THE EFFECTS OF PROSODY ON VOICELESS STOP-RELATED GESTURES IN ENGLISH

André M. Cooper
The University of Michigan, Ann Arbor, Michigan USA

ABSTRACT

This study examines the contextual variation in a number of indices of aspiration that appear in the literature in order to determine whether the variation in these indices can be accounted by phonological rules based on syllable structure. Results suggest that effects of both stress and word structure, rather than syllable-based category changing rules, best describe the contextual variation in the indices.

1. INTRODUCTION

In English voiceless stops vary between aspirated and unaspirated. Aspirated stops are said to occur word initially, and syllable initially in stressed syllables. Although phonologists have devised category changing rules to describe the distribution of these voiceless stop allophones (e.g., [1], [2], [3]), it unclear exactly what aspect of a voiceless stop's production corresponds to aspiration. If the category changing rules capture facts about speakers' productions of voiceless stops, there should be a corresponding physical index of aspiration (IOA) that varies as a function of syllable structure.

The goal of the present study is to examine a number of possible IOAs that appear in the literature, in order to test which, if any, is categorically distributed. An additional goal is to test whether the contextual variation in the indices is best accounted for by a categorial rule (aspiration-category proposal), or by continuous effects of prosody on oral and laryngeal gestures and on the way these gestures are coordinated in time and space (prosody proposal). The IOAs include: (a) voice onset time--the interval from the release of a stop and the onset of glottal pulsing (e.g., [4], [5]), (b) peak glottal magnitude--the maximum degree to which the glottis opens for devoicing, (c) glottal magnitude at oral release--the degree to which the glottis is open at the time of oral release [6], (d) the timing of the onset of glottal adduction relative to the oral release of a stop [7]. Longer VOTs, larger glottal openings and later onsets of glottal adduction relative to oral release are all associated with greater amounts of aspiration.

2. EXPERIMENT 1

2.1. Methods

Two male speakers of English, ES and KM, spoke the nonsense words /pipip/, tɪtɪt, kɪkɪk/ with primary stress on either the initial or the final syllable in the carrier phrase "say___again." Both acoustic (as a measure of oral closure and release) and transillumination (as a measure of glottal activity) signals were recorded synchronously.

2.2. Data Analysis

For each speaker separate ANOVAS were performed comparing the effects of stress and word position on each IOA for each stop category. When there were significant interactions, separate protected t-tests were performed for each word position to determine whether there was an effect of stress on the IOAs. Approximately twenty four repetitions of utterance are included in the analyses. The aspiration-category proposal predicts that there should be a significant interaction between the effects of stress and word position such that there is no difference between word-initial IOAs and a significant difference between medial IOAs. The prosody proposal predicts there should not be an interaction between stress and word position on the IOAs. Finally, if there were both a significant interaction and a significant stress effect on IOAs in both initial and medial positions, this result would be ambiguous between the aspiration-category and the prosody proposals. Probabilities less than .01 are considered significant.

2.3. Results

2.3.1. Acoustic Data

The VOT data for ES lend strong support for the aspiration-category proposal. There is a significant interaction between stress and word position. In addition, there is no significant difference between prestressed and preunstressed VOT in initial position and a significant difference in medial position.

The data for KM are not as uniform. The data for /t/ support the prosody proposal, while the data for /p, k/ are ambiguous between the two proposals. For /p, k/ there is a significant interaction of stress and word position on VOT, as the aspiration-category predicts, but there are also significant stress effects in word-initial and medial positions.

2.3.2. Transillumination Data

For both speakers the peak glottal magnitude data for the labial stops are ambiguous between the aspiration-category and the prosody proposals, while the data for the lingual stops support the prosody proposal.

The pattern of results for glottal magnitude at oral release are virtually identical to those for the peak glottal magnitude. Peak glottal magnitude, however, is greater than the glottal magnitude at oral release.

2.3.3. Interarticulator Timing

There are no consistent patterns of oral-laryngeal timing across speakers or across stop categories within speakers. Thus, it does not appear that the onset of glottal adduction always occurs later for stops which are supposed to aspirate than for stops which are supposed to be unaspirated.

2.4. Summary and Discussion

Both the aspiration-category and the prosody proposals find some support. Surprisingly, there was no single IOA, whose distribution (across speakers and stop categories) fit either proposal exactly. These finding suggests that aspiration, however defined, is neither solely a function of syllable structure, nor solely a function of prosody.

An alternative interpretation of these results is that both stress and word position (prosody + word position proposal), rather than syllable structure, per se, affect the contextual variation in the IOAs. This interpretation could subsume each of the previous proposals. Specifically, IOAs in word-initial position might simply hold a unique status.

Consider the fact that in many dialects of English, word-initial stops are distinguished physically by differences in voicing lags, rather than by voicing lead versus voicing lag. Thus, word-initial /b, d, g/ are realized physically as [p, t, k] and word-initial /p, t, k/ are always realized as [p^h, t^h, k^h] in order to be differentiated from their voiced counterparts. In word-initial position the articulators may work to minimize stress-related differences in IOAs so that voiced and voiceless stops will not be confused perceptually.

Finally, these data suggest a difference in the way that the glottal IOAs for labial and lingual stops behave. This difference may serve to enhance the perceptional distinction between voiced and voiceless labial stops. All else being equal, voicing will begin earlier for labial stops than for lingual stops because it takes a longer time to build a pressure differential across the glottis (a physical condition necessary for voicing to occur) for smaller cavities than for larger ones. Consequently, in order to insure an a voicing lag sufficient for bilabial stops to be perceived as voiceless, more extreme laryngeal and oral-laryngeal timing maneuvers may be required for labial stops than for lingual stops.

3. EXPERIMENT 2

Experiment 2 seeks to distinguish between the aspiration-category, the prosody, and the prosody + word-position proposals by examining voiceless stops in additional segmental contexts. Two types of stimuli are used. For both stimulus types voiceless stops appear in contexts where aspiration categories should not vary as a function of syllable structure. The effects of stress on IOAs for these stimuli are then compared with the data in Experiment 1.

According to the aspiration-category proposal stress is predicted to have a large effect on IOAs only when it produces a change in syllable structure. For the present stimuli the aspiration-category proposal would find further support if stress effects on the IOAs were small, and comparable to those for word-initial singletons in Experiment 1

that supported the aspiration-category proposal.

If, however, stress effects on these IOAs are large and comparable to those for medial singletons in Experiment 1, it can be argued that stress has similar effects on IOAs regardless of the intended aspiration categories (prosody proposal), with the caveat that stress can affect word-initial IOAs differently than it affects non-word-initial IOAs (prosody + word-position proposal).

3.1. Methods

The two males from Experiment 1 spoke the nonsense words /pɪspɪp, pɪpsɪp, pɪsɪp, pɪptɪp, pɪtpɪp/ in the carrier phrase "say___again." KM did not produce any of the final stops in the target words or the word /pɪtpɪ/. Primary stress occurred on either the initial or the final syllable. Again, both acoustic and transillumination data were collected synchronously.

3.2. Data Analysis

First two-way ANOVAs were performed to investigate how the combined effects of stress and utterance type affect each IOA for the present stimuli. Then ANOVAs were performed to examine the effects of stress and utterance type on the stop-stop clusters vs. the initial singleton stops from Experiment 1. Finally, ANOVAs IOAs were performed to examine the effects of stress and utterance type on the stop-stop clusters vs. the medial singleton stops. Where there were interactions, additional ANOVAs were performed to determine their source. Probabilities less than .01 are considered significant.

3.3. Results

3.3.1. Acoustic Data

The VOT data for stop-stop clusters support the prosody + word position proposal. For both speakers stress has significant and equivalent effects on VOT for /pt, tp/. Furthermore, the magnitude of stress effects on VOT for stop-stop clusters, for which stress should not produce shifts in aspiration categories, is comparable to that for singletons where stress is predicted to affect aspiration categories. Stress did not have a significant effect on VOT for /sp/ for either speaker. It was not appropriate to measure VOT for the other utterances with fricatives.

3.3.2. Transillumination Data

Like the VOT data, the present results provide support for the stress + word position proposal. For both speakers stress effects on peak glottal magnitude for stop-stop clusters are comparable to those for singletons in whatever position stress effects are greatest.

For both speakers stress effects on peak glottal magnitude differ for stop-stop clusters versus the utterances with fricatives. Stress affects all of the utterances with fricatives in a uniform fashion and there is a significant main effect of stress.

4. General discussion and conclusions

The results for the stop-stop clusters directly support the prosody proposal and implicitly support the prosody + word position proposal. In particular, stress effects on the IOAs for stop-stop clusters are most similar to those for singletons which vary between aspirated and unaspirated.

The stop-stop cluster data also have implications for the VOT results in Experiment 1. Recall that these data appeared to offer support for the aspiration-category proposal. The present results, however, indicate that the contextual variation in the IOAs cannot be explained by a need to produce aspirated allophones in certain phonological environment and unaspirated allophones in others. Rather, it appears that stress has large effects on nonword-initial IOAs--regardless of whether stress differences cause changes in syllable structure--and potentially smaller effects on word-initial IOAs.

The stops in /s/ stop clusters do not aspirate. Therefore, the IOAs are predicted to exhibit little or no stress effect according to the aspiration-category proposal. According to the prosody + word position proposal, however, these IOAs might be expected to show relatively large stress effects since the stops are not word initial. Although the peak glottal magnitude shows significant stress effects, the VOT results show no stress effect for /sp/, suggesting that the lack of stress-related variation in VOT might be most economically described by an aspiration rule that makes reference to syllable structure.

Browman and Goldstein [8] explain the defective distribution of stops in /s/-stop clusters as a constraint on the articulatory structure of English words. They propose that English words can begin with only one devoicing gesture. Thus, the constituents of /s/-stop clusters share a single devoicing gesture rather than each having its own. The lack of voicing and aspiration for the stop is then explained by a general principle governing gestural coordination in English. The devoicing gesture begins at the onset of the fricative and ends at the release of the following stop, thus, generating a voiceless unaspirated stop.

Lisker [9] states that the problem of the status of aspiration in voiceless stops following /s/ is one of English orthography rather than contextual variants. Unlike some environments in which the phonological status of aspiration can be determined paradigmatically, (e.g., the labial stops in "rapid" and "rabid" which contrast in voicing or the stops in "bin" and "pin" which contrasts in aspiration), the status of stops in /s/-stop clusters cannot be distinctively contrasted and are, therefore, phonologically ambiguous. Thus, it is just as plausible to attribute the lack of aspiration and voicing of stops in word-initial /s/-stop clusters to a devoicing rule since /b, d, g/, which never aspirate, are generally voiceless following any voiceless obstruent.

In summary, no physical IOA was found whose contextual variation could be described as a function of syllable structure. Instead, the physical realization of nonword-initial IOAs may be predictable largely as a function of stress. The physical realization of word-initial stops, however, form a special case. The unique status of word-initial sounds is not idiosyncratic to the present data. Indeed, word boundaries are important junctures in speech and consonants and vowels generally have been found to behave differently in word-initial versus non-word initial position (e.g., [10], [11]).

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