ACCOMMODATION TO THE AERODYNAMIC VOICING CONSTRAINT AND ITS PHONOLOGICAL RELEVANCE

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ABSTRACT

The aerodynamic voicing constraint presents the speaker with some physical limits on maintaining voicing during obstruents. Languages' phonologies reveal a variety of strategies in the face of this constraint. These strategies raise serious questions about constraints in Optimality Theory (OT).

Keywords: voicing, speech aerodynamics, sound change, Optimality Theory

1. INTRODUCTION

The Aerodynamic Voicing Constraint" (AVC) has long been recognized in phonetics-phonology [2, 13, 17]: voicing requires a sufficient airflow through the adducted vocal cords. The airflow requires a sufficient pressure difference (ΔP) between subglottal pressure (P_s) and oral pressure (P_o). During an obstruent air accumulates in the oral cavity thus increasing P_o. When the P_o approaches Ps, the airflow falls below that needed for vocal cord vibration and thus voicing is extinguished.

2. ADAPTING TO THE AVC

There are two basic ways that speakers adapt to the AVC: 1) let the AVC prevail and 2) circumvent the AVC.

2.1. Do nothing: Let the AVC prevail

Consequences of letting the AVC prevail include:

2.1.1. Obstruents will be voiceless

(For supporting data on this and the following sound patterns, see [13].) Languages which have only voiceless obstruents include Cantonese, Hawaiian, Zuñi, Ainu, and Quechua. This pattern is especially evident with geminate stops where the longer duration of the stop closure aggravates the AVC.

2.1.2. Fricatives and the AVC

Among obstruents there will be a greater tendency for fricatives to be voiceless than stops. This asymmetry arises because optimal voicing requires that Po be substantially below P_s but optimal frication requires P_o be substantially higher than atmospheric pressure. Languages that have voiced and voiceless stops but only voiceless fricatives include Malayalam, Welsh (Cymraeg), and Thai.

2.1.3. [-Anterior] Stops and the AVC

Voicing may be present only on anterior stops because more forward articulations expose a greater amount of compliant surfaces to the impinging P_o and so more glottal airflow can be accommodated before ΔP falls below the level needed to support voicing. Languages which manifest voicing on anterior stops but not non-anterior consonants (primarily velars) include Thai, Dutch, Czech, and some dialects of Arabic.

2.1.4. VOT variations due to vowels

Voiceless stops will have VOT proportional to the degree of constriction of the following vowel or glide [12]. A close constriction attenuates the rate of airflow exiting the vocal tract after a stop and thus delays the time when P_o is low enough to initiate voicing. Occasionally this longer VOT before close vowels leads to a sound change where aspiration becomes distinctive. E.g., The Bantu language Ikalanga merged the 'superclose' high vowel *i and the lower vowel *ɪ in the proto-language into their /i/ vowel but in the process gave rise to distinctive aspiration (and affrication, due to the high airflow) in the voiceless stops that had appeared before the higher vowel:

Proto-Bantu	**Ikalanga**	**meaning**
*tɪma	tima	*heart*
*tima	t͡sʰima	*well*

2.1.5. Voiceless vowels

For similar reasons, if languages exhibit voiceless vowels there is a tendency for them to be high close vowels such as /i/ and /u/ (although typically other conditions apply as well, e.g., that the vowels are short and/or appear between voiceless consonants or pre-pausally) [6].

2.2. Circumvent the AVC

Speakers have discovered a number of strategies to circumvent the consequences of the AVC in order to maintain voicing in obstruents. But, as often happens, once implemented the particular strategy may lead to sound changes where other features become distinctive.

2.2.1. Make closure durations short

Cross-linguistically the duration of voiced obstruent closures is less than that for cognate voiceless obstruents [11]. A shorter closure duration helps to avoid the buildup of P_o to the point where ΔP becomes too low to support voicing. One consequence of this is that it is voiced stops which are prone via sound change to become voiced approximants, e.g., b > β or ʋ, d > ð, g > ɣ, and the like, A further consequence of making voiced obstruents short is that the preceding vowel can become long. (Whether this comes about because the vowel now occupies more of the time allotted to the VC sequence or because the longer vowel length creates a useful contrast with the shorter C whose shortness is itself a cue to its identity is an open matter.) In many dialects of English the duration of the preceding vowel is a more salient phonetic feature differentiating minimal pairs conventionally characterized as differing in the voicing of the following obstruent, e.g., *dice* vs. *dyes*.

2.2.2. Prenasalize the voiced stop

Prenasalized voiced stops are found in many languages and are often the only form of voiced stop in opposition to voiceless stops (e.g., in Fijian). Prenasalization is a strategy to circumvent the AVC by venting P_o so that it does not lead to a reduction in the needed ΔP [22]. Closing the velic valve shortly before the release enables the stop to retain the two features essential to a voiced stop: its voicing and the cues for a stop: a burst and a rapid rise time in the amplitude of the following vowel.

2.2.3. Change voiced stops to voiced implosives

There is abundant documentation of the link between voiced stops and voiced implosives [6] as evidenced by diachronic data showing the origin of implosives in Sindhi:

Prakrit	Sindhi	Meaning
pabba	pɑɓuṇi	*lotus fruit*
bʱɑggɑ	bʱɑːʛu	*fate*

Even voiced stops are associated with a lower larynx position vis-à-vis voiceless stops [5]. Voiced implosives skirt the AVC by actively creating more volume in the oral cavity to accommodate the accumulating airflow.

2.2.4. Implement voiced apicals as retracted

There is evidence of a link between retroflexion and voicing in apical stops [7, 8]. Using the 'artificial venting' method of [15, 23] presented evidence that a retroflex tongue configuration permitted voicing to persist longer than in an apico-dental configuration They hypothesize that the retroflex configuration is more conducive to voicing because it exposes more compliant surfaces of the tongue to the impinging P_o.

2.2.5. Produce stops with [ATR]

Much phonological evidence points to a link between voicing in obstruents and the appearance of [ATR] (Advanced Tongue Root) on adjacent vowels [24, 25, 26]. Diachronically it is evident that it was the [+ATR] on the voiced obstruents that subsequently triggered a change in the adjacent vowels to become [+ATR]. There is also phonetic evidence that the pharyngeal cavity shows expansion during the production of voiced stops [19, 27]. [16] also found a lesser incidence of German voiced stops devoicing medially if the coarticulated vowel was a front vowel (which are known to involve tongue root advancement). In addition, visual inspection of my pharynx with a fiberscope revealed quite dramatic movement of the lateral pharyngeal walls synchronized with onset and offset of a voiced stop. It would be precisely the lateral pharyngeal walls that would receive greater exposure with an advancement of the tongue root.

2.3. Interpretation of the preceding patterns

Ten ways of adapting to the AVC were discussed; there undoubtedly are more. Those in section 2.1. essentially adapt by letting the AVC act to passively restrict voicing. The adaptations in 2.2. to circumvent the AVC are perhaps more interesting. How did these various strategies come about? I hypothesize that they were serendipitously "discovered" by speakers, i.e., via random explorations of what could be done with the vocal organs. The fact that there are such different strategies suggests to me that there were no innately-specified routes to follow.

Further research is needed to support the scenarios presented. In particular, for the sake of confirming the offered accounts of 2.1.3. (only anterior stops will retain voicing), 2.2.4. (retracting apical stops), and 2.2.5. (implementing ATR), it would be desirable to have a complete map of tissue compliance of all relevant surfaces in the vocal tract for particular stop types as coarticulated with different vowels. In addition, quantitative measures on how much additional volume is added to the vocal tract during the production of implosives are necessary.

3. IMPLICATIONS FOR PHONOLOGY

3.1. Explanation, not just description of patterns

For a phonetically based phonology looking to explain phonological universals [13], the AVC helps to account for a diverse set of sound patterns which, on the surface, would seem to have little in common: closure duration, VOT, implosion, retroflexion, ATR, pre-nasalization of stops, etc. It has an explanatory value similar to the 'nodes and antinodes' analysis of the standing waves of the resonances in the vocal tract as given by [3].

3.2. Teleology in sound change?

There is an issue in diachronic phonology as to whether sound changes are teleologically driven or not, that is, whether changes are purposefully implemented to achieve some goal, e.g., easier articulation for the benefit of the speaker or greater clarity for the benefit of the listener. My own belief is that neither of these factors plays a role in sound change. But there is some teleology and that is to *maintain pronunciation according to what the speaker-listener takes to be the accepted norm.* From the point of view of the listener-speakers responsible for implementing the changes mentioned above, they were doing their best to implement the voice feature of sounds (cf. also [9]). An unintended consequence (due to how other listeners misinterpreted what they heard) would be the implementation of implosives or retroflex apicals or [+ATR] vowels, etc. as new elements constituting a new pronunciation norm. But at its point of origin there would be no teleology for *change*, as such.

3.3. Constraints within Optimality Theory

Optimality Theory (OT) [20] as applied to phonology also claims to use constraints to guide derivations from an underlying form to a surface form. It is not clear how OT would make use of the AVC as a *general constraint* underlying what have so far been presented in OT as individual constraints (e.g., *[+voice,][-son]). OT's representation of constraints in a simplistic shorthand is no substitute for the kind of quantitative modeling of speech production evident in, e.g., [21].

Two other aspects of constraints within OT deserve scrutiny: First, according to some, the constraints posited within OT are claimed to be innate [1]. This is surprising since it is well established in evolutionary genetics that only structures or behavior that impart increased survivability manage, via selection, to get encoded in species' genomes. There's no evidence that speakers of languages with simple voiced stops have any different survivability than those with voiced implosives or [+ATR] consonants. Second, OT constraints are not offered just as simple descriptions of universal phonological tendencies, rather they are claimed to be elements in speakers' mental grammars and used to make derivations, e.g., English *congress* from an underlying /kɑngɹ̩ɛs/ (with alveolar /n/) to the surface pronunciation [kʰɑŋgɹ̩ɛs] (with the velar /ŋ/) [10].

3.4. A "Chicken Little" inquiry

One might think that these are empirical matters requiring further psychological or genetic study. I propose an epistemological inquiry, otherwise known as a "Chicken Little Inquiry" [14]

Chicken Little is the principal figure in a children's story familiar to English speakers. One day she was injured when something struck her head. She then set the entire barnyard into a panic with her claim that the sky was falling. The resolution of the story did not involve experiments testing whether the sky was, in fact, falling; it involved an inquiry as to why Chicken Little *thought* it was falling. The immediate evidence was a swelling on the top of her head. Where was she when the injury occurred? Under an oak tree. A large acorn was found there, very likely what had caused the injury. The moral of the story—not stated quite so explicitly—is that before investing a lot of time and effort in costly experiments evaluating a given hypothesis, one should first look at the motivation for the hypothesis having been made. Then we should ask whether the observation prompting the hypothesis might be accounted for by other, less extravagant, hypotheses.

So what is the motivation for OT? In the late 1960's Chomsky & Halle [4] persuaded phonologists that they could discover speakers' grammars -- the mental mechanisms used to derive, e.g., in English, *obscenity* and *obscene* from the same root via processes that previously were the domain of historical phonology which had no such psychological pretensions. It seems that many phonologists still believe that they can discover psychological – and, now, genetic – elements and mechanisms just by applying the methods of historical phonology. This was an extravagant and empirically unsupported hypothesis in the 1960's and is still so today.

4. CONCLUSION

The AVC, like the bases for other phonological universals, arises from physical and physiological constraints on speech. There is no compelling evidence that such universals require psychological or genetic intervention for their manifestation in human language.

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