsagittal plane of the velar fleshpoint marker for each subject. Points during lowering and during elevation are included on the same graph, and the corresponding paths (that is, lowering versus elevation) are essentially the same. It can be seen that the paths are quite linear forming

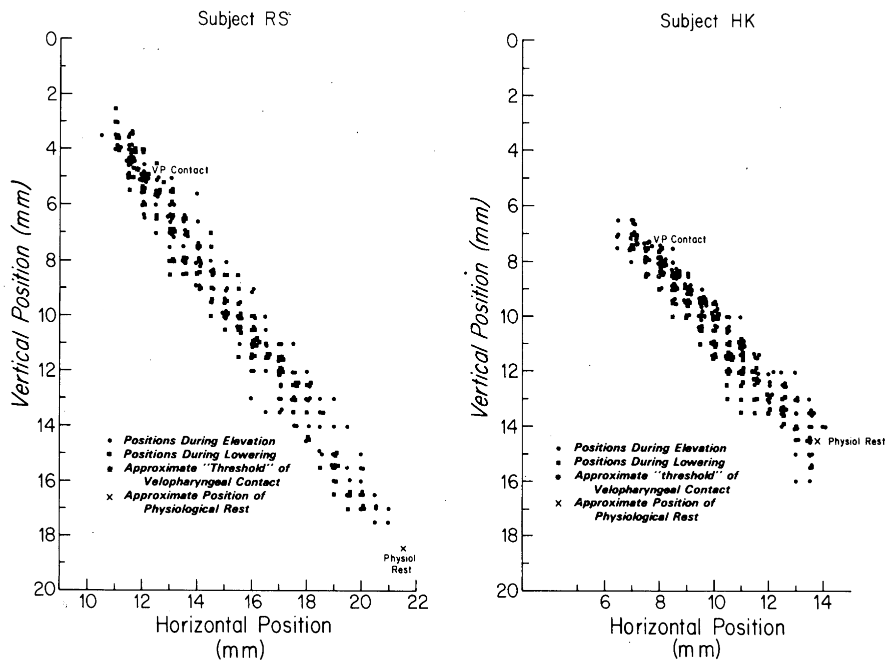

FIGURE 2. Trajectories of the velar fleshpoint marker for each subject. The x and y axes correspond approximately to the planes of the hard palate and posterior pharyngeal wall respectively. Individual data points represent instantaneous velar positions during various elevating and lowering gestures throughout the speech sample. A = Subject RS; B = Subject HK

TABLE 2. Velar transitional movement measures: velocity, displacement, and time.

utterance	*velar lowering (CN sequences)* subject HK velocity mm/sec.	displacement mm	time msec.	subject RS velocity mm/sec.	displacement mm	time msec.
VCNV						
/a*tn*a/	31	4.7	150	78	6.8	100
/a*dn*a/	72	7.6	120	132	7.0	80
/i*tn*i/	58	3.1	70	97	5.9	90
/u*tn*u/	51	3.0	50	116	7.3	80
/a*sn*a/	50	6.3	100	107	7.3	100
/a*ln*a/	47	3.2	80	38	5.0	130
/a*pm*a/	34	4.5	80	97	8.4	100
/i*pm*i/	48	3.8	60	98	6.5	80
/a*pn*a/	49	5.8	150	101	9.8	110
mean	49	4.7	96	96	7.1	97
std. dev.	12	1.6	37	26	1.4	17
VNCV						
/a*nt*a/	86	10.2	140	114	8.3	100
/a*nd*a/	88	10.3	150	104	11.7	140
/i*nt*i/	59	3.3	60	107	9.6	110
/u*nt*u/	66	5.5	100	108	8.1	120
/a*ns*a/	71	9.6	150	113	11.3	100
/a*nl*a/	67	6.6	140	54	5.8	120
/a*mp*a/	65	9.5	140	115	10.7	100
/i*mp*i/	53	6.0	100	99	8.0	90
/a*np*a/	72	9.8	140	121	10.5	100
mean	70	7.9	124	104	9.3	109
std. dev.	11	2.6	31	20	1.9	15

an angle with the hard palate of approximately 60° for Subject RS (the male) and approximately 50° for Subject HK (the female). These values are within the range (41° to 74°; 54° mean angle) reported by Simpson and Austin (1972), and the steeper movement path exhibited by the male appears to be consistent with previously reported sex differences (McKerns and Bzoch, 1970).

The velar fleshpoint movement paths reported by Kent. et al, (1974) can be compared directly to those shown in Figure 2 of the present study. The movement paths shown in their study appear to be much more curvilinear than those of Subject RS and Subject HK. A contributing factor to curvilinear movement would be the sliding motion upward along the posterior pharyngeal wall after palate-to-pharyngeal wall contact has been made. It is possible that their subjects (two males) exhibited a greater degree of this sliding motion than the subjects in the present study.

VELAR VELOCITIES, DISPLACEMENTS, AND TRANSITION TIMES. Table 2 shows the velocity, displacement, and time measures obtained for velar fleshpoint movement from one steady-state position to the next within the utterances listed. The consonant sequences involved are italicized. For example, during the phrase "say /atna/ again," Subject HK lowered the soft palate marker a total distance of 4.7 mm from a position appropriate for /t/ to a position appropriate for /n/ at a speed of 31 mm/sec, and it required 150 msecs. to accomplish this maneuver. It can be seen that the measures varied considerably depending on the phonetic context and speaker. Because of the need to restrict the size of the speech sample, multiple tokens of a given utterance to determine intra-utterance variability were not obtained.

It should be noted that values listed in Table 2 have been obtained for sequences involving presumably oral consonants and nasal consonants immediately juxtaposed. It is known that velar movement may in some cases extend over at least two vowel segments between a position of closure for an oral consonant and a position of opening for a nasal consonant (Kent, et al, 1974; Moll and Daniloff, 1971). In such cases, it follows that the duration of velar transitional movement would be substantially longer than the values shown in Table 2 and that the velocity of movement would probably be much slower. Therefore, the velar movement values presented in Table 2 should be viewed as among the most rapid and involving the shortest duration for these two speakers for their normal speaking rate mode. It can be seen that, for Subject HK, velar elevating gestures during NC sequences were substantially faster, involved greater total displacements, and usually took longer than velar lowering movements during mirrored CN sequences. The same general trend was observed for Subject RS, but the mean differences in the elevating and lowering measures were not as large.

Table 2 also shows that Subject RS (the male and larger of the two) exhibited velar transitional movements that were generally faster and of greater magnitude than Subject HK, but velar transitional durations were not systematically different for the two subjects. These results are consistent with previously observed trends suggesting that speakers with relatively large oral structures tend to move their articulators greater distances between steady-state positions and at faster speeds than speakers with relatively small oral structures while the time intervals involved in such maneuvers do not vary as consistently (Kuehn, 1973).

Velar velocities also were measured for the initial palatal elevation required for the consonant /s/ in the carrier word "say." For one subject, it was noted that the palate sometimes began its elevation after the tongue tip moved toward /s/ constriction. In these cases, the palate moved relatively rapidly from a lowered position to an elevated position. On the other hand, when the palate began its movement in advance of the tongue tip, it moved more slowly. Figure 3 shows this relationship. The other subject did not exhibit the strong relationship ($r = .91$) shown in Figure 3, but for this subject palatal movement always began well in advance of tongue tip movement for the /s/ in "say."

Final velar lowering at the end of each carrier phrase appeared to con-

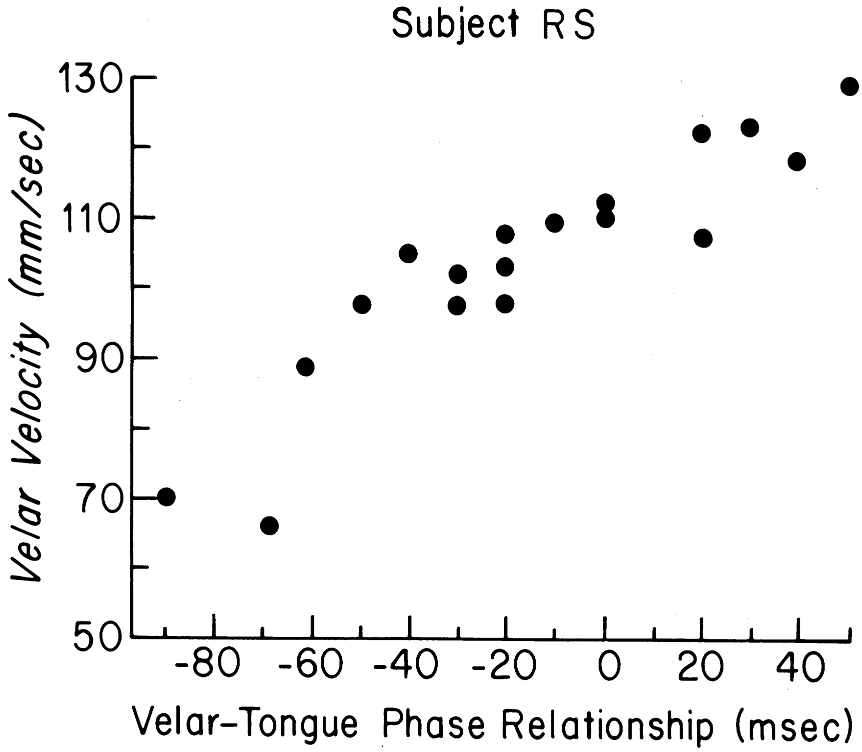

FIGURE 3. Velar velocities in relation to the relative initiation of velar and tongue movements for /s/ at the beginning of the carrier phrase. Positive values along the abscissa indicate occurrences in which the initiation of palatal movement followed the beginning of tongue tip movement.

sist of two distinct quasi-linear velocity functions: 1) a relatively rapid lowering in anticipation of the final /n/ (in the carrier phrase) followed by 2) a very slow and gradual lowering to physiological rest position. This pattern was consistent for both subjects.

Comparison of Velar and Lingual Velocities and Displacements. In viewing cineradiographic films of cleft palate individuals with surgically repaired palates, one sometimes has the impression that certain patients exhibit palatal movements that are inordinately slow compared to movements of other articulators. To gain a gross indication of the relative speed and magnitude of palatal movement compared to that of other articulators in normals, average measures of velocity and displacement of the velar fleshpoint were compared to those of the lingual fleshpoint markers. The results are shown in Table 3. The lingual measures involve transitional movements from vowel steady-state positions to consonant steady-state positions (oral cavity occlusions or constrictions) and vice-versa. Tongue tip measures are shown for both the maxillary and mandibular coordinate systems. Tongue dorsum measures are shown for the maxillary coordinate system only since the jaw contributed very little to dorsal movement for these two subjects. That is, tongue dorsum measures were very similar for both coordinate systems. Velar measures involve the same sequences (raising and lowering) as those listed in Table 2.

The results shown in Table 3 indicate that the palate generally moves slower than the tongue for both subjects. However, it may also be seen that palatal displacements between steady-states also are generally less than those of the tongue. These results are consistent with those of a previous investigation (Kuehn, 1973) which showed a fairly close relationship between the magnitude of displacement of an articulator and the speed with which it is moved. That is, if an articulator is moved farther than that of another during a phone-to-phone gesture, it generally is moved faster. These results suggest that, in assessing the rate of articulatory movement of an articulator among patients, the relative distances moved by that articulator should be taken into account. This would appear to be especially relevent in patients exhibiting a large adenoidal mass which would restrict the magnitude of velar movement.

VELAR POSITIONING AND COARTICULATION. With regard to the effects of phonetic context, the extent of velar coarticulation was studied for all oral-nasal and nasal-oral consonant sequences. Most of the supposedly oral consonants studied were indeed characterized by a closed or nearly closed velopharyngeal port at least during a portion of the oral consonant steady-state even though each was either preceded or followed by a nasal consonant. An exception to

TABLE 3. Means, standard deviations, and ranges of the velar and lingual fleshpoint marker velocities and displacements.

subject	*articulator*	*velocity (mm/sec)*			*displacement (mm)*		
		mean	*SD*	*range*	*mean*	*SD*	*range*
HK	velum	59	16	31–88	6.3	2.6	3.0–10.3
	tongue tip (re: maxilla)	120	42	53–221	9.3	2.9	3.0–13.7
	tongue tip (re: mandible)	107	38	51–208	8.0	2.5	2.8–12.7
	tongue dorsum (re: maxilla)	81	31	27–147	7.1	3.3	1.6–13.9
RS	velum	100	23	38–132	8.2	2.0	5.0–11.7
	tongue tip (re: maxilla)	152	46	58–270	11.3	3.3	4.6–15.9
	tongue tip (re: mandible)	125	41	50–246	8.8	2.6	3.4–14.0
	tongue dorsum (re: maxilla)	118	37	67–185	10.0	3.7	4.1–16.5

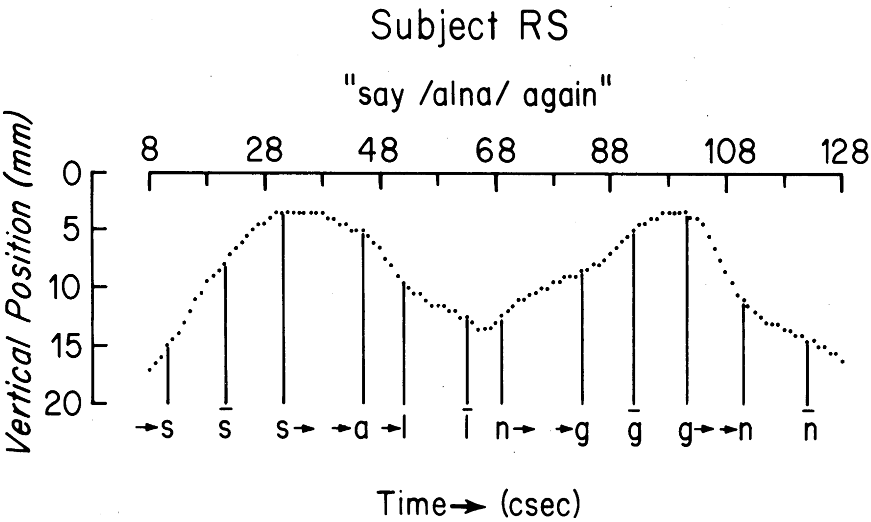

FIGURE 4. Vertical movement of the velar fleshpoint marker during the phrase "say /alna/ again" for Subject RS. An arrow pointing to a phoneme (eg. → s) indicates the first film frame of observable articulatory movement toward that phoneme; a line over a phoneme (eg. s̄) indicates the first film frame of its steady-state; and an arrow pointing away from a phoneme (eg. s →) indicates the first film frame of articulatory movement away from its steady-state. Vertical lines indicate time points (film frames) during which these events occur.

this was the consonant /l/. Figure 4 is a velar movement profile showing the instantaneous vertical positions of the velar fleshpoint marker as a function of time with various articulatory events marked along the abscissa. The phrase is "say /alna/ again" (not all the phonemes have been labeled along the abscissa) and the profile shows that the velar lowering gesture for the nasal consonant /n/ in the word "/alna/" is almost fully completed at the beginning of the steady-state /l/. A similar profile was observed for the other subject. Moreover, both subjects also exhibited a large velopharyngeal opening during /l/ in the word /anla/. This suggests that velopharyngeal closure for /l/ is not crucial if it is in a nasal consonant environment.

For one subject, production of the low vowel /a/ had a pronounced lowering effect on velar positioning even if the vowel was not immediately preceded or followed by a nasal consonant. Figure 5 shows a velar movement profile of such an occurrence. It can be seen that the palate was lowered through a large portion of the /a/ preceding /s/ in "/asna/", then was elevated to increase oral pressure during the /s/, and then was lowered again to accommodate the following /n/. The velopharyngeal port was not completely closed during any portion of the /s/ in "/asna/." This was true for the other subject as well even though the low vowel /a/ had a much smaller lowering effect while the palate was in an elevated position for this subject.

In studying the production of /-sn-/ sequences among normals, Lubker, et al (1970) consistently found an interval of acoustic silence during the /s/-to-/n/ transition. One of the explanations offered by these authors was that

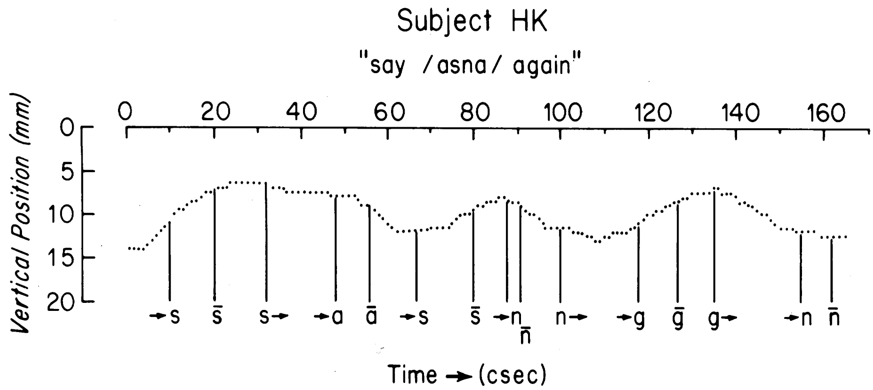

FIGURE 5. Vertical movement of the velar fleshpoint marker during the phrase "say /asna/ again" for Subject HK. (See Figure 4 legend for description of symbols.)

"velopharyngeal opening may occur, in anticipation of the /n/, during the last part of the /s/ production so that air escapes through the nose instead of producing the turbulent noise source at the oral constriction." Since velopharyngeal opening was observed throughout /s/ constriction for both subjects in this study, it is possible that the /s/-to-/n/ silent interval also may be related to adduction of the vocal folds in anticipation of the voiced nasal which would greatly reduce the oral air pressure at the termination of the fricative allowing this pressure to be expended through the nasal and oral cavities with little or no audible turbulence. It would appear that a rather delicate balance between intraoral air pressure and nasal coupling in such consonant sequences must be maintained throughout the fricative. Otherwise, excessive nasal emission of air might result.

For phone sequences that differed only with regard to place of consonant production (the utterances /atna, apma, apna/ and /anta, ampa, anpa/), patterns of velar movement were found to be quite similar within subjects. This was determined by studying movement profiles such as those in Figures 4 and 5. A certain degree of economy in velar movement programming is suggested by these results. Although velar positioning and timing of movement are importantly related to the sequencing of oral and nasal consonants, relatively invariant patterns of velar movement might be utilized in some cases despite rather gross variation in oral cavity occlusions and constrictions.

One final note concerning the effects of phonetic context involves the positioning of the velum during the nasal consonant. This has received little attention in the literature. To determine the effects of vowel context on velar positioning during the nasal consonant, the lowest coordinate position of the velar fleshpoint marker was recorded for each of the high vowel utterances /ipmi/, /inti/, /impi/, /itni/, /utnu/, /untu/, and the low vowel utterances /apma/, /anpa/, /atna/, /ampa/, /apna/, /anta/. The two groups were matched for manner and sequencing of consonant production. Intragroup averages were computed and the results are shown in Table 4. Numerous studies (Bzoch, 1968; Lubker, 1968; Moll, 1962) have shown that velar elevation is higher within a high vowel context than a low vowel context. The results presented in Table 4 suggest that, during velar lowering for the nasal consonant, the velum also is higher within a high vowel context than within a low vowel context. It appears that the entire locus of normal palatal movement between lowered and elevated positions rather than just the highest point of elevation is shifted depending on the particular vowel or vowel category within the phonetic environment.

THE EFFECTS OF SPEAKING RATE VARIATION. Table 5 summarizes the effects of an increase in speaking rate on velar movement variables. The consonant sequences italicized were compared for the normal and rapid speaking rate conditions. It can be seen that velar transitional displacements and durations (time) were consistently reduced with an increase in speaking rate for both subjects while velar velocity either increased or decreased. The reduction of velar displacements with an increase in speaking rate has been demonstrated previously (Kent, et al., 1974; Moll and Shriner, 1967) and is another example of the well-documented phenomenon referred to generally as articulatory undershoot (Lindblom, 1964).

TABLE 4. Means and ranges in mm's of the lowest velar fleshpoint position during the nasal consonant within high (/i, u/) and low (/a/) vowel contexts. (The smaller the value, the higher the vertical position within subjects.)

vowel category	*subject HK*		*subject RS*	
	mean	*range*	*mean*	*range*
high	10.6	9.5–11.5	9.7	8.5–11.0
low	14.3	12.5–15.5	12.3	11.0–13.5

TABLE 5. Velar transitional movement measures: velocity, displacement, and time for normal and rapid speaking rate conditions.

utterance	*speaking rate*	*subject HK*			*subject RS*		
		velocity mm/sec.	*displacement mm*	*time msec.*	*velocity mm/sec.*	*displacement mm*	*time msec.*
/a*pm*a/	normal	34	4.5	80	97	8.4	100
	rapid	57	4.1	70	75	4.2	70
/a*mp*a/	normal	65	9.5	140	115	10.7	100
	rapid	74	6.4	110	121	7.6	90
/a*tn*a/	normal	31	4.7	150	78	6.8	100
	rapid	45	3.0	70	77	4.1	80
/a*nt*a/	normal	86	10.2	140	114	8.3	100
	rapid	81	9.1	130	120	7.1	90
means	normal	54	7.2	127	101	8.5	100
	rapid	64	5.6	95	98	5.7	82

The two subjects appeared to differ in their control of velar undershoot. Figures 6 and 7 show velar movement profiles for the utterances labeled above them, each of which was produced at a rapid speaking rate. To the right of each profile are pairs of horizontal lines which indicate the vertical range and position of the velar fleshpoint excursion during the corresponding utterance produced in the normal speaking rate condition. Subject RS (Figure 6) did not elevate the palate as far superiorly for rapid speech as for the normal speaking rate whereas the most inferior palatal positions were essentially the same for both speaking rates. Figure 2 shows that, during the normal speaking rate for Subject RS, the palate often slid up the posterior pharyngeal wall after velopharyngeal contact had been made. This movement during closure would appear to be aerodynamically dispensable and thus permissible for this subject to elevate the palate during rapid speech to a position just sufficient to achieve velopharyngeal closure. This would allow reduction of the total upward excursion. On the other hand, during the normal speaking rate condition Subject HK did not exhibit a great deal of upward palatal movement after velopharyngeal closure (see Figure 2) and could,

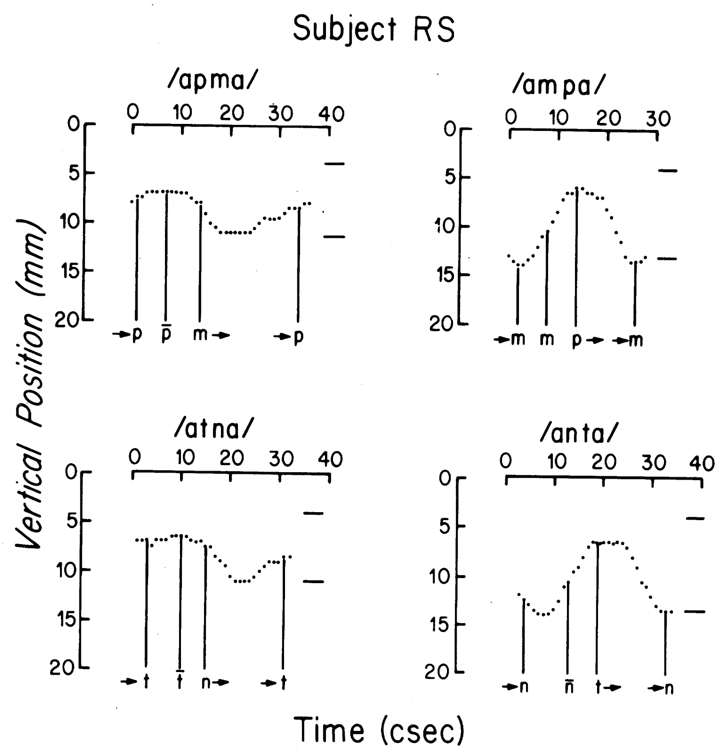

FIGURE 6. Vertical movement of the velar fleshpoint marker for Subject RS during rapid production of the utterance indicated above each graph. (See Figure 4 legend for description of symbols.) Pairs of horizontal lines to the right of each graph indicate the vertical range and position of the velar fleshpoint excursion during the corresponding utterance produced at the normal speaking rate.

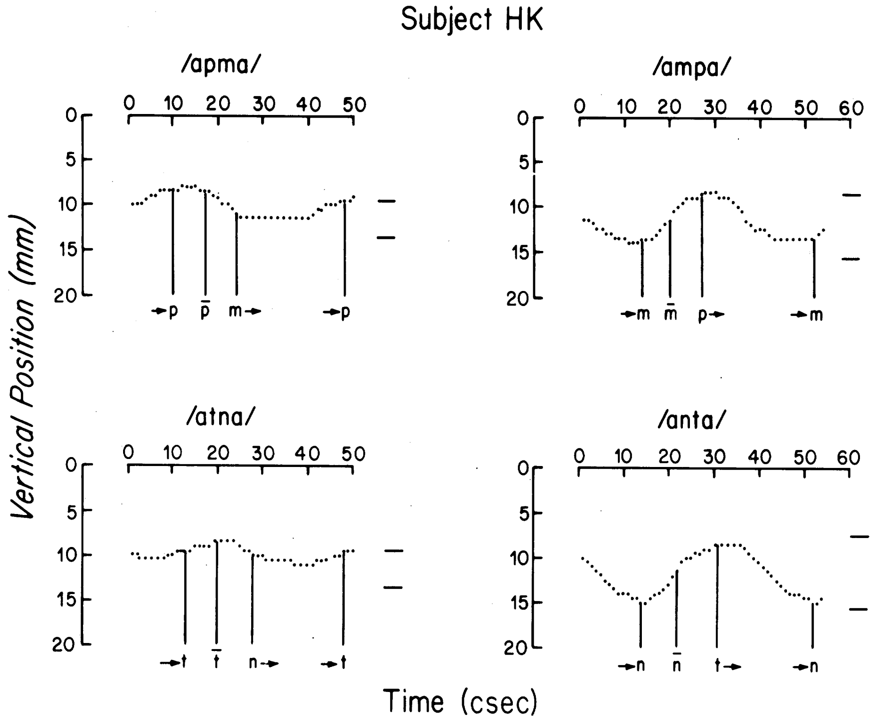

FIGURE 7. Vertical movement of the velar fleshpoint marker for Subject HK during rapid production of the utterance indicated above each graph. (See Figure 4 legend for description of symbols.) Pairs of horizontal lines to the right of each graph indicate the vertical range and position of the velar fleshpoint excursion during the corresponding utterance produced at the normal speaking rate.

therefore, not reduce upward palatal movement during rapid speech. Consequently, to reduce total displacement (undershoot) Subject HK tended not to lower the palate as far inferiorly during rapid speech as she did during the normal rate.

Figures 6 and 7 also show that patterns of velar movement and timing in relation to other articulatory activity are similar for the pairs /apma/-/atna/ and /ampa/-/anta/. These pairs differ in place of oral production but not in manner of production or voicing characteristics. It was noted previously that in the normal speaking rate mode, patterns of velar movement were similar for phone sequences that differ only with regard to the place feature. These results indicate that this similarity is maintained within speakers even with an acceleration in speaking rate.

Discussion

As in any study involving a small number of subjects, the results of this investigation must be considered typical for the subjects involved, and generalization to the population of normal speakers awaits further experimentation. Nevertheless, certain tentative conclusions may be drawn. In general, the results suggest that certain aspects of normal palatal movement are rather simple. In agreement with previous research (Kent, et al, 1974) the trajectory of normal palatal movement appears to be fairly constant regardless of the magnitude or speed of movement or whether the palate is being lowered or elevated. However, the degree of curvilinearity of velar trajectories may vary considerably among normal speakers. It appears that very similar patterns of velar movement may be appropriate for different consonant sequences provided the consonants differ in place of oral occlusion rather than in manner of production (for example, nasal, glide, fricative, plosive). The effect of changing the vowel context may be to produce a constant shift in the locus of velar movement. With regard to the effects of speaking rate variations, the normal velopharyngeal mechanism appears to deal with such changes quite efficiently so that adequate closure is still achieved at appropriate times even though speaking rate may be accelerated appreciably. Speakers may adopt different strategies for changing velar activity to accomodate to speaking rate variation.

Movement of the normal velum may be characterized by a fairly wide range of velocities and displacements depending on the demands of the speaking situation. Whether this versatility is attributable to graded input commands to the velopharyngeal musculature, to peripheral feedback loops, to purely mechanical constraints, or to a combination of all these cannot be specified at the present time. With regard to the cleft palate individual, the range of velar movement variation in relation to such factors as phonetic context and speaking rate changes is not known. One might speculate, for example, that an inadequate increment in velar velocity or displacement when needed may be an important contributive factor to oral-nasal resonance and/or air flow imbalances. Other possible contributive factors to such imbalances may be poor timing of velar movements in relation to the activity of other articulators or the lack of the interarticulator monitoring, when necessary, observed between the palate and tongue of one subject in the present study. These are areas that all clearly require further investigation.

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