Aerodynamic Evidence for Articulatory Overlap in Korean

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Abstract. Aerodynamic evidence indicates the existence of overlapped labial//velar sequences in Korean. Oral pressure readings for [ipku] show a brief rarefaction in oral pressure during the consonantal sequence, indicating that tongue retraction during a front-back vowel sequence occurs simultaneously with full closures at the labial and velar places of articulation. This confluence of phenomena results in the observed pressure rarefaction due to expansion of the sealed oral cavity. Similarly, pressure readings for [upki] show a brief, marked increase during the consonantal sequence, indicating that tongue advancement during a back-front vowel sequence temporally overlaps with full closures at both the labial and velar places of articulation. This results in a pressure increase due to contraction of the sealed oral cavity. To our knowledge, the present study is the first to demonstrate consonant co-production in terms of oral pressure, and to report on coarticulatory effects involving four sequenced segments.

1. Introduction

In this study we present evidence for the existence of overlapped labial//velar sequences in Korean. A native speaker of the Seoul dialect (one of the authors) was recorded in the UCLA Phonetics Laboratory uttering [VCCV] sequences involving both labial and velar consonants, and front and back vowels, in a variety of combinations ([ipki, upku, ipku, upki, ikpu, ukpi, ikpi, ukpu]). Both nonsense words (Experiment One) and real words (Experiment Two) were employed. Oral airflow, as well as pharyngeal and supropharyngeal pressure, were recorded. It was found that back-front vowel combinations, in conjunction with intervocalic -pk- sequences ([upki]), produced a marked increase in supropharyngeal (henceforth oral) pressure during the course of the consonantal sequence -- a far greater increase than was found when the same consonantal sequence was flanked by vowels of identical phonemic quality ([ipki, upku]). We claim that these oral pressure readings are the result of tongue advancement during a back-front vowel sequence, temporally overlapping with full closures at both the labial and velar places of articulation. The result is a brief increase in oral pressure due to oral cavity contraction. Relatedly, front-back vowel combinations in the same consonantal environment ([ipku]) produced a marked rarefaction in oral pressure: tongue retraction during a front-back vowel sequence, occurring simultaneously with full closures at the labial and velar places of articulation, results in a decrease in oral pressure due to cavity expansion.

Previous studies investigating gestural timing relationships in terms of air pressure include Ladefoged (1962) and Demolin (1992), which report on phonological labio-velar stops in West and Central African languages, respectively. Ohala (1981) investigates epenthetic stop production in English through similar techniques. Kozhevnikov and Chistovich (1965), and Maddieson (1990), investigate medial consonant clusters using nasal and oral airflow measurements respectively. Marchal (1987) investigates consonant co-production employing electropalatography. Relatedly, Nolan (1992), and Zsiga (1993) employ electropalatography to investigate coarticulation. Spectrographic analyses are employed in Öhman (1966), and Zsiga (1992). Finally, Bird (1992) presents a study of consonant co-production involving synthesized speech production. To our knowledge, the present study is the first to demonstrate consonant co-production in terms of oral pressure.

Moreover, earlier studies have reported either (i) trans-consonantal vowel-to-vowel effects, to the exclusion of intervening consonant effects (Öhman 1966, Fowler 1983 *inter alia*), or (ii) inter-consonantal overlap, to the exclusion of flanking vowel effects (Browman and Goldstein 1986,1990, Zsiga 1992,1993, Bird 1992, Nolan 1992). The present study investigates the co-production of adjacent consonants in conjunction with their flanking vowels. To our knowledge, no previous study has reported on this confluence of phenomena.

2. Experiment One

The sole subject was an adult male speaker of the Seoul dialect (one of the authors). The subject has no history of pathological speech, and considers his Korean untainted by foreign languages. The subject was fitted with a mouth mask connected to pressure/flow transducers. One pressure tube was inserted behind the lips, thus recording oral pressure. A second tube was inserted nasally into the pharyngeal cavity, thus recording pharyngeal pressure. Finally, oral airflow was recorded. Eight combinations of VCCV sequences were employed, involving -pk- and -kp-clusters flanked by i-u, u-i, i-i, and u-u. The wordlist, read three times by the subject, is shown in (1).

(1) upki, upku, ipki, ipku, ukpi, ukpu, ikpi, ikpu

As can be seen, these nonsense forms consist of an onsetless syllable followed by a codaless one. Only two vowels, [i,u], were used, to control for features other than frontness and backness. Due to a regular process of post-obstruent fortition in Korean (See Kim-Renaud 1986 for more details), [pk] and [kp] will surface [pk'] and [kp'], respectively ([k'] and [p'] represent glottalized obstruents.) We assume that this fortition process has no effect on the coarticulatory phenomena under investigation, and therefore have not included this detail in our transcriptions. The list was read in the order shown, without a carrier phrase. An additional list of actual Korean words was recorded as well. This list is presented and discussed in Section 2.

Results

Figure (1) shows sample flow and pressure data for [upku] and [ipki]. These sequences consist of labial and velar voiceless stops flanked by vowels of identical phonemic quality. Comparable results were obtained in the other two trials.

The pressure records show that pharyngeal and oral pressure increase at exactly the same point in time (Point A). This indicates, as expected, that labial closure either temporally precedes or is simultaneous with dorsal closure, for an increase in oral pressure entails an increase in pharyngeal pressure as well. Were the dorsal closure to precede the labial one, there should be an increase in pharyngeal pressure *before* an increase in oral pressure. This is confirmed in Figure (2), which shows sample flow/pressure data for [ukpu, ikpi]. In Figure (2), increases in pharyngeal pressure temporally precede oral pressure increases (Point A precedes Point B), indicating that the dorsal closure temporally precedes the labial closure, as expected.

Returning now to Figure (1), observe that pharyngeal pressure is sustained as oral pressure returns to normal (Point B). That is, the increase in pharyngeal pressure is sustained for a longer period than the increase in oral pressure. This indicates both that dorsal closure precedes labial release, i.e., that the two closures temporally overlap for a period, (resulting in the phonetic equivalent of a labio-velar stop), and that the release of the dorsal closure occurs *after* the release of the labial closure.

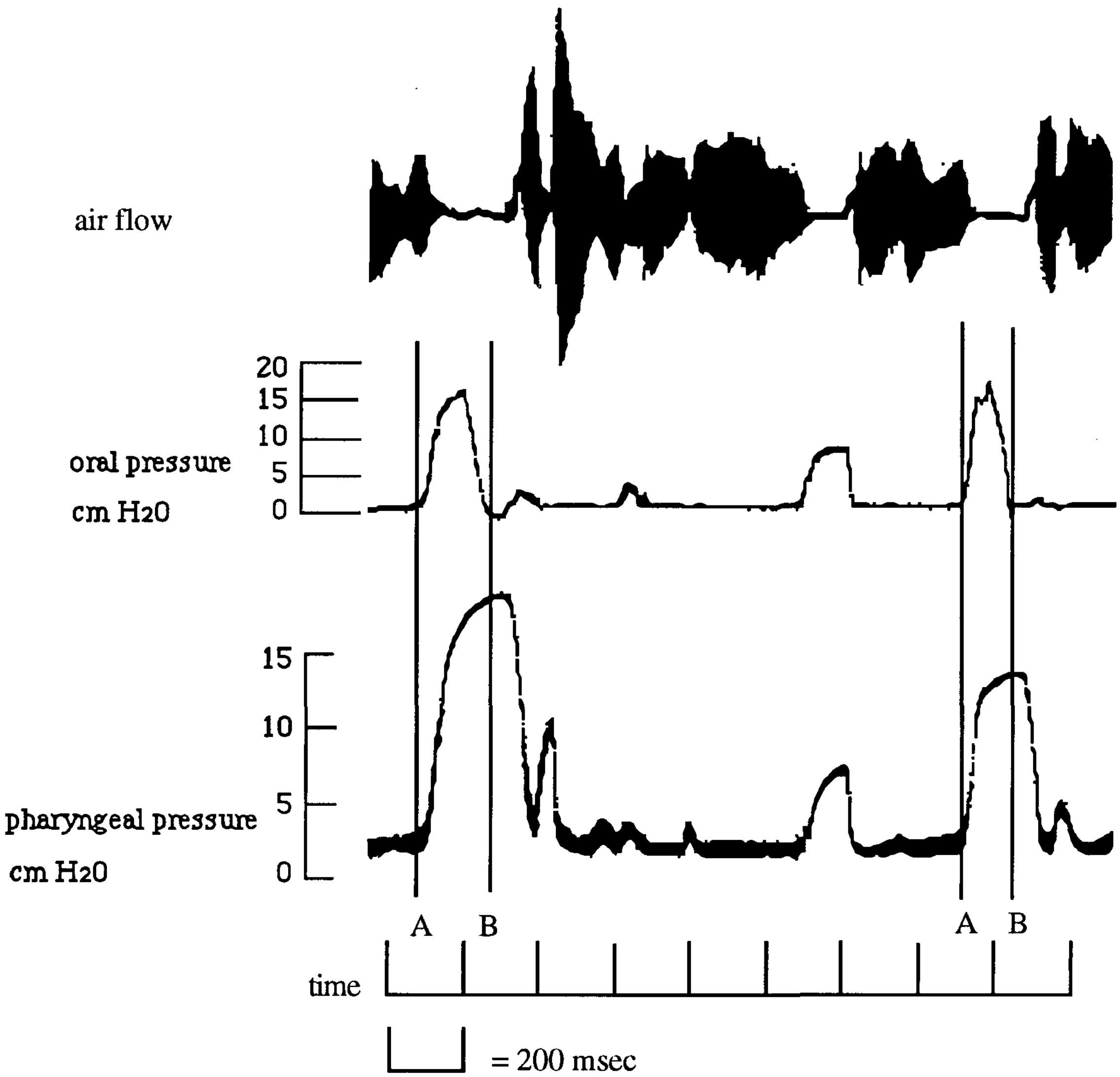


Figure 1. Sample airflow, oral pressure, and pharyngeal pressure records for [upku] and [ipki].

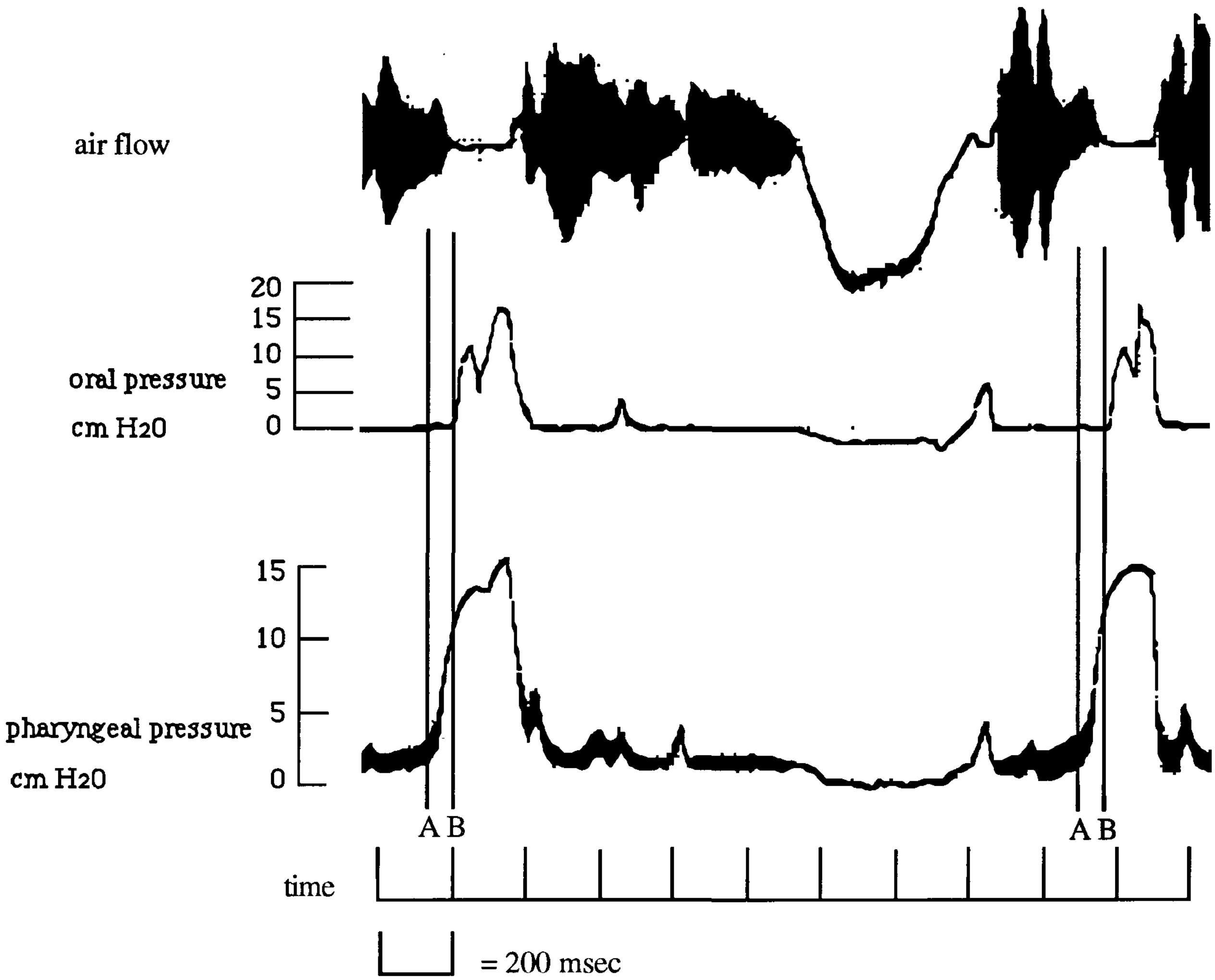


Figure 2. Sample airflow, oral pressure, and pharyngeal pressure records for [ukpu] and [ikpi].

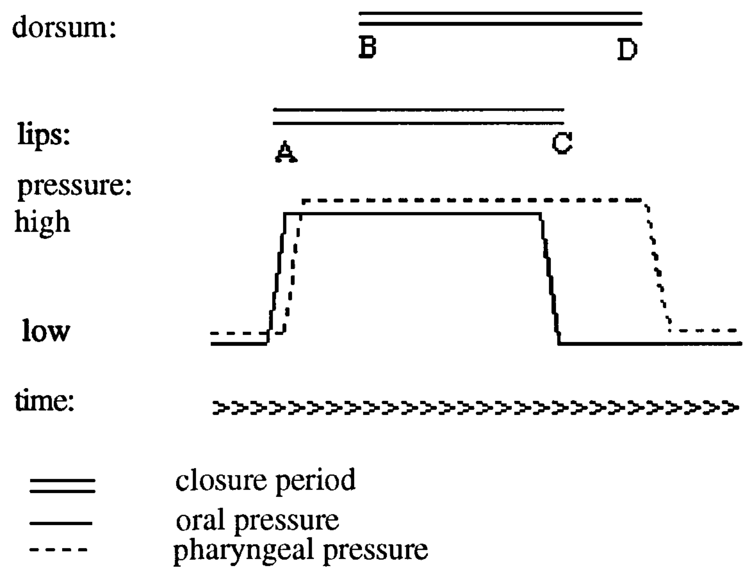


Figure 3. Schematic representation of dorsal and labial activity, as well as oral and pharyngeal pressure effects for [upku] and [ipki].

Figure (3) summarizes in schematic form the hypothesized articulatory configurations which produce the attested pressure data in Figure (1). Below the schematized closure record is the pressure data , also in schematized form.

At Point A, labial closure results in an increase in both oral and pharyngeal pressure. At Point B, dorsal closure occurs. (Point B, it should be noted, can only be estimated, as the pressure record for these data provides insufficient information to determine its exact point in time.) At Point C, the labial closure is released, resulting in oral pressure returning to normal, while pharyngeal pressure is maintained, due to the continuing dorsal closure. Finally, at Point D, the dorsal closure is released and pharyngeal pressure returns to normal.

If the schematic representation in Figure (3) truly reflects the actual state of articulatory affairs, it is predicted that manipulating the volume of the oral cavity during the point of closure overlap should result in pronounced pressure effects. That is, expanding the volume of the sealed cavity should result in a marked *decrease* in oral pressure. Conversely, contracting the sealed cavity should result in a marked *increase* in oral pressure.

This hypothesis is confirmed upon observing the pressure record for the same labial-velar consonantal sequence in a modified vocalic environment consisting of front-back vowels (i-u), and back-front vowels (u-i). Pressure/flow data for two tokens of [ipku] are presented in Figure (4).

Note the pronounced oral pressure rarefaction just after the labial closure (Point A). This, we claim, is due to the tongue retracting from a front position (for [i]) to a back position (for [u]) as the dorsal closure is implemented. Oral pressure rarefaction begins soon after the labial closure, indicating that the dorsal closure follows the labial closure almost immediately. The volume of the sealed oral cavity which results from overlapping labial and dorsal closures increases upon tongue retraction. This increase in volume is due, we claim, to the tongue body's sliding back across the soft palate. This articulatory configuration is schematized in Figure (5).

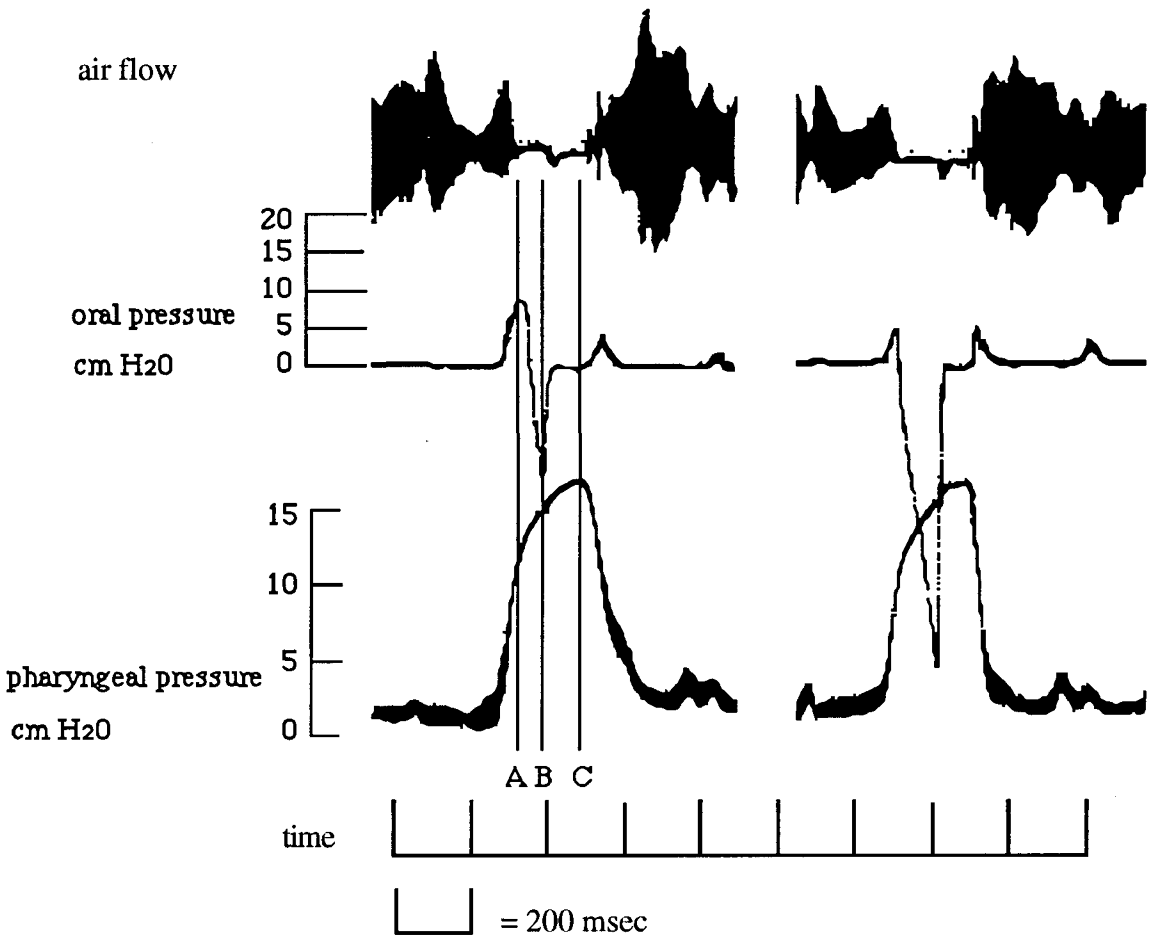


Figure 4. Airflow, oral pressure, and pharyngeal pressure records for two tokens

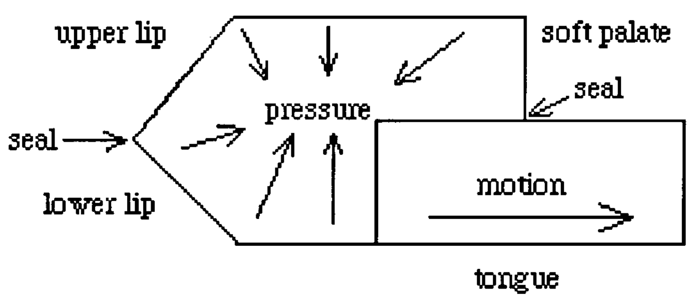


Figure 5. Schematic representation of articulator dynamics and resultant pressure effects during consonantal overlap in [ipku].

As the oral cavity is sealed at both ends, and as the labial closure is by and large fixed, cavity expansion due to tongue retraction across the soft palate is the only reasonable explanation of the pressure facts.

Returning now to Figure (4), as the labial closure is released, oral pressure increases back to normal (Point B). However, pharyngeal pressure remains high until dorsal release (Point C).

Results consistent with our hypothesis were found for the sequence [upki]. Figure (6) indicates a very pronounced increase in oral pressure upon labial closure for one token. Comparable results were obtained in the other trials.

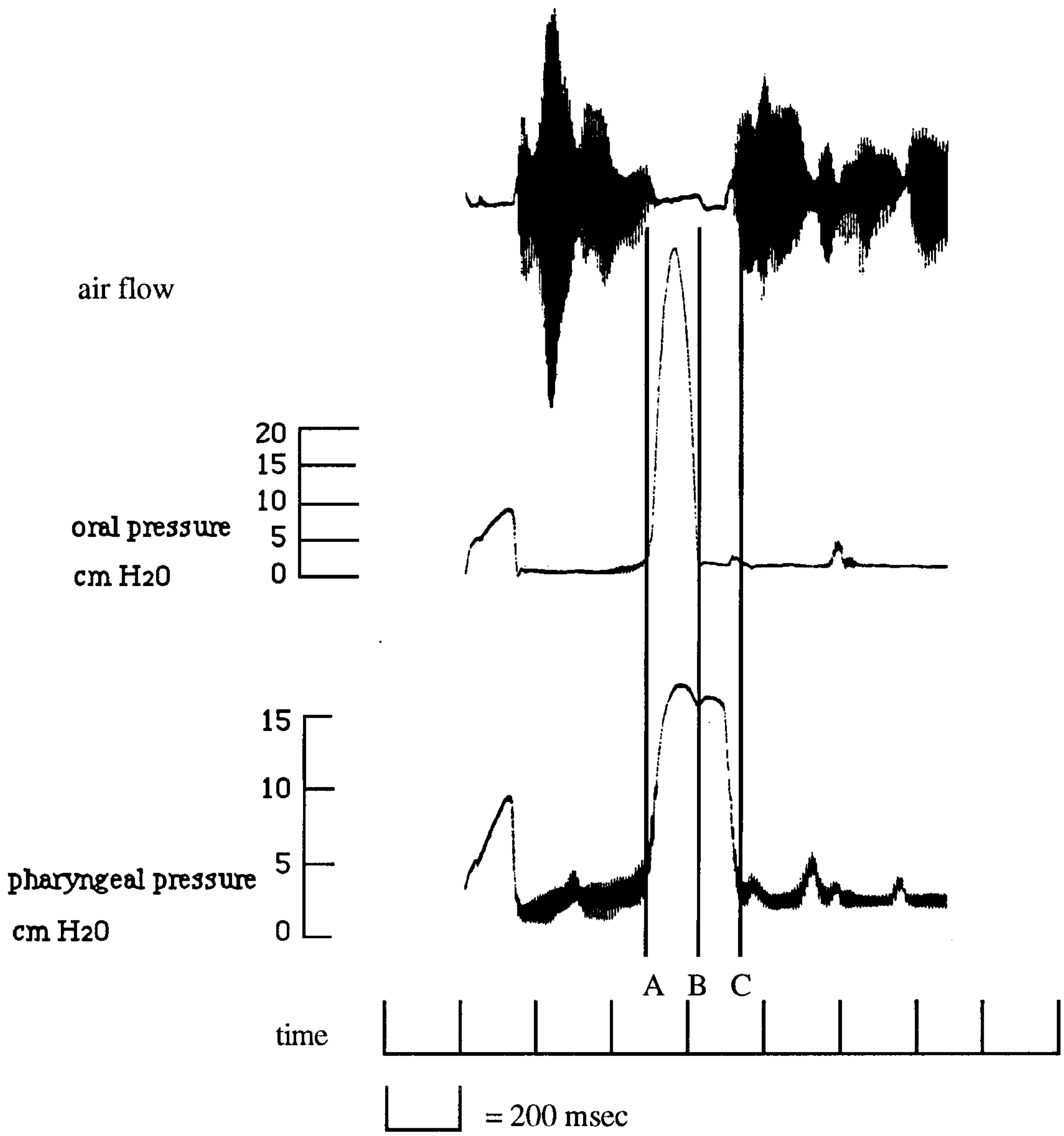


Figure 6. Airflow, oral pressure, and pharyngeal pressure records for [upki].

During the multiple closure, the oral pressure in Figure (6) is far greater than that observed when this same consonantal sequence is flanked by vowels of identical quality (cf. Figure (1)). This result is consistent with our hypothesis that the two closures overlap in time, and in addition, temporally co-occur with vocalic tongue movement: during the course of the overlapped labial and dorsal closures, the tongue body slides forward across the palate in its movement from back to front. The resulting contraction of the sealed oral cavity results in a marked increase in oral cavity pressure (Point A), which persists until the labial seal is broken (Point B). Pharyngeal pressure is maintained until the dorsal closure is released (Point C). This articulatory configuration is schematized in Figure (7).

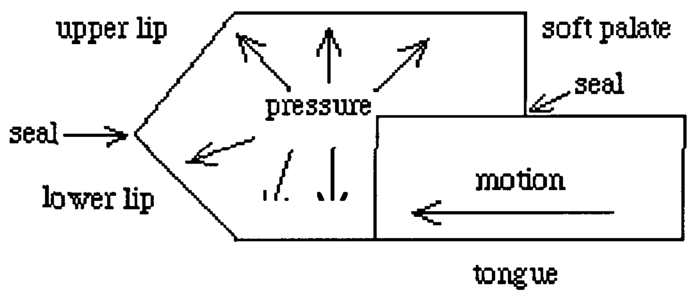


Figure 7. Schematic representation of articulator dynamics and resultant pressure effects during consonantal overlap in [upki].

Figures (8) and (9) provide a schematized representation of the data in Figures (4) and (6), with tongue body movement superimposed on the labial and dorsal records.

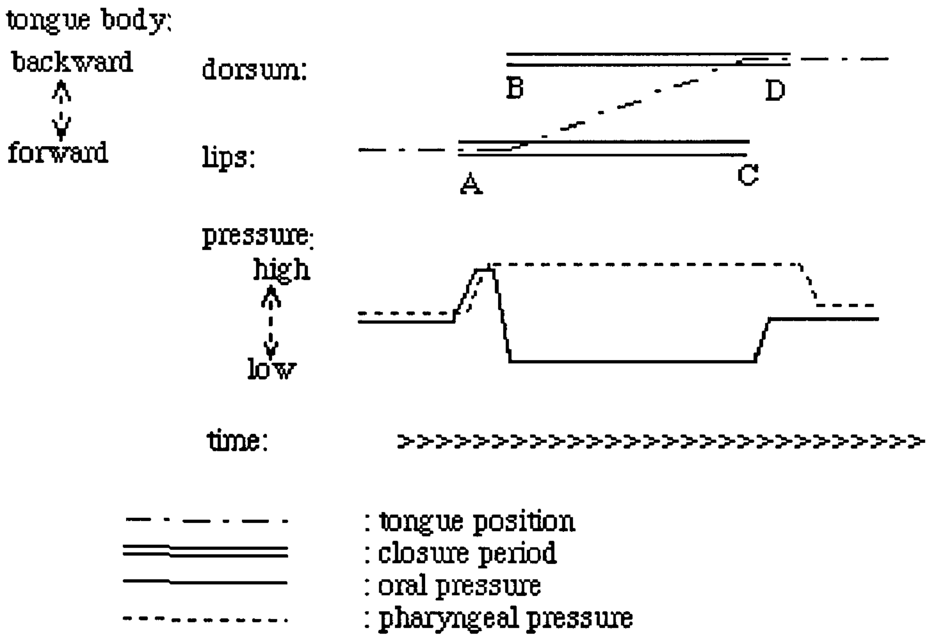


Figure 8. Schematic representation of dorsal and labial activity, tongue body activity, and pharyngeal pressure effects for [ipku].

In Figure (8), at Point A, a labial closure is formed, followed almost immediately by a dorsal closure (Point B). Simultaneously, the tongue body retracts, sliding back along the soft palate. Oral pressure rarefies due to oral cavity expansion. At Point C, the labial closure is released, and oral pressure returns to normal. Finally, at Point D, the dorsal closure is released, and pharyngeal pressure returns to normal. A similar scenario obtains for Figure (9), the only difference being that tongue advancement during the multiple closure results in greatly increased oral pressure. Note finally sample pressure records for the sequences [ukpi, ikpu] (Figure 10).

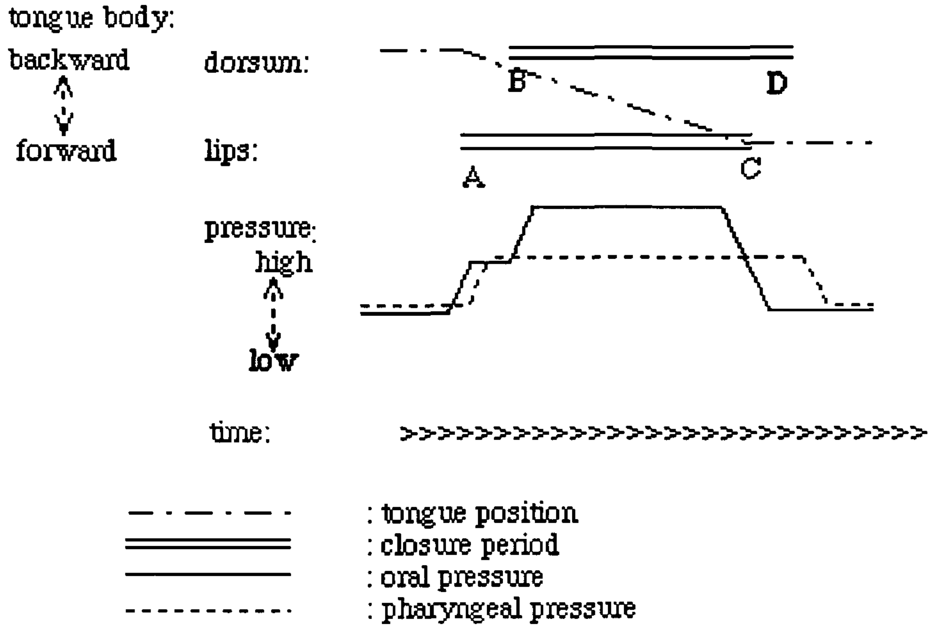


Figure 9. Schematic representation of dorsal and labial activity, tongue body activity, as well as oral and pharyngeal pressure effects for [upki].

For [ukpi], after an increase in pharyngeal pressure (Point A), a marked increase in oral pressure is observed (Point B). In contrast, for [ikpu] an oral pressure rarefaction is observed (Point B). Here again, these pressure effects are a result of the confluence of consonantal and vocalic articulations.

For [ukpi], at Point A, dorsal closure for [k] results in an increase in pharyngeal pressure. Immediately following, at point B, labial closure proceeds, with concomitant tongue advancement. The now sealed oral cavity experiences a marked pressure increase, just as observed for [upki]. At Point C, the dorsal closure is released, and oral pressure is reduced to equivalency with pharyngeal pressure. Finally, at Point D, the labial seal is broken, and both pressure records return to normal.

For [ikpu], comparable results were obtained. At Point A, dorsal closure results in heightened pharyngeal pressure. At Point B, labial closure with concomitant tongue retraction for the i-u vowel sequence results in a brief period of oral pressure rarefaction. At Point C, dorsal release results in an oral pressure increase to match pharyngeal pressure. Finally, at Point D, the labial closure is released, and both pressure records return to normal.

These results are schematized in Figures (11) and (12).

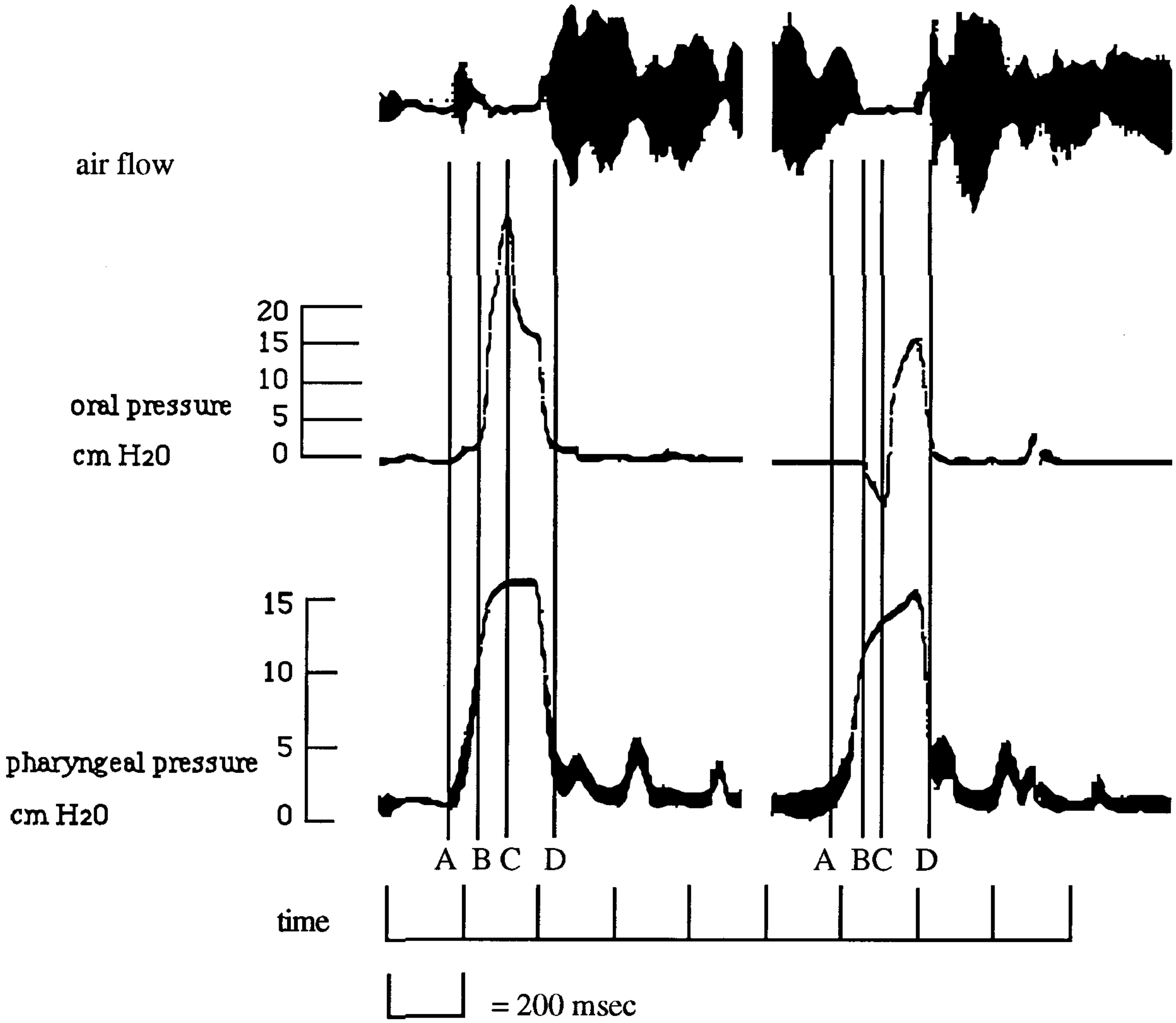


Figure 10. Sample airflow, oral pressure, and pharyngeal pressure records for [ukpi] and [ikpu].

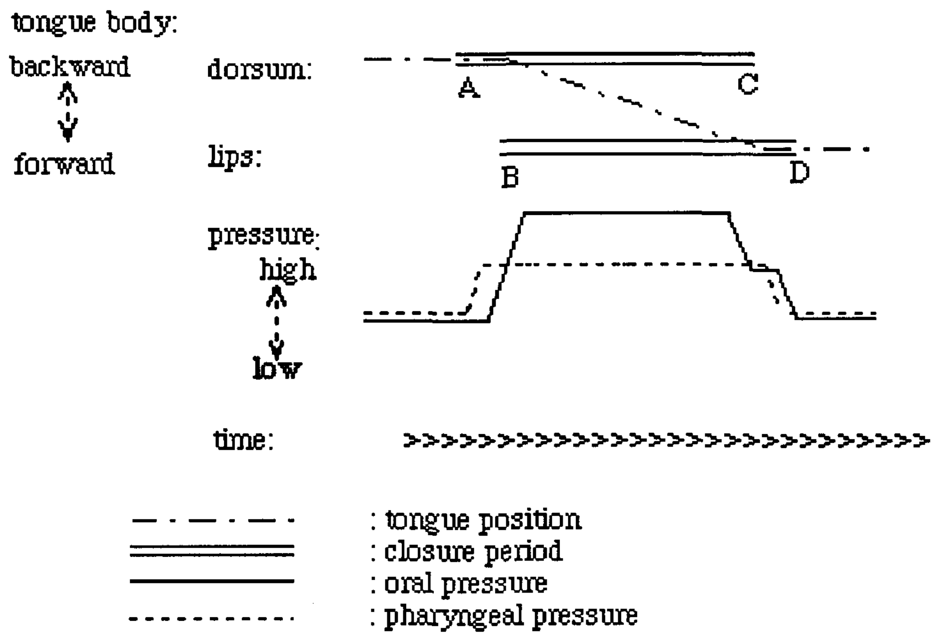


Figure 11. Schematic representation of dorsal and labial activity, tongue body activity, and oral and pharyngeal pressure effects for [ukpi].

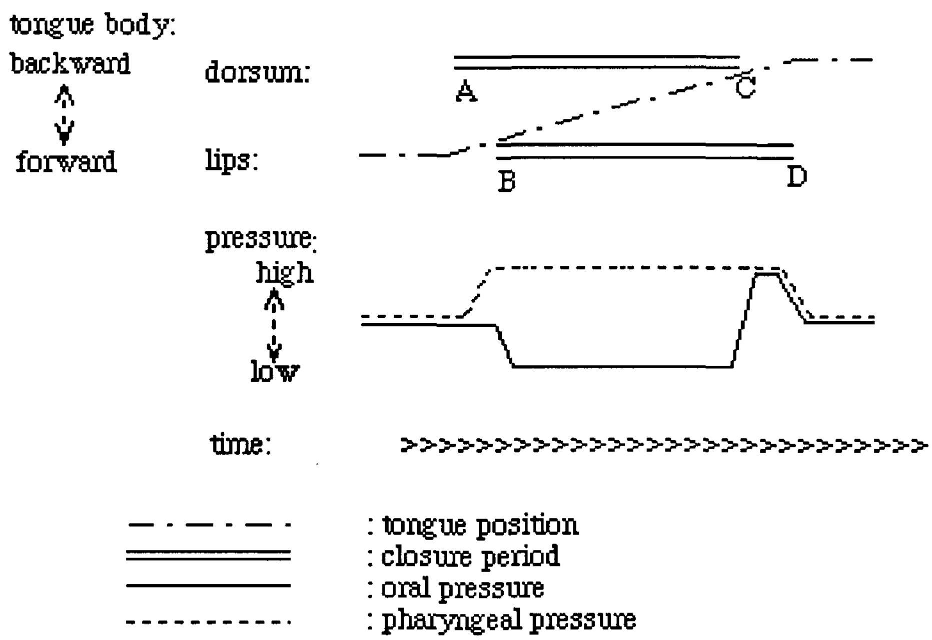


Figure 12. Schematic representation of dorsal and labial activity, tongue body activity, and oral and pharyngeal pressure effects for [ikpu].

Summary

Back-front vowel combinations, in conjunction with intervocalic -pk- or -kp-sequences produced a far greater increase in oral pressure during the course of the consonantal sequence than was found when the same consonantal sequence was flanked by vowels of identical phonemic quality. Front-back vowel combinations in conjunction with intervocalic -pk- or -kp- sequences produced a marked rarefaction in oral pressure.

Note finally the telling asymmetry in oral pressure between [ipku] (Figure 4) and [ikpu] (Figure 10). In [ipku], the pressure drop occurs after the pressure increase, whereas in [ikpu] the pressure drop occurs before the pressure increase. This shows that phonological ordering persists into the phonetics, despite the lengthy period of temporal overlap. Thus for [ipku], the labial closure precedes the dorsal closure, resulting in an initial oral pressure increase, followed by a rarefaction upon dorsal closure and concomitant tongue retraction. For [ikpu] however, oral pressure initially rarefies. The labial closure occurs only after dorsal closure. This second closure, with concomitant tongue retraction, results in an initial oral pressure rarefaction.

3. Experiment Two

The same subject and methods were employed in Experiment Two. Also, the same VCCV sequences were employed as in Experiment One. However, this time real Korean words were used in phrasal/sentential contexts. In (2) is a complete list of the employed phrases/sentences. The relevant segmental sequences are underlined. The abbreviations used in (2) indicate the following: Con = Verb connective; SE = Sentence Ender; Acc = Accusative case marker; Nom = Nominative case marker

(2) a. /cəki nupki siləjo/
there lying hate
I hate lying over there

b. /cəki nup-ku sip-ne/ ([ku] is a free variant of the standard pronunciation, [ko].)
there lie-Con want-SE
I want to lie over there

c. /os-l ipki-ka himtɨl-ta/
clothes-Acc wearing-Nom hard-SE
It is hard to wear the clothes

d. /hakkyo ipku/
school entrance
school entrance

e. /kukpi juhak/
awarded by the nation studying abroad
overseas study fellowship

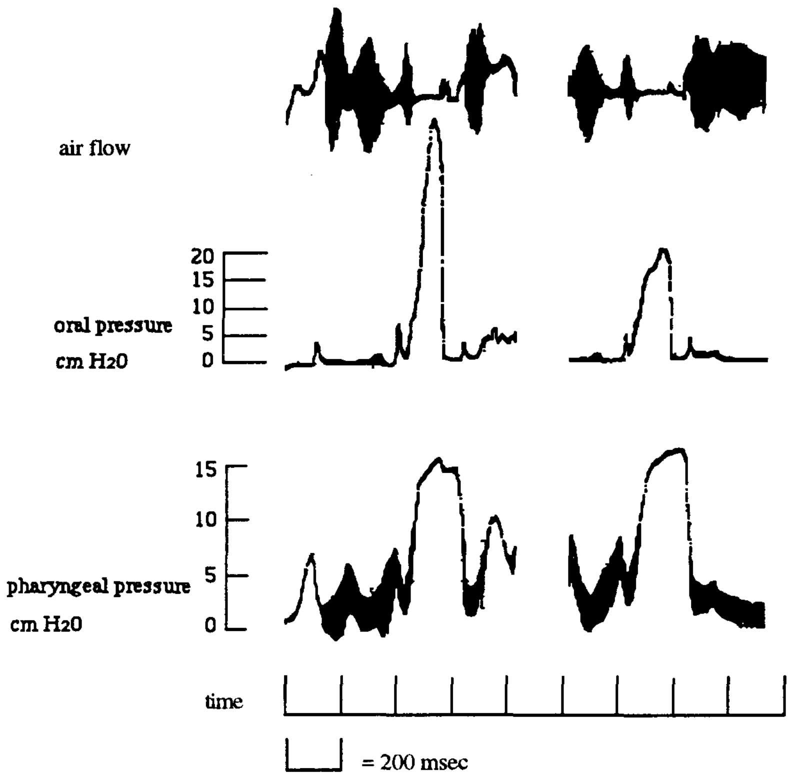
f. /pukpu cipaŋ/
north province
north area

g. /sikpi putam/
food expense burden
burden of food expenses

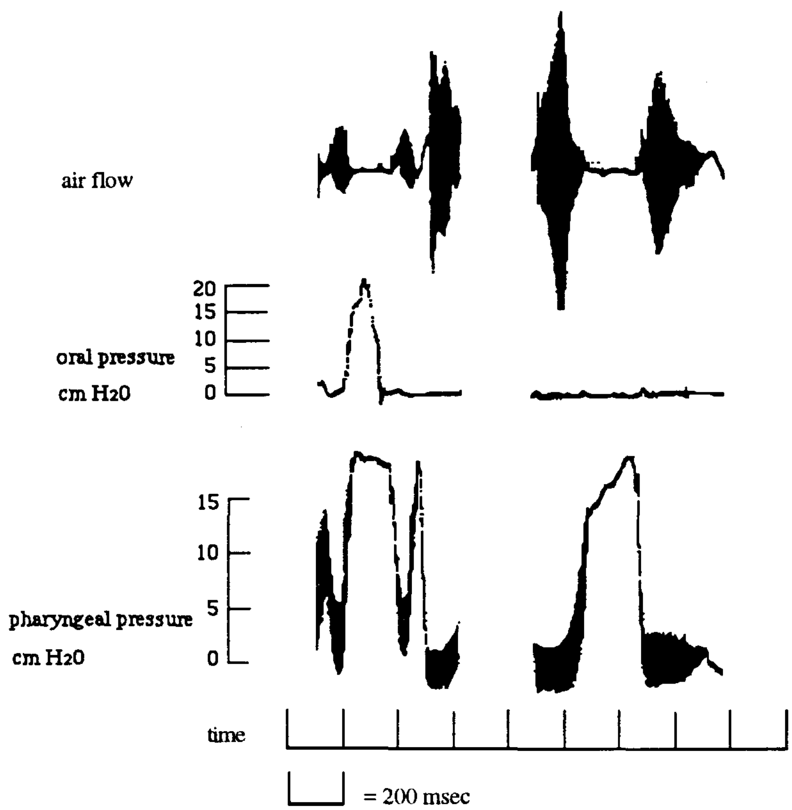
h. /sikp^{h}um-pu/
food section
food section

Results

The results of Experiment Two are shown in Figures 13a-h.



a **b**



c **d**

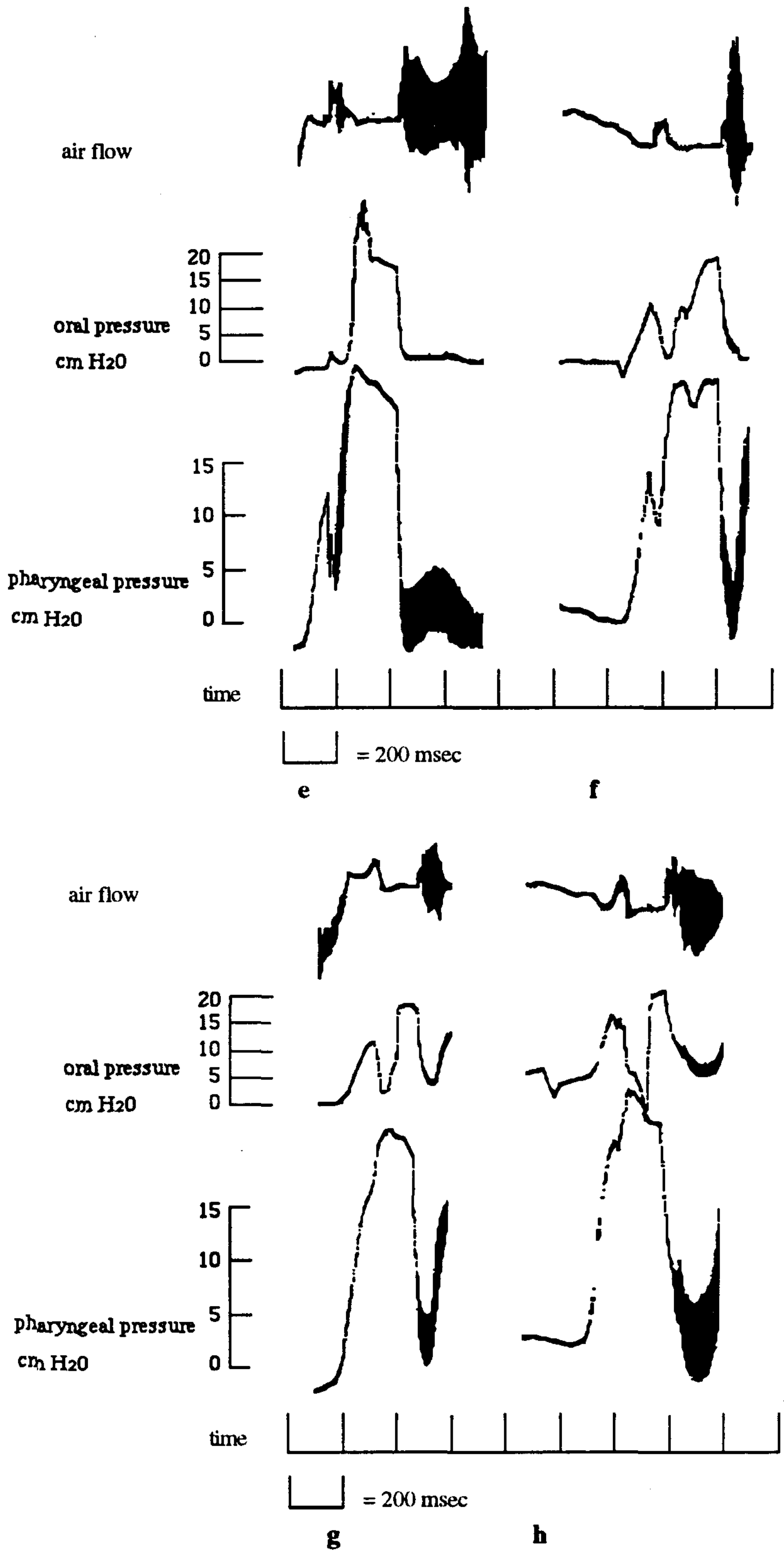


Figure 13. Sample airflow, oral pressure, and pharyngeal pressure records for [upki, upku] (a,b), [ipki, ipku] (c,d), [ukpi, ukpu] (e,f), and [ikpi, ikpu] (g,h), extracted from real words.

Results are identical, except for the pressure readings for [ipku]. Figure 13c indicates no change in oral pressure for this form. Identical results were obtained in another trial, for this form only. This, we think, is due to a process of Korean place assimilation whereby labial consonants assimilate in place to a following velar consonant. If /ipku/ is realized [ikku], no change in oral pressure is expected, as there is no labial closure. It should be noted that this is an optional process, thus accounting for the mixed results obtained. In the following section, this result is considered in more detail. We conclude that the results of Experiment Two are consistent with those of Experiment One.

4. Discussion

In Experiment Two, no change in oral pressure for /ipku/ was observed. This, we suspect, is due to an optional process of place assimilation. Based on previous work in Korean phonology (Kim-Renaud 1974; Cho 1990 among others), we assume that this process is optional, and dependent on the style and the rate of speech. In casual speech, coronal obstruents assimilate in place to a following consonant (3a, b); labials assimilate only to a following velar (3c, d).

(3) Korean Place Assimilation

a.	/tat	+	ko/	-->	[takk'o]	'close + and'
b.	/nac	+	pam/	-->	[napp'am]	'daytime (and) night'
c.	/ip	+	ko/	-->	[ikk'o]	'wear + and'
but						
d.	/ip	+	ta/	-->	[ipt'a]	'wear + Sentence ender'

We briefly discuss the implications of these results for the theory of Articulatory Phonology (Browman and Goldstein 1986, 1990, 1992). Within this theory, casual speech alternations such as those in (4) (and presumably (3)) are seen as the result of gestural overlap and/or gestural reduction. Gestural overlap involves the obscuring of one gesture by another temporally co-occurring gesture. Gestural reduction involves the reduction in magnitude of a gesture.

(4) Browman and Goldstein (1990:359)

(a) /'mʌst bi/	-->	['mʌsbi]	("must be")
(b) /hʌndrəd 'paʊndz/	-->	[hʌndrəb 'paʊndz]	("hundred pounds")
(c) /'graʊnd 'prɛʃɚ/	-->	['graʊm 'prɛʃɚ]	("ground pressure")

Thus, what a phonologist might model as the regressive place spreading of /p/ with place delinking of /d/ in (4b), emerges from the gestural model as /p/ superimposed on /d/, with the /d/ gesture maintained, though possibly in reduced form.

The present data are in accordance with this approach to casual speech alternations. Experiment One shows that nonsense forms with labial//velar sequences involve a high degree of gestural overlap. Experiment Two, in which real words are employed, also shows this high degree of gestural overlap. In addition, however, those -pk- sequences in which no oral pressure change is observed indicate that gestural reduction is playing a role here as well: when no oral pressure change in -pk- sequences is observed, we may conclude that labial closure does not take place. Instead, this labial gesture is reduced, perhaps to zero.

Jun (in prep.) investigates in greater detail the distinct roles of both gestural overlap and gestural reduction in the production and perception of casual and formal speech involving /pk/

sequences in Korean. Thus far fourteen native Korean speakers have been tested. Preliminary results suggest that gestural reduction plays a decisive role in the perception of /pk/ sequences: /pk/ sequences displaying pressure changes, and those not displaying pressure changes, are seemingly perceived as unassimilated and assimilated respectively. That is, /pk/ with no labial closure is perceived as [kk], while /pk/ with labial closure is perceived as [pk].

5. Conclusion

The significance of the present study rests in the methodology employed, in the results obtained, and, potentially, in the theoretical conclusions that may be drawn. To our knowledge, no previous study demonstrates consonant co-production in terms of oral air pressure, and further, no previous study reports on coarticulatory effects involving four ordered segments. The theoretical implications of the obtained results may prove useful to both phoneticians and phonologists in their investigations of phonetic coarticulation and phonological spreading processes.

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