An Interface between Phonetics and Phonology: Evidence from Implosives

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Abstract*. The traditional notions of segmental phonetic representation and rule systems formulated in terms of discrete operations have paid little attention to the processes of "phonetic implementation" as opposed to "physiological implementation". This paper argues that some details of speech such as timing and coordination of articulatory gestures have language-specific conditioning, and therefore should fall within the scope of phonology. Evidence will be provided from implosives in Sindhi and some other languages in support of the premise, and the status of low-level phonetic implementational phenomena in phonological theory will be discussed*

1. Introduction

Sounds of one language may differ from those of another because of the phonetic value of the segments along the same continuum. To take an example, the linguistic specification that distinguishes between [p] and [b] in English is that they are [-voice] and [+voice] respectively. The articulatory instruction that accompanies the feature [+voice] is "vibrate the vocal cords". In order to implement this instruction, a number of articulatory gestures have to be performed, such as keeping the vocal folds sufficiently lax, reducing the distance between the vocal folds, keeping the airflow through the glottis powerful enough to cause vibration, and maintaining the difference between the sub-glottal and supra-glottal air pressure by lowering the larynx, allowing air to escape through a small velic opening, and/or expanding the walls of the pharynx. "Vibrating the vocal folds", however, is the primary instruction that is associated with the linguistic feature [+voice], and the rest of the articulatory gestures are ways of implementing this instruction. Speakers of different language backgrounds choose different combinations of parameters for the implementation of voicing in stops. The phonetic implementation of these differences is as much important as those in the sound patterns. As phonologists, we tend to get involved in the description of the sound patterns so much so that we forget to point out that many of the sounds of English, for example, are not the same as the similarly specified sounds of, say, Hindi, Sindhi, French or Telugu. It may be pointed out here that SPE is only a description of the patterns, and not of the phonetic correlates of these sounds. The theory may perhaps make it possible to give precise description of the sounds of English; but the fact remains that SPE does not tell us all we need to know about the phonetic properties of these sounds.

The inadequacy of SPE phonological theory becomes clearly apparent particularly when we consider sounds like the voiced stops in Sindhi and English, for example. It is a common practice to represent these two sounds with the same symbol [b] and they have the same set of feature specifications at the phonemic level. However, when one listens very carefully to the sounds produced by an Englishman and a Sindhi speaker, one would unhesitatingly say that they sound far from being alike; voiced stops in English are partially devoiced pre-pausally and post-pausally whereas these are fully voiced in Sindhi during the entire period of closure and are characterized by a slight nasalization (Nihalani, 1975). Lindau (1984) has convincingly demonstrated that sounds that are usually classified as the same in different languages may differ along any one of the various articulatory and acoustic parameters associated with a feature.

In order to illustrate this point, I will discuss some phonetic differences between implosives in Sindhi (an Indian language) and a few other languages from Nigeria.

Implosives have been traditionally characterized as glottalic ingressive sounds produced by lowering the vibrating glottis (Catford, 1939; Pike, 1943). Lindau (1984, p.152) notes that Hausa implosives are produced with aperiodic, inefficiently closing vocal cord vibrations and that there is considerable speaker to speaker variation between implosives in languages, and that languages may differ in the way that they maintain distinction between implosives and the corresponding plosives. Ladefoged (1964, p.6) noted that his Igbo implosives only produced negative pressures 8% of the time. Ladefoged therefore observes:

> "… the action of the vocal cords in the production of these implosive sounds has been one of a leaky piston…Often the piston is so leaky that the air stream is not actually ingressive nor the sounds really implosive. In many of the languages I have observed (cf. Ladefoged 1964) the pressure of the air in the mouth during an ingressive glottalic stop is approximately the same as outside the mouth, since the rarefying action of the downward movement of the glottis is almost exactly counterbalanced by the leakage of lung air up through the vocal cords. Although these sounds may be called implosives, in ordinary conversational utterances air seldom flows into the mouth when the stop closure is released". (Ladefoged 1971:25-26)

These observations lead Ladefoged to the conclusion that "the difference between implosives and plosives is one of degree rather than of kind… an implosive is simply a sound in which this downward movement is comparatively large and rapid" (Ladefoged, 1971, p. 27).

In this connection, Painter (1978:254) observes: "Despite Ladefoged's caveat (1964:6) that his Igbo implosives only produced negative pressure 8% of the time … my physiological data for Ga□, Sindhi and Yoruba show negative pressures most of the time". Nihalani (1974, 1991) has shown that there exist natural languages like Sindhi (spoken in India and Pakistan) and Kalabari (spoken in Nigeria) in which implosives do involve an ingressive airflow in addition to the downward displacement of the vibrating glottis. The quantitative measurements of the air flow dynamics run counter to Ladefoged's assumption that there are no real implosives.

Ladefoged (personal communication) has commented that Nihalani's findings are based on his own speech (one single speaker), and that the aerodynamic data are collected from citation forms. Ladefoged has valid criticism in that we should always use large enough sample to base our generalizations. It is obviously crucial to any study of this sort to have as many speakers as practicable, in order to increase the possibility of making meaningful language-specific generalizations.

The present author therefore decided to expand the data on pressure-flow dynamics from a much larger number of speakers in order to explore aerodynamic characteristics of implosives in Sindhi and also to determine whether these articulatory strategies are consistent within a language or vary according to speaker-specific idiosyncracies**.**

2. Test Materials

Data on the intra-oral pressure and oral airflow were collected from 3 speakers (1 male and 2 females. The following minimal pair representing the bilabial implosive sound positioned syllable-initially was selected:

. [barU] 'a piece of baggage'
["arU] 'a child'

The speakers were requested to utter words in a carrier phrase: "hi□ "arU" 'this child'.

3. Instrumentation

The subjects spoke into a specially constructed mouthpiece pressed against the face, which took the oral airflow through calibrated resistance so that a pressure transducer provides a signal that is directly proportional to the rate of airflow. If one can find a subject who is willing to tolerate a nasal catheter, then it is possible to record the pressure build up behind stop closures anywhere in the vocal tract (see Nihalani, 1974). Alternatively, a simple way of obtaining supra-glottal air pressure and airflow data on just bilabial sounds was used by inserting a small tube between the lips. For a detailed discussion of the instrumentation, see Ladefoged, 1991. All these parameters were digitized along with the audio signal from a microphone at the rate of 11000 samples/sec**.**

4. Results

Figure 1 gives the aerodynamic records of the phrase [hi□ "arU] 'this child'. The top channel records the audio-signal, the middle channel represents oral airflow and the bottom channel represents intra-oral air pressure.

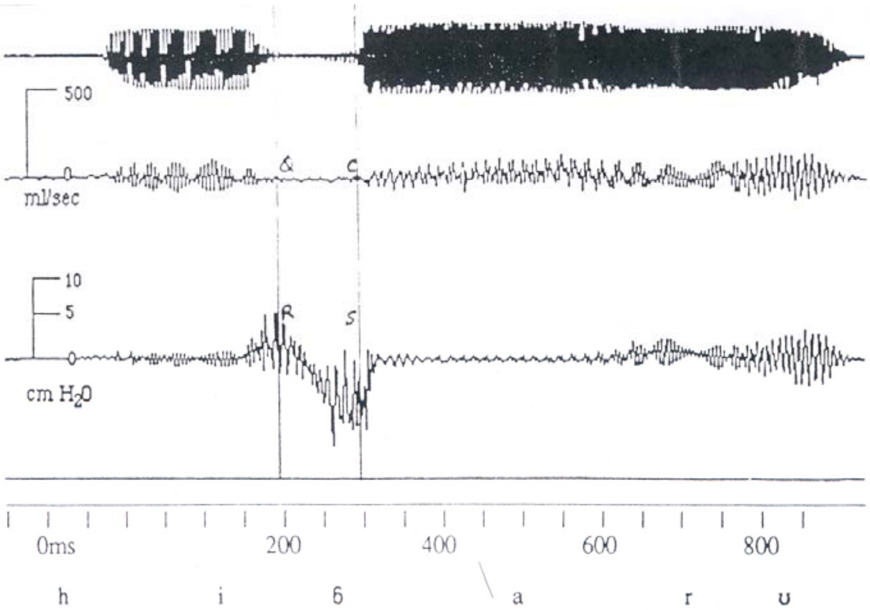

Figure 1. Acoustic waveform, air flow and intraoral pressure records of the word [ɓarʊ] "child".

The closure period in the articulation of the implosive sound is characterized by a straight line Q-C (channel 2) indicating the absence of airflow in either direction through the mouth. The large periodic fluctuations in the delimited segment R-S on the pressure tracing (channel 3) reflect the vibrations of the vocal cords. A mid-line was drawn through these ripples by hand. The maximum pressure was measured on the mid-line. The measurements of the supra-glottal air pressure were made at the point of release of closure. Table 1 presents the Peak Psupra values of the syllable-initial implosives/explosives.

Table 1: Peak Measurements of Supra-glottal Air pressure

	b	"	**Difference**
HW	7.5 CmH2O	-2 CmH2O	9.5 CmH2O
SS	6.5 CmH2O	-5 CmH2O	11.5 CmH2O

In the production of the implosive ["], the vocal cords are brought together before the larynx is lowered. Vocal folds remain fairly tightly together throughout the articulation so that air will not pass through the glottis in such large volume as to destroy the negative pressure necessary for an implosive. Lowering of the larynx obviously enlarges the supra-glottal cavity behind the oral closure, which results in generating negative pressure inside the mouth. Since the larynx lowers only after the vocal folds are constricted, the lips brought together and velopharyngeal port closed, the rarefaction process in the expanding supra-glottal cavity is not affected, so much so that the air is sucked in when the outer closure is released. These results were typical of the male speaker as well.

Another interesting feature was noted consistently in the speech of both speakers. Implosives are produced, relatively, with shorter closure duration. The following table presents the durational measurements of voicing in both ‘implosives’ and ’explosives’:

Table 2: Duration of Voicing in Milliseconds

	b	"	**Difference**
HW	140 msec	100 msec	40 msec
SS	125 msec	90 mes	35 msec

Data given in Table 2 reveal that the voicing of implosives ranges between 70% to 72% of the corresponding explosives.

The third speaker, however, produced implosives with a voiceless beginning of the closure. The closure displays highly aperiodic vibration, whereas the voiced plosive [b] in the speech of the third speaker has periodic voicing vibrations during the closure phase. So the voicelessness or aperiodicity in the case of third speaker may serve to keep the implosives apart from the voiced plosive. However, the spectrograms made from the independent recording of the same speaker clearly indicate presence of vocal fold activity throughout the period of closure in the articulation of implosives. Thus considerable variation was noted within the speech of the same speaker. This might be an idiosyncratic feature of the third speaker.

5. Discussion

The aerodynamic records show that the movement of the larynx occurs while the vocal cords are vibrating. This downward movement of the vibrating glottis enlarges the supra-glottal cavity behind the closure. These vibrations are maintained by a small amount of lung air, which is not of sufficient volume to destroy the partial vacuum caused by the downward laryngeal movement and thus prevent the occurrence of suction pressure. The negative pressure ranging between –2 CmH2o to –5 CmH20 was generated in the mouth. On separation of the articulators, the airflow was found to be ingressive. Thus the quantitative measurements, on the whole, confirm the results reported earlier by Nihalani (1974, 1986). Recently, while referring to Lindau’s work, Ladefoged (1996:84) has observed: “she did not have any aerodynamic data, but her acoustic records indicate that the implosives in these languages (Kalabari, Degema and a number of other languages spoken in the southeast of Nigeria) are very similar to those in Sindhi.”

6. Theoretical Issues

The preceding discussion makes it clear that Sindhi implosives show negative pressure most of the time in contrast to the implosives observed by Ladefoged in which negative pressure was produced only 8% of the time. The main question that arises is whether the linguistic characterization of implosives be based on negative pressure/suction, with the greater degree of downward displacement of the larynx being a physiological consequence of the need to maintain the pressure difference for suction, OR should the linguistic characterization specify (as Ladefoged implies) the greater displacement of the larynx?

This question requires further elaboration. It is well known that phonetic representations are not records of speech the way audio tapes and spectrograms are records of speech. They are rather abstract representations of the linguistically relevant properties of speech. In abstracting away the linguistically relevant properties of speech, phonologists usually eliminate those aspects of speech that are purely physiological, and do not distinguish one language from another. To take an example, the linguistic specification that distinguishes between [p] and [b] in English is that they are [-voice] and [+voice] respectively. Even though the articulatory instruction that accompanies the feature [+voice] is "vibrate the vocal folds", speakers of different language backgrounds may choose different combinations of parameters for the implementation of voicing in stops.

Suppose we took the position that the linguistic instruction that is associated with the production of implosives is "lower the larynx". Voiced explosives and the implosives would then be linguistically distinguished from each other in that the instruction to lower larynx is implementational in the former (the larynx is lowered in order to keep vocal folds vibrating), while it is phonological in the latter. This distinction in the phonological function of the articulatory gesture of 'larynx lowering' is parallel to that of 'velum lowering'. In the production of nasal sounds, the instruction to lower the velum is phonological in that it is associated with the feature [+nasal], while in the production of voiced plosives in Sindhi the lowering of the velum is only a means of implementing the vibration of the vocal folds (Nihalani, 1975).

The distinction between the implosives in Hausa, on one hand, and Sindhi, on the other, in 'not having' and 'having' ingressive airflow would then be a difference in the implementation of the instruction to lower the larynx. In Hausa, the oral closure is released only when the supra-glottal air pressure is neutralized with the ambient pressure, while in Sindhi the oral closure is released when the supra-glottal air pressure is less than that of the atmospheric pressure. As a result, there is an ingressive airflow in Sindhi but not in Hausa.

An alternative would be to hold that the relevant phonological feature of implosives is [+suction], which is associated with the instruction "create an ingressive air flow". The lowering of the larynx would then be a procedure for the implementation of this instruction. That this instruction is not actually realized in languages like Hausa would then be analogous to the fact that the phonological instruction to vibrate the vocal folds fails to apply prepausally and postpausally during the closure period of voiced stops in languages like English.

Another interesting theoretical issue that arises from the study of implosives in Sindhi is the status of implementation phenomena in phonological theory. There has been a growing body of literature in phonetics and phonology in recent years arguing that some details of speech, such as timing and coordination of articulatory gestures, have language-specific conditioning, and therefore they fall within the scope of phonology (Ladefoged, 1980, 1985; Liberman, 1983; Port, Al-Ani and Maeda, 1980; Port and Mitleb, 1983; Mohanan 1986; Cohn, 1990; Huffman, 1990). These processes of "phonetic implementation" as opposed to "physiological implementation" pose a challenge to the traditional notions of segmental phonetic representation and rule systems formulated in terms of discrete operations, and are therefore of profound theoretical interest.

Sounds of one language differ from those of another because of the phonetic value of the segments along the same continuum. If there is a noticeable difference between two sounds in different languages, such that either of them would sound foreign if it were used in the other language, then this difference is part of the linguistic facts of each language. Both Kalabari and Hausa, languages of Nigeria, have voiced bilabial and alveolar implosives. In Hausa words, the vowel that precedes, is marked by irregular vibrations of the vocal cords, and there is, at best, laryngealized voicing throughout the closure. But in Kalabari words, the implosive sounds are fully voiced throughout the closure, and there is no tendency toward creaky voice or larngealization" (Ladefoged 1980:500). A comparison between these two sets of spectrograms clearly brings out the distinction between the implosives in Sindhi and Kalabari on the one hand, and those in Hausa on the other. Evidently, Sindhi implosives are fully voiced through the entire period of closure and there is no tendency toward creaky voice or laryngealization. As a native speaker of Sindhi, I would say that Kalabari implosives, even perceptually, sound much closer to those of Sindhi. In order to give a precise account of what makes a particular language sound the way it does, it is necessary to describe the phonetic properties of individual segments. Such differences of each language will have to be described in terms of language-specific low-level rules of "phonetic implementation", and these must form part of the phonological description of natural languages.

Until recently, a widely accepted view, following Chomsky & Halle was that phonetic implementation was universal and this was discussed explicitly in terms of coarticulation. Phonetic implementation or the physical realization of the abstract patterns represented by the phonology was assumed to be mechanical. As a consequence, a phonological output was assumed to have a unique physical realization. It was also assumed that phonetic differences occurred cross-linguistically. Within this framework, the distinction between phonetics and phonology appeared clear-cut. Phonology involved language-specific rules, whereas phonetics was the universal mechanical realization of the phonology. Since the mapping was thought to be universal, little attention was paid to the phonetic implementation of phonological representation from a linguistic point of view. However, the more phoneticians looked for cross-language phonetic generalizations, the more exceptions they found to possible universal phonetic generalizations. Many phonetic processes that were assumed to be mechanical and to follow automatically from physiological factors, on clearer examination, turned out to demonstrate significant differences between languages. Thus a pure physiological explanation was no longer tenable (see Keating, 1985). Some portion of phonetic rules is indeed part of the linguistic grammar and is not to be relegated to the "universal phonetic" component. These language-specific phonetic rules are a subset of phonological rules and should be accounted for, using phonological rule mechanisms and representations. Linguistic descriptions therefore must be accompanied by a detailed, language-specific set of algorithms before they can be interpreted in terms of actual sounds. An understanding of the mapping processes from discrete, categorical and timeless phonological units to continuous articulatory and acoustic quantitative physical manifestations is a real central issue in the general understanding of phonology, and is the important goal of linguistic phonetics.

Given that the implosives that Ladefoged has investigated are produced without ingressive airflow, unlike the Sindhi implosives, it is necessary to encode this information in phonetic representations, whatever may be the phonological characterization of implosives.

In conclusion, I would propose that implosives are best characterized linguistically in terms of [+/- suction] feature rather than the greater degree of downward displacement of the larynx which is just a physiological mechanism adopted in order to maintain the pressure difference for suction. The absence of suction in other types of implosives (such as Hausa and other Nigerian languages) could be explained in terms of the implementation of the linguistic features in terms of physiological mechanisms.

References

Cohn, A. Phonetic and phonological rules of nasalization. *UCLA Working Papers in Phonetics*, 76) Ph.D. Thesis. University of California, Los Angeles, 1990.

Huffman, M. Implementation of Nasal: timing and articulatory landmarks. *UCLA Working Papers in Phonetics*, 75, 1990.

Keating, Patricia. Phonology, experimental phonetics, and coarticulation. *UCLA Working Papers in Phonetics*, 62: 1-13, 1985.

Ladefoged, P. *Preliminaries to Linguistic Phonetics*. Chicago: University of Chicago Press, 1971.

Ladefoged, P. What are Linguistic Sounds made of? *Language* 56: 485:502, 1980.

Ladefoged, P. 1985. Redefining the scope of phonology. *UCLA Working Papers in Phonetics*, 60: 101-108, 1985.

Ladefoged, P. Computerized phonetic fieldwork. *UCLA Working Papers in Phonetics*, 78: 1-6, 1991.

Ladefoged, P. and Ian Maddieson. *The Sounds of the World's Languages*. Oxford: Blackwell, 1996.

Liberman, M. Phonetic representations. Paper presented at the Stanford Workshop on Lexical Phonology and Morphology, 1983.

Lindau, M. & Ladefoged, P. Variability of feature specifications. Paper presented at the Symposium on Invariance and Variability in Speech, MIT, 1983.

Lindau, M. Phonetic differences in glottalic consonants. *Journal of Phonetics* 12: 147-155, 1984.

Nihalani, P. An aerodynamic study of stops in Sindhi. *Phonetica* 29: 193-224. 1974.

Nihalani, P. Velopharyngeal opening in the formation of voiced stops in Sindhi. *Phonetica* 32: 98-102, 1975.

Nihalani, P. Phonetic implementation of implosives. *Language and Speech* 29: 253-262, 1986.