SOME PHONETIC BASES FOR THE RELATIVE MALLEABILITY OF SYLLABLE-FINAL VERSUS SYLLABLE-INITIAL CONSONANTS

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ABSTRACT

Syllable-final consonants seem to be more susceptible to assimilation and deletion than are syllable-initial consonants. We are using instrumental data to augment earlier claims about the phonetic bases of such asymmetries.

1. INTRODUCTION

It is often noted that syllable-final consonants are more malleable (subject to deletion, lenition and assimilation) than syllable-initial consonants [1,3]. If speech sounds weren't made by a real mouth, then V-C sounds might be mirror images of C-V sounds, and there would be no phonetic bases for such asymmetric phonological behaviors. However, speech sounds *are* produced by real vocal tracts, and there *are* certain asymmetries in the acoustics of movements into and out of consonant closures, as outlined by Ohala and Kawasaki [8]. Some of these asymmetries are simply due to the way aerodynamic forces change over time, given symmetric movement into and out of consonant closure. Other acoustic asymmetries may be due to the relative timing of oral vs. velar and/or glottal gestures, differences which result in different overall vocal tract shapes at closure implosion versus closure release. Importantly, these asymmetries are such that various features of consonants should be more salient at releases than at implosions.

Here we compare some of the acoustic characteristics of particular consonants, in order to determine possible sources for certain phonological asymmetries. Thus, we are following John Ohala and others [2,4,5,7,8,10,11] who have sought to find, in the architecture and acoustics of the vocal tract, explication of (at least some) phonological behaviors.

2. SYLLABLE-INITIAL VERSUS SYLLABLE--FINAL STOP CONSONANTS

2.1 Syllable-initial stop consonants

During the closure interval of an oral stop consonant, air pressure builds up in the oral cavity as air flows through the glottis into the mouth. At the release of the stop, a brief burst occurs at the oral constriction. This noise source, which has an abrupt onset, has cue value for manner feature - generally it is absent in sonorant consonants and it does not have an abrupt onset for fricatives. The burst is filtered by the cavity in front of the constriction, and consequently its spectrum varies as a function of the place of constriction. As the oral cavity continues to open, the primary acoustic source switches to the larynx. This laryngeal source is also filtered by the changing oral tract shape, producing consonant-to-vowel formant transitions. Since the formant transitions reflect the changing oral tract configuration from the constriction to the following vowel, they too are strong cues as to the place at which the oral constriction was made. The rate of the transitions, determined by the rate of the articulatory movements, is a further cue to manner, as stop-vowel movements are much more rapid than glide-vowel movements [6].

If the vocal folds are sufficiently adducted at the release of the oral constriction, the vocal folds will vibrate immediately following the release and the laryngeal source will be periodic. If the glottis is appreciably open at the moment of oral release, the laryngeal source will be aspiration noise until the vocal folds have adducted sufficiently to permit glottal vibration. The acoustic correlates of aspiration and the way in which this source couples with the oral tract has the consequence that the first formant is very weak in amplitude, and the upper formants are noise-excited [9]. These differences in source characteristics show up in the formant transitions, and the transitions at the release of a stop consonant are cues to the voicing feature for the consonant.

Thus syllable-initial consonants have rich information in that (1) **bursts** provide a good source of information for manner and place and (2) **formant transitions** provide a good source of information for manner, place, and voicing.

2.2 Syllable-final stop consonants

On the other hand, the acoustic consequences of movement from a vowel *into* a stop consonant constriction are less rich. As the talker moves from a vowel into a consonant, in most cases there is little or no noise generation, but formant transitions are observable as long as the glottal source continues during the movement into the constriction. However, unlike releases of consonants into vowels, movement from vowels into consonants does not entail a burst. As noted above, the burst at a C-V release is due to pressure buildup in the mouth, but this pressure buildup occurs precisely because the oral tract is closed during the consonant, and therefore is not relevant to the movement *into* the constriction.

In syllable-final position, manner distinction between the glides and stops may not be as well maintained as it is in syllable-initial position, since there seems to be a tendency for gestures to diminish at end of syllables [5].

2.2.1 Implementing voicing distinctions for syllable-final stops may put place distinctions at risk.

If fully voiced, the transitions from a vowel into a stop closure provide little information about voicing of the consonant, since they should be identical for both voiced and voiceless consonants. If these consonants are unreleased (as they often are when utterance-final or when followed by another consonant), then how are voicing distinctions maintained? Languages use several strategies, including cutting off voicing very near oral closure for voiceless stops by:

- opening the glottis, or
- constricting the glottis (making a glottal stop)

If timed to occur by the time oral closure is achieved, either of these devoicing gestures would aid in preventing vocal fold during the beginning of the oral closure period.

In English, it is quite common to achieve devoicing for syllable-final voiceless stops by making a glottal stop very close to oral implosion [3]. Note that if this glottal stop is timed too late with respect to oral closure, then it won't serve to distinguish voiced and voiceless stops, since at the moment of oral implosion the vocal folds would still be in a configuration suitable for vibration. To ensure devoicing, a better strategy would be to error on the side of making the glottal stop relatively early.

However, if the glottal stop is timed *too* early with respect to oral closure, the formants won't be excited during the V-C closing movement. This in turn would result in loss of place information. Eventually speakers may not bother to make the oral gesture at all, and this presumably explains the development of dialects that have glottal stops instead of oral stops in final position.

Figures 1a-c show acoustic data from a study [7] which used simultaneous electropalatographic (EPG) recordings, fiberoptic views of the larynx, and acoustic recordings, to illustrate this point. In each of the figures is shown the F1 movements toward the end of an English word that phonologically ends in /t/. What we are interested in is whether or not F1 falls toward the end of the vowel which precedes the /t/, as F1 fall is an acoustic consequence of oral closure (F1 fall can clearly be seen in the reference word that ends in /d/).

The data in Figure 1a are from a speaker who heavily glottalized his /t/, but who actually made an alveolar closure at about the acoustic end of the vowel, as evidenced by our EPG data. Acoustic evidence of the oral closure can be seen in the F1 fall.

In contrast, Figure 1b shows the same speaker's production of a /t/ in *absolute utterance-final* position. EPG data indicated that while the speaker *did* make an alveolar closure, he made it very late with respect to the end of the vowel. Fiber-optic data indicate that in this case devoicing was achieved with a glottal stop. As can be seen by the slight fall in F1, there is some acoustic evidence that at the end of the vowel the speaker is beginning to make an oral constriction.

Figure 1c shows data from a different speaker. The EPG signal indicated that this speaker did not make an oral constriction for the /t/ in the target utterance. Rather, the vowel was terminated solely by making a strong glottal stop. And, we see very little fall in F1, which is expected since the speaker *in fact did not make an oral closure* (there may or may not have been some residual of a *weakened* oral closing gesture, one that did not result in apico-alveolar closure).

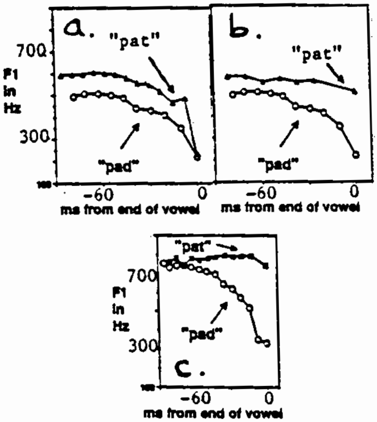

Figure 2a-c. Acoustic evidence of presence or absence of oral closure prior to cessation of vocal fold vibration.

3. SYLLABLE-INITIAL VERSUS SYLLABLE-FINAL NASAL CONSONANTS

During the oral closure period of a nasal consonant, the mouth is closed and the velum is lowered, with the acoustic consequence that much of the sound is filtered and propagated through the nasal cavities. When the oral occlusion is released, there is a sudden increase in the amount of energy in the sound as the principal sound output switches to the mouth opening. This increase is especially marked in the F2 region for labial and alveolar consonants, since the nasal murmur tends to have weak energy in this region. Conversely, with the velum down, oral implosion will result in a sudden *decrease* in the amplitude in the F2 region. This sudden change in F2 is a cue to the implosion or release of the consonant, and the F2 frequency indicates the place of articulation for the consonant.

The amount by which the amplitude of the F2 peak changes as a function of opening or closing the oral cavity is expected to be dependent on the degree to which the velum is lowered [10]. If the velum is very low, then a high percentage of the energy will go through the nose, regardless of whether or not there is a change in the oral constriction, and the resulting change in the amplitude of F2 will be relatively small as the oral constriction is made or released. However, if the velar-pharyngeal opening is somewhat smaller, then the sudden change in the oral constriction will have a very large effect. Thus the consonant/nonconsonant (oral constriction vs. no oral constriction) distinction is most clearly maintained when the velum is not too low.

Several studies [e.g. 11] suggest that the velum is generally lower at the time the oral constriction is being made for a syllable-final nasal consonant than it is at the time oral constriction is released for a syllable-initial consonant. Thus we might expect that going into a syllable-final nasal consonant there is less of a V-C demarcation than the C-V demarcation we get when moving from a nasal consonant into a vowel. If this is the case, then syllable-final nasals might be expected to delete more often than syllable-initial nasals, since they would be less salient to listeners.

An example is shown in Figures 2a and 2b. Figure 2a shows smoothed spectra for the 30 ms periods preceding (solid line) and following (dashed line) the nasal release of [m] in [#mIb#]. There is a 21 dB increase in the F2 region from the spectrum of the nasal murmur to the spectrum of the vowel.

Figure 2b shows spectra for the periods preceding (dashed line) and following (solid line) the oral implosion for the [m] in [#bIm#]. Here there is only a 14 dB difference between the vowel and the consonant, in the F2 region. We have observed similar patterns for a number of utterances and speakers. We are proceeding to quantify these differences, and crucially, we will be looking at the acoustic signal of utterances for which there is accompanying velotrace [5] date to indicate velum height.

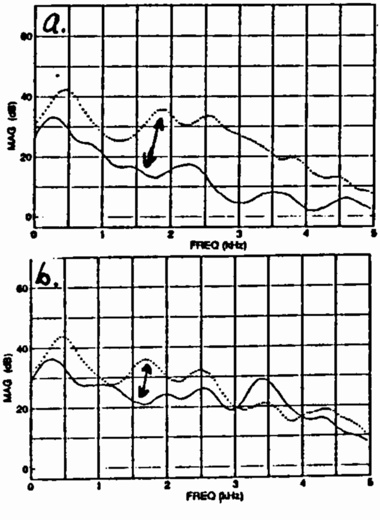

Figure 2a-b. Spectra before and after /m/ closure and release. Arrows point to F2 region.

4.SUMMARY

These are just a few of the differences between the acoustic consequences of making and releasing consonant constrictions. As we have seen, some differences, such as the presence or absent of a burst, are simply due to physics. Other asymmetries are due to the ways in which velar or glottal gestures are used to implement the features voicing and manner. Implementation of these features may involve different or differently timed gestures, depending on syllable position. These articulatory asymmetries can put at risk the saliency of certain other features, particularly in syllable-final position. Listeners may not hear, for example, that a speaker has actually made a consonant closure, or a closure at a particular place. These listeners might reasonably assume that a consonant was not made (deletion), or that it was made at some place other than what the articulatory facts would have revealed (assimilation). When those listeners take their turn at speaking, they may articulate in the way they *assume* other speakers do - omitting, weakening, or assimilating syllable-final oral gestures.

5. REFERENCES

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