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Larynx height during English stop consonants*

Carol J. Riordan
Department of Linguistics, Phonology Laboratory, University of California, Berkeley, Ca. 94720, U.S.A.

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Abstract: Many studies argue that larynx lowering would effectively maintain the transglottal airflow necessary for voicing to continue during stop closure. The empirical support for this hypothesis is primarily the tendency of the larynx to be lower for voiced than for voiceless stops. Earlier discussion, however, frequently do not state that a larynx height difference affects glottal airflow only if it implies an increase in supraglottal volume during closure. To investigate larynx movement during closure and how it relates to oral pressure build-up, larynx height and intraoral air pressure were monitored while two subjects produced intervocalic bilabial stops. The results are damaging to the hypothesis that speakers regularly lower the larynx during voiced stops only to reduce the pressure-equalizing effect of oral closure. Although differences in larynx height between voiced and voiceless stops were observed, there were no consistent differences in the magnitude or frequency of larynx *lowering* during closure between the stop categories. Further, the larynx lowered during nasal stops, although nasal airflow presumably maintains transglottal airflow without cavity-enlarging maneuvers. Finally, there was no unique relationship between paired larynx height/ pressure values for the voiced stop as might be predicted.

Introduction

If transglottal pressure equalization stops glottal pulsing within 4–20 ms of oral closure (Rothenberg, 1968; Catford, 1977), how do speakers produce voiced stop closures of 80–100 ms (Lisker & Abramsom, 1964)? Larynx lowering might increase the capacity of the vocal tract to absorb glottal airflow and thus delay pressure equalization.

The empirical support for the larynx lowering hypothesis is primarily an observed difference in larynx height between voiced and voiceless stops during closure: the larynx tends to be lower for the voiced series (Jespersen, 1889; Hudgins & Stetson, 1935; Kent & Moll, 1969; Even & Krones, 1974), particularly at the moment of release (Ewan, 1976). Discussion of these data, however, do not always make explicity that a difference in larynx height affects glottal airflow only if it implies an increase in supraglottal volume *during the closure interval.*

In this paper I shall present additional larynx height data and try to show that they are consistent with previously reported data, but at the same time damaging to the hypothesis that, at least in English, the larynx lowers during voiced stop production only to prolong vocal cord vibration.

Method

Other things being equal, differences in larynx height between voiced and voiceless stop cognates imply differences in supraglottal cavity volume. However, calculations by

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Rothenberg (1968) and Catford (1977) indicate that a larger *vs* smaller oral volume would not substantially affect the time to pressure equalization brought on by articulatory closure. On the other hand, an increase in oral volume during closure which more or less compensated for the volume of air flowing into the cavity could delay equalization. To find out whether such a change in larynx height actually occurs, larynx height was measured every 8 msec while two adult male English speakers produced 16 tokens each of intervocalic /p,b,m/ produced in a sentence frame. VCV sequences were used since continuous glottal pulsing (and, therefore, pharyngeal expansion) is most likely to occur in this context (Lisker & Abramson, 1964, 1967). Three vowel contexts were used: /a/, /i/ and /u/. Subjects were instructed to stress the second vowel. Larynx height data was obtained using the thyroumbrometer, a photoelectric device which can detect vertical larynx movements of 1 mm or more (Ewan & Krones, 1974; Riordan, 1978). Simultaneous intraoral air pressure changes were sampled using a nasal catheter and recorded along with a reference audio signal. The complete instrumental set-up is shown schematically in Fig. 1.

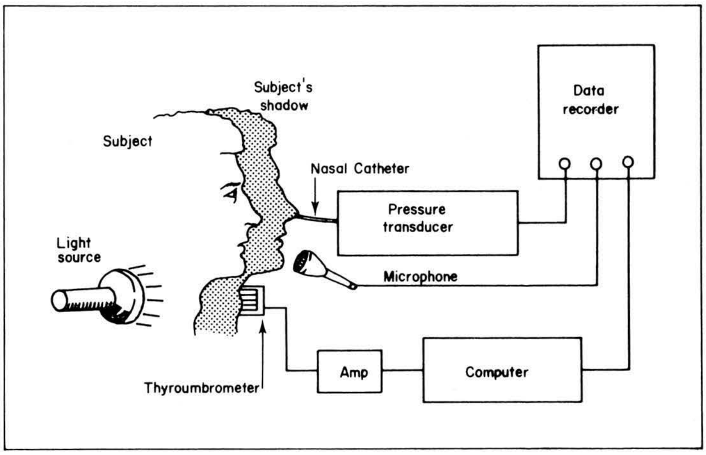


Figure 1 Instrumental set-up.

Results

Change in larynx height during closure

Figure 2 presents the frequency distributions for the change in larynx height during closure (ΔLH) for /p/ and /b/ produced by both subjects. At the top of each graph is a histogram showing the distribution of ΔLH values during the production of /p/ (open bars), and at the bottom of the graphs the distribution for /b/ (filled bars). Although the distributions for /p/ and /b/ are not the same, the extensive overlap in the histograms for the two stop categories is remarkable. A t-test revealed no significant difference in ΔLH observed for /p/ versus /b/ produced by each subject. Of course, given the different durational characteristics of voiced and voiceless stops, the timing of larynx movements may vary. Nonetheless, although the larynx is generally lower for /b/ than for /p/ consistent with earlier studies, larynx *lowering* is not limited to voiced closures given the prosodic conditios of this sample (VCV).

Larynx behavior during occlusion appears to depend on vowel context. Figure 3 presents some representative data from one subject. In this figure, /p/ and /b/ are differentiated with respect to vocalic context, and vertical larynx movement for the three utterance types is plotted as a function of time. Each point is the average of 10 measurements, and measurements were taken every 8 ms from 80 ms before consonant closure to 80 ms after release. The data for the voiced stop (filled circles) and voiceless stop (open circles) are lined up at consonant onset. It is evident that vowel context affects larynx height in at least two ways. First, the absolute level of the larynx varies: the larynx is lower for sequences containing rounded /u/ than for those with spread /i/ or /a/, agreeing with the findings of Sundberg (1968, 1969), Perkell (1969), Ewan & Krones (1974) and Riordan (1978), among others. Second, and more relevant for this discussion, it is only in the /a/ context that the larynx lowers during closure only for /b/ and not for /p/, as might be predicted if lowering were primarily to maintain voicing. The larynx lowers for both voiced and voiceless stops produced in /i/ and /u/ contexts. In fact, the larynx lowers more for /p/ than for /b/ in /u-u/ sequences, partly, of course, because the rate of larynx lowering is about the same for the two stops, but /p/ has longer duration.

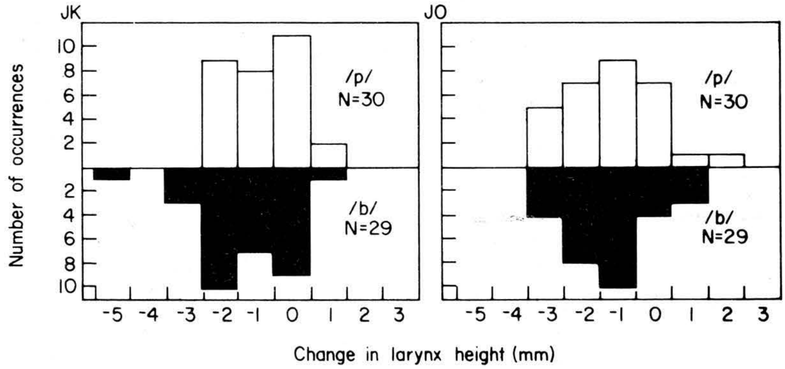


Figure 2 Frequency distributions of the change in larynx height during closure for /p/ and /b/ produced by two subjects. In each graph, the height of the open bars is proportional to the number of /p/ repetitions for which the difference in larynx height between oral closure and release corresponds to the millimeter intervals along the x-axis. Solid bars indicate the data for /b/.

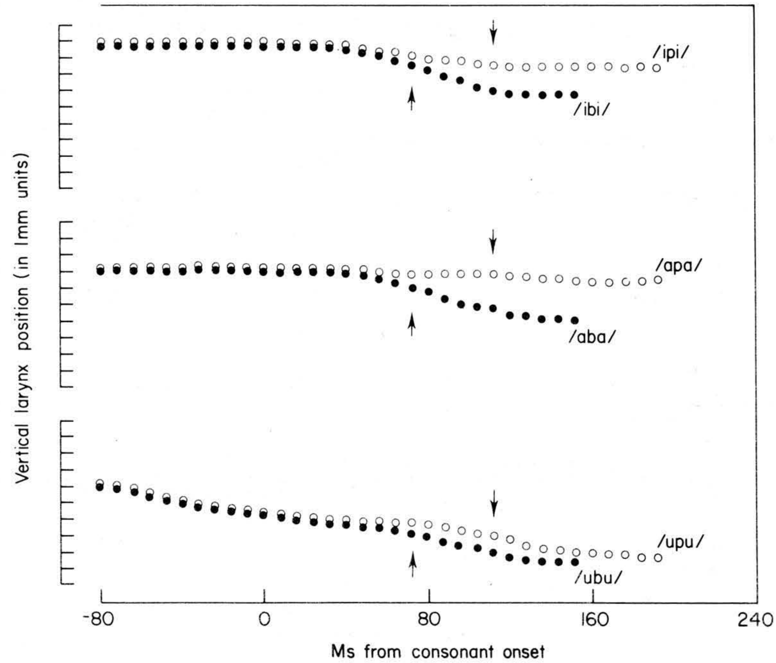


Figure 3 Vertical larynx movements during 1 subject's production of intervocalic /p/ and /b/ in three vowel contexts. Each point is the average of 10, measured at 8 ms intervals from 80 ms before consonant closure (line-up point) to 80 ms 80 ms after release (→). (●) data for /b/; (○) data for /p/.

If the larynx lowers only to compensate for oral pressure build-up, then one would predict lowering during voiced stops but not during nasals, since they have no appreciable pressure increase (Yanagihara & Hyde, 1966). For both subjects in this study, however, the data are not consistent with the latter prediction. Figures 4 and 5 compare vertical larynx movement during oral and bilabial stops produced in the /a/ context. Figure 4 presents the frequency distribution for ΔLH for /b/ and /m/ produced by both subjects. The histogram at the top of each graph shows the distribution of ΔLH values during the production of /m/ (slashed bars), and at the bottom the distribution for /b/ (filled bars). In Fig. 5, larynx height is plotted as a function of time as in Fig. 3. Notice that even in the /a-a/ sequences (where differences in laryngeal behavior between voiced and voiceless stops seem most

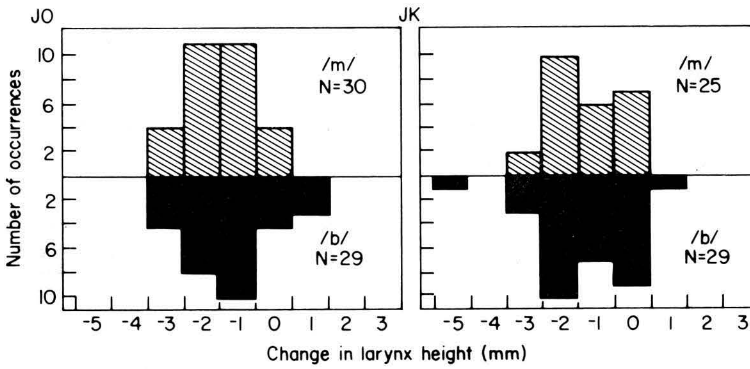


Figure 4 Frequency distributions of the change in larynx height during closure for /b/ and /m/ produced by two subjects. The height of the slashed bars is proportional to the number of /m/ repetitions for which the difference in larynx height between oral closure and release corresponds to the millimeter intervals along the x-axis. Solid bars indicate the data for /b/.

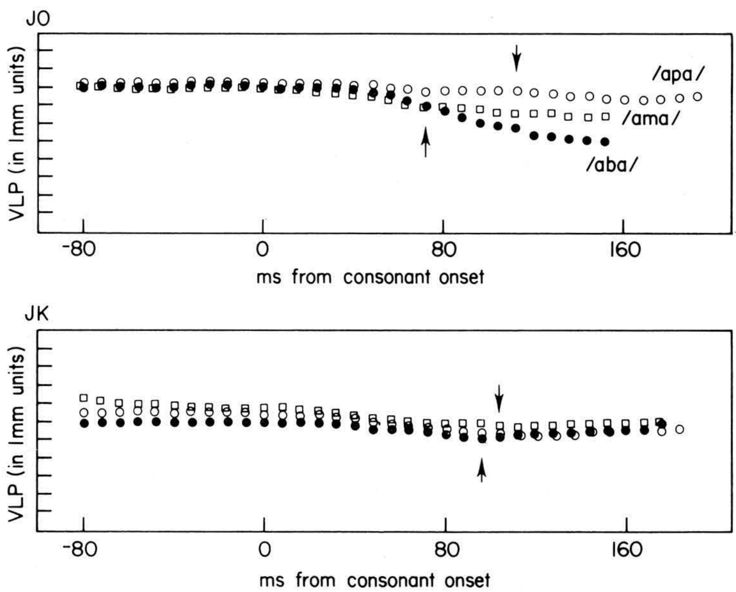


Figure 5 Vertical larynx movements during two subjects' production of /apa/, /aba/ and /ama/. Each point is the average of 10, measured at 8 ms intervals from 80ms before consonant closure (line-up point) to 80 ms after release. (→). (●) data for /b/; (○) data for /p/; (□) data for /m/.

apparent), both the magnitude and frequency of larynx lowering observed for /m/ is about the same as that observed for /b/. These data agree with Perkell's report that the pharynx enlarges more (in both vertical and anterior-posterior directions) for /n/ and /d/, than for /t/. Thus, notwithstanding the effectiveness of larynx lowering to enlarge the oral cavity, the larynx height data for the nasal suggest the question, posed by Lisker (1977), of whether it is the voicing or devoicing of a closure interval, or both, which may require supraglottal adjustment (see also Stevens, 1977).

Of course, suprasegmental variations in speech affect larynx height (Ohala, 1978), and may explain why the larynx lowers for the nasal. One possibility (which could be looked at here) is the role of gross larynx movements in pitch control (Ohala, 1972; Shipp, 1975; Ewan, 1976; Kakita & Hiki, 1976; Hombert, Ewan & Ohala, in press). Fundamental frequency was extracted from the audio signal of both subject's production of /a-a/ sequences, and corresponding pitch patterns and larynx height changes were analyzed. Figure 6 presents some representative data from one subject. Larynx lowering during the first half of the nasal closure is fairly well synchronized with a descending fundamental frequency. However, a straightforward view of the relationship between larynx height and pitch soon gives way to a more complicated picture. As pitch begins to ascend to a level for the following vowel, elevation of the larynx is considerably delayed. Since little is known about how the direction, extent or speed of pitch change may affect the contribution of vertical larynx movements to its control (Ohala & Ewan, 1973), evaluation of this relationship is difficult.

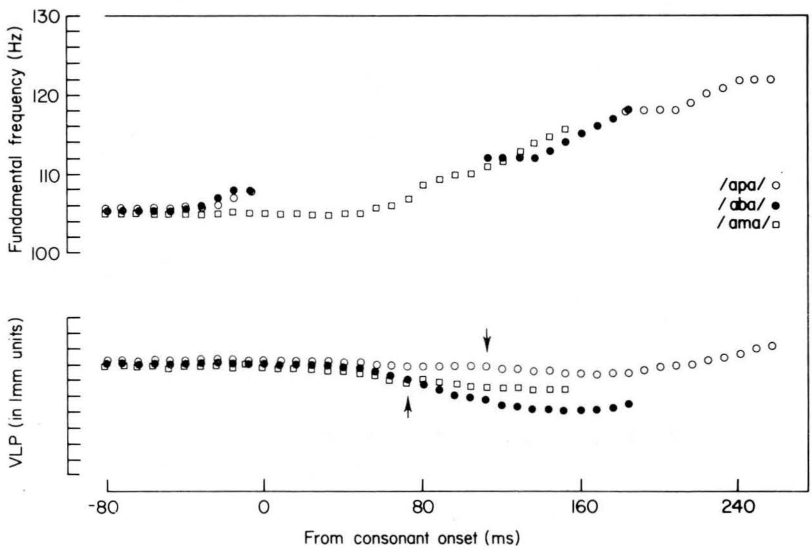


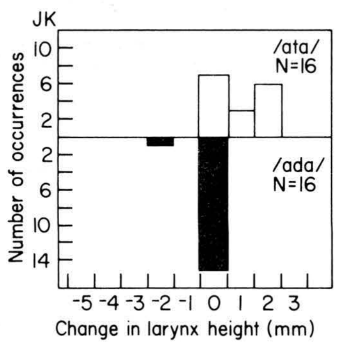
Figure 6 Vertical larynx movements and fundamental frequency during one subject's production of /apa/, /aba/ and /ama/. Each point is the average of 10, measured at 8 ms intervals from 80 ms before consonant closure (line-up point) to 80 ms after release (→). (●) data for /b/; (○) data for /p/; (□) data for /m/.

Larynx height and intraoral air pressure

If ΔLH during voiced stops compensates for oral pressure build-up (ΔPIO), then the lowering larynx and the rate of pressure increase would be inversely correlated. Product moment correlations were calculated between simultaneous larynx height and pressure measurements, and a significant inverse correlation ($P < 0.01$) was found to apply in the case of /p/ as well as /b/. Thus, not only does the larynx lower during closure intervals which presumably do not require cavity enlargement, but a relationship between this lowering and the rise in intraoral pressure is not peculiar to the voiced stop. The obvious explanation is the presence of some factor not controlled for sn this study.

The magnitude of larynx lowering

Finally, the magnitude of larynx lowering observed during voiced closure intervals deserves mention. Rothenberg (1968) estimates that the vertical dimension of the pharynx can be increased 0·5 cm in plosive production. If this increase acts on an area approximately 4 cm^2 (an area slightly larger than the average area of the oropharynx), then the resulting 2 ml volume change prolongs vocal chord vibration some 20 ms. In this study, however, the larynx lowered during /b/ on average less than 0·15 cm, considerably below Rothenberg's estimates and prolonging voicing some 6 ms. It could be the case, of course, that the contribution of larynx lowering to cavity enlargement depends on the relative contribution of other available mechanisms. If this were the case, then /b/ would be produced with little (or no?) lowering since bilabials can make use of other cavity-enlarging strategies, e.g. jaw lowering, tongue lowering and/or advancement, velum elevation, tissue compliance (Javkin, 1977).



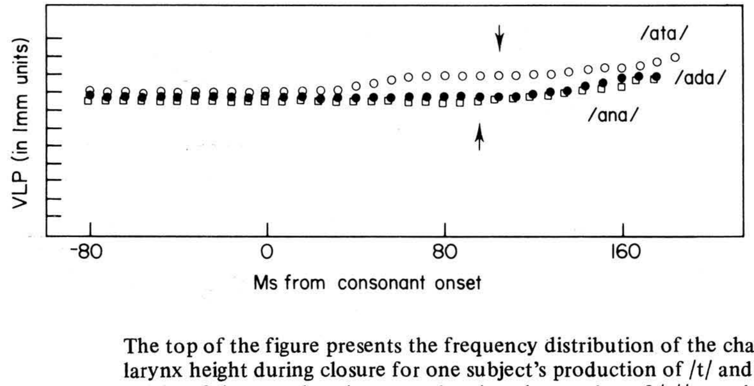


Figure 7 The top of the figure presents the frequency distribution of the change in larynx height during closure for one subject's production of /t/ and /d/. The height of the open bars is proportional to the number of /t// repetitions for which the change in larynx height between oral closure and release corresponds to the millimeter intervals along the x-axis. The solid bars indicate the data for /d/. In the lower half of the figure, vertical larynx movement is plotted as a function of time. Each point is the average of 16, measured at 8 ms intervals from 80 ms before consonant onset (line-up point) to 80 ms 80 ms after release (→). (●) data for /d/; (○) data for /t/; (□) data for /n/.

Preliminary data on voiced stops produced further back in the mouth, however, do not support these predictions. For two subjects' productions of English alveolar stops, vertical larynx movements closely pattern those of the bilabial series. Figure 7 presents some representative data from one subject. Note that: (1) there is considerable overlap between the frequency distributions of ΔLH for /t/ and /d/ (and what differentiation can be observed reflects a rraising of the larynx for /t/ rather than a lowering for /d/); (2) the larynx lowers consistently during the closure interval for /n/; and (3) mean larynx lowering for the voiced stop is less than 1 mm. Data on velar stops from one English subject show much the same pattern.

Conclusion

Although differences in larynx height between voiced and voiceless stop cognates suggest the role of larynx lowering for maintaining voicing, results of other empirical tests of this hypothesis are suspect. First, the larynx lowers frequently during closure intervals which presumably do not require cavity enlargement. Second, larynx lowering observed for voiced stops only minimally increases the capacity of the vocal tract to absorb glottal airflow, contributing little to an explanation of voiced closure durations commonly observed in speech. Finally, the data for the voiced stop reveal no distinctively characteristic relationship between larynx movement and intraoral air pressure.

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