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Prosodic-structural modulation of stop voicing contrast along the VOT continuum in trochaic and iambic words in American English

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A B S T R A C T

This study explores the phonetic nature of phonological stop voicing contrast in American English by investigating how phonetic implementation of the voicing contrast is modulated by the prosodic structure along the continuum of phonetic voicing. In particular, the present study examines (1) the effects of two kinds of prosodic strengthening that can arise with prosodic structuring, a boundary-related domain-initial strengthening (DIS) and a prominence-induced strengthening, and (2) the possible enhancement types of linguistic contrasts that can underlie prosodic strengthening. The phonetic voicing was estimated using the *Integrated Voicing Index* (IVI), taking into account both the voicing lag (positive VOT) and the voiced interval during the closure. Results obtained with initial stops in both trochaic and iambic words are encapsulated as follows. Under the influence of DIS, both voiced and voiceless stops were produced with an increase in voicelessness, showing an enhancement of structurally motivated syntagmatic (CV) contrast. The effect size was larger for voiced stops, yielding a boundary-induced phonetic *reduction* of voicing contrast. Under the influence of prominence (focus), both voiced and voiceless stops showed an increase in voicelessness only in trochaic words, but this time, it was voiceless stops that showed a far greater effect, resulting in a *maximization* of voicing contrast—i.e., an enhancement of paradigmatic contrast. Moreover, the *reduced* voicing for voiced stops under prominence even in the medial position indicates that voiced stops are realized in reference to the phonetic feature {vl. unaspirated} rather than {voiced}. These findings imply that seemingly non-contrastive low-level variation is indeed systematically modulated by the prosodic structure in reference to phonetic representations that regulate the phonetic implementation of phonological contrast in a given language. An alternative account is also discussed in the framework of Articulatory Phonology.

1. Introduction

It has been well established in the field of phonetics and phonology that when an utterance is produced, phonological constituents of various levels (such as syllables, words, and phrases) must be put together in a hierarchically organized way according to the prosodic structure stipulated by the grammatical system of a given language (e.g., Beckman, 1996; Shattuck-Hufnagel & Turk, 1996). A growing body of studies on the phonetics–prosody interface has further suggested that the phonetic realization of individual segments is fine-tuned systematically depending on where in a prosodic structure they occur (e.g., Cho, 2016; Fletcher, 2010). An important assumption that underlies the phonetics–prosody interface is that prosodically conditioned phonetic granularity operates systematically at the subphonemic (phonetic) level, such that phonological units are fleshed out with fine-grained phonetic content in a way that serves the linguistic functions assumed by the prosodic structure (Cho, 2011; Fletcher, 2010; Keating & Shattuck-Hufnagel, 2002), often modulating phonetic implementation of phonological contrast (e.g., de Jong, 1995, 2004; Cho & McQueen, 2005; Cho, Lee, & Kim, 2014). In the present study, we build on that premise by exploring how the phonetic implementation of phonological *voicing* contrast of stops in American English can be modulated by prosodic structure and how the prosodically conditioned fine-tuning of

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voicing contrast illuminates the phonetic nature of phonological stop voicing contrast.

1.1. Background

The modulation of phonetic implementation according to the prosodic structure has been discussed in terms of prosodic strengthening, which arises with boundary and prominence marking (see Fletcher, 2010, or Cho, 2016, for a review). Boundary-induced and prominence-induced strengthening refer to a spatiotemporal expansion of segmental realization at the edges of a prosodic constituent (e.g., phrase-initial/final positions) and in stressed/accented syllables, respectively (e.g., Beckman & Edwards, 1994; Cho, 2005, 2006; de Jong, 1995; Fougeron & Keating, 1997; Turk & White, 1999, *inter alia*). The two kinds of prosodic strengthening can be linked to the dual functions of prosodic structure (the delimitative function for boundary marking and the culminative function for prominence marking) and are often construed to enhance different kinds of linguistic contrast, such as syntagmatic or paradigmatic contrast (see Fougeron, 1999; and Cho, 2011, 2016, for a review). The term *syntagmatic* pertains to the structural relationships between neighboring linguistic elements that form a sequence in speech. The boundary-marking function of a prosodic structure can be syntagmatically, or structurally, motivated, to enhance the contrast between neighboring segments (or the syntagmatic contrast) localized at prosodic junctures. The term *paradigmatic*, on the other hand, pertains to the relationship among linguistic units such as phonemes (or words) that can substitute for one another in a given context. The paradigmatic contrast enhancement used here generally describes the maximization of phonemic distinction of contrastive sounds, which is often considered to be associated with prominence. Given the potentially different functions of prosodic structures and their relevance to linguistic contrast with different locality conditions (edges vs. stressed syllables), we specifically address the relationship between English stop voicing contrast and enhancement associated with different prosodic strengthening effects. In what follows, we elaborate on specific issues, along with our research questions and hypotheses.

1.2. Issues and research questions about boundary-related stop voicing contrast

Research on domain-initial strengthening (DIS), which arises with boundary marking, has indicated that the DIS effect is closely linked to phonetic feature enhancement. For example, in an acoustic-aerodynamic study of the DIS effect on three-way contrastive stops in Korean (lenis, fortis, aspirated; e.g., Cho, Jun & Ladefoged, 2002), Cho and Jun (2000) reported that voice onset time (VOT) was more lengthened in domain-initial than in domain-medial positions for aspirated stops, and it was shortened for fortis stops. These results were interpreted as indicating enhancements of different laryngeal features: [spread glottis] for the former and [constricted glottis] for the latter. In a similar vein, Cho and McQueen (2005) showed that the DIS effect in Dutch induced a shortening of VOT for phonologically voiceless stops, the opposite of the DIS effect found in English (Pierrehumbert & Talkin, 1992; Cho & Keating, 2009), despite the fact that the voiceless stop in both languages can be specified with the same phonological feature [-voice] (e.g., Keating, 1984, 1990; Kingston & Diehl, 1994). The asymmetrical boundary-induced modulation of VOT between the two languages was attributed to language-specific constraints on what phonetic features can be involved in the phonetic implementation of the phonological feature [-voice]—i.e., {vl. unaspirated} ({-spread glottis}) vs. {vl. aspirated} ({+spread glottis}) for voiceless stops in Dutch vs. English. In other words, it is not the phonological feature but the language-specific phonetic feature with phonetic content that operates in fine-tuning phonetic implementation under prosodic strengthening. This is in line with Keating's (1984; cf. 1990) view that stops in world languages can be further distinguished in terms of three phonetic categories, {vl. aspirated}, {vl. unaspirated}, and {voiced}, based on which actual phonetic content is determined (but see Cho & Ladefoged, 1999 for linguistic arbitrariness in choosing a modal VOT value in a given language; cf. Chodroff & Wilson, 2017).

Under the assumption that English voiceless stops are phonetically implemented on the basis of the phonetic feature {vl. aspirated}, the boundary-related enhancement of {vl. aspirated} for English voiceless stops might be evident in an increase in the amount of glottal opening (e.g., Cooper, 1991) and longer VOT (Cho & Keating, 2009; Cho et al., 2014; Pierrehumbert & Talkin, 1992), which can be interpreted as a case of paradigmatic enhancement. The increased glottal width and longer VOT, however, could also be interpreted as evidence for a syntagmatic (CV) enhancement because the augmented voicelessness (as reflected in the larger glottal width and longer VOT) would make the consonant more consonant-like, enhancing its structural distinction from neighboring vowels.

One way of testing these possible explanations of enhancement would be to examine how *voiced* stops are phonetically realized compared to voiceless stops under the influence of DIS. If the DIS effect is driven by an enhancement of paradigmatic (phonemic) contrast, voiced stops in the domain-initial position would be produced with an increase in voicing in the direction of phonological contrast between voiced and voiceless stops. The expected polarization effect is schematized as Type 1 in Fig. 1, which shows a leftward polarization of voiced stops (with voicing lead) along the phonetic voicing continuum to be maximally contrastive with the voiceless counterpart. Type 2 in Fig. 1, in which the phonetic voicing for voiced stops is assumed to remain more or less stable, could also be acceptable evidence of paradigmatic enhancement, given that the polarization is still achieved by an increase in voicelessness for the voiceless counterpart. (See below for further discussion on this possibility under prominence-induced strengthening.) Alternatively, however, if the DIS effect is driven by a syntagmatic enhancement of CV contrast, voiced stops are expected to be produced with an increase in voicelessness, just as voiceless stops are, to enhance their consonantality, as schematized as Type 3 in Fig. 1.

However, our understanding of how voiced stops are actually realized along the phonetic voicing continuum under the influence of DIS has been extremely limited, making it difficult to test these possibilities. DIS effects have been explored on some voiced segments in English (e.g., /b, n/) but only in the