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4pSCb24. Effects of prosodic strengthening on /s/-stop sequences in English

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This study examined the effects of prosodic strengthening (arising with prosodic boundary and accent) on English /s/-stop sequences in a sentence. First, the domain-initial strengthening effect was not strictly confined to the first segment, but it could extend into the second consonant and, at least partially, into the following vowel in the #/sCV/ sequence. However, some effects of domain-initial strengthening were sensitive to the presence or absence of accent. Second, prosodic strengthening gave rise to the 'shortened' VOT for the voiceless stop in the #/sCV/ sequence, suggesting that prosodic strengthening can operate on the phonetic manifestation of a phonological rule by reinforcing its phonetic outcome. Third, although two aspects of prosodic marking patterned significantly differently, their interactions revealed that accent-induced strengthening are employed not to emphasize every accented word with the same degree, but to put more weight on the accented word that also reflects important positional information. Overall, the results show that phonetic realization of a /s/-stop sequence is conditioned by an interaction of boundary and prominence factors, which is further modulated by the phonological system of a given language.

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1. RESEARCH QUESTIONS

In the field of phonetics-prosody interface, there have been extensive studies on the phonetic manifestations of prosodic strengthening arising with boundary and accent. However, there is still much room for further investigation to fully understand the nature of prosodic strengthening. Building on the previous findings, the present study explores boundary-induced strengthening and accent-induced strengthening in producing English /s/-stop sequences, coming from either /s/#/CV/ or #/sCV/ (where # indicates a lexical word boundary). It is interesting to examine English /s/-stop sequences in that it allows us to address research questions regarding some important issues that have not been fully investigated in the literature of prosodic strengthening.

This study has the following specific goals with respect to acoustic realization of prosodic strengthening in /sCV/. First, it will examine the domain initial strengthening (DIS) of English #/sCV/, which has been hardly examined in the literature, in order to see how far its effect can spread beyond the first segment. Second, it will examine how accentuation, as another type of prosodic strengthening, will influence the #/sCV/ sequences, and how it will interact with the boundary-induced strengthening. Third, it will examine how the phonetic implementation of the phonological rule by which a voiceless stop becomes unaspirated after /s/ will be phonetically realized in prosodically strong locations. For this specific question, it is of interest how VOTs for the voiceless stop in English #/sCV/ sequences will be realized in prosodically strong locations.

2. METHOD

Ten native speakers of American English, five females and five males, participated in the experiment.

The test consonant cluster was a /s/-stop sequence composed of one voiceless fricative /s/ and one of the three voiceless stops /k,p,t/ in English. The test consonant cluster was embedded in a two-word sequence, in which a lexical boundary was placed either between /s/ and the following stop (e.g., 'ice # can', where # indicates a lexical boundary) or before /s/ (e.g., 'eye # scan') so that it could form a complex onset of the second word with the following stop. For each /s/-stop sequence, two items were included (i.e., for /s/#/k/, 'ice # can' and 'rice # cone'; for #/sk/, 'eye # scan' and 'rye # scone'; for /s/#/p/, 'dice # pot' and 'lace # pin'; for #/sp/, 'dye # spot' and 'lay # spin'; for /s/#/t/, 'peace # tax' and 'base # tone'; for #/st/, 'pea # stacks' and 'bay # stone'). The two-word sequences then appeared in carrier sentences, in which the three critical factors of the present study, Boundary (IP vs. Wd conditions), Accent (Accented vs. Unaccented conditions), and Lexical boundary (s#CV vs. #sCV conditions) were manipulated. In the experiment, the participants were presented with test sentences on a computer screen and asked to read the sentences aloud. Each experimental trial was composed of two sentences to induce desired renditions of the various conditions. Two different sentence types were used for different boundary conditions. In order to induce the accented condition, the participants were asked to make contrast between the two sentences, in which only two pairs of words are contrastive. The items that are contrastive were printed in bold uppercase letters. An example set of test sentences is given in TABLE 1.

TABLE 1. An example set of test sentences containing /s/#/k/ and #/sk/. The test word is underlined, and accented items are in bold uppercase letters.

Test Conditions	Test Sentences
(a) IP /s/#/k/: Accented	After **THEY** say 'ice', '**PAN** again' will be the next phrase to say. But after **WE** say 'ice', '**CAN** again' will be the next phrase to say.
(b) IP /s/#/k/: Unaccented	After **THEY** say 'ice', 'can again' will be the **NEXT** phrase to say. But after **WE** say 'ice', 'can again' will be the **FINAL** phrase to say.
(c) Wd /s/#/k/: Accented	To say 'ice **PAN** again' with me is going to be **DIFFICULT**. But to say 'ice **CAN** again' with me is going to be **EASY**.
(d) Wd /s/#/k/: Unaccented	To say 'ice can again' with **JOHN** is going to be **DIFFICULT**. But to say 'ice can again' with **ME** is going to be **EASY**.
(e) IP #/sk/: Accented	After **THEY** say 'eye', '**SPAN** again' will be the next phrase to say. But after **WE** say 'eye', '**SCAN** again' will be the next phrase to say.
(f) IP #/sk/: Unaccented	After **THEY** say 'eye', 'scan again' will be the **NEXT** phrase to say. But after **WE** say 'eye', 'scan again' will be the **FINAL** phrase to say.
(g) Wd #/sk/: Accented	To say 'eye **SPAN** again' with me is going to be **DIFFICULT**. But to say 'eye **SCAN** again' with me is going to be **EASY**.
(h) Wd #/sk/: Unaccented	To say 'eye scan again' with **JOHN** is going to be **DIFFICULT**. But to say 'eye scan again' with **ME** is going to be **EASY**.

In total, 1440 tokens were collected and analyzed in the present study (6 items x 2 (prosodic) boundaries x 2 accent conditions x 2 lexical boundaries x 10 speakers x 3 randomized repetitions).

Acoustic measurements included /s/ duration, the spectral center of gravity (COG) and RMS spectral energy for /s/, the closure duration and VOT for the following stop, vowel duration, and vowel intensity peak.

Three-way repeated measures Analyses of Variance (RM ANOVAs) were carried out. When necessary, univariate ANOVAs with the method of Bonferroni/Dunn were conducted. In all ANOVAs, *p*-values less than 0.05 were considered significant.

3. RESULTS AND DISCUSSION

The results revealed several important points. First, we found that the domain-initial strengthening (DIS) effect was not strictly confined to the very first segment, but it indeed spread into the second consonant and the following vowel in #/sCV/. There were DIS effects on the first segment of the #/sCV/ syllable: /s/ was produced with longer frication duration and smaller RMS energy (indicating a greater oral constriction) in IP-initial than in Wd-initial position. The voiceless stop as the second member of the #/sCV/ syllable also underwent DIS. It was produced with longer closure duration in IP-initial than in IP-medial position, which is comparable to the lengthened constriction formation duration for the stop after /s/ found in Byrd and Choi (2006)'s articulatory study. This therefore confirms that the DIS effect is not strictly local to the first segment, but it spreads into the next member of the consonant cluster in the acoustic dimension. The boundary effect on the initial vowel, in general, showed increased amplitude. The vowel was louder IP-initially than Wd-initially, which is exactly what was observed in Cho and Keating (2009). Unlike with the intensity measure, however, the Boundary factor did not generate a significant main effect on the vowel duration either in #/CV/ or in #/sCV/, in line with previous studies on English #/CV/ syllables (Cho & Keating, 2009; Fougeron & Keating, 1997; Keating, Cho, Fougeron, & Hsu, 2003). This suggests that DIS does affect the vowel to some extent, although temporal expansion was not observable. Despite the fact that there was no main effect of boundary on the initial vowel duration, the present study found the partial effect of DIS that was sensitive to the presence or absence of accent, suggesting that DIS is often suppressed by prominence in English.

Second, we found evidence that prosodic strengthening patterns are systematically conditioned by the language-specific phonological/prosodic structural constraints. The results showed that both boundary and accent effects gave rise to temporal expansion of the /sC/ onset cluster, as reflected in lengthened frication duration for /s/ and lengthened closure duration for the following stop. Most notably, however, prosodic strengthening arising with both accent and boundary (only in the unaccented condition) showed the opposite direction of VOT results for the voiceless stops in #/CV/ and #/sCV/ sequences. That is, VOT for the stop was longer in #/CV/, but it was 'shorter' in #/sCV/. Here, we propose that prosodic strengthening can operate on a phonetic feature, which is a language-specific phonetic feature {+spread glottis} (i.e., longer VOTs for the stop of #/CV/) or it operates on a phonetic feature as a result of a language-specific phonological rule, which is, in this case, {-spread glottis} (i.e., *shorter* VOTs for the stop of #/sCV/). (See Keating (1984) and Cho & McQueen (2005) for detailed discussion on language-specific phonetic category.) Taken all together, the results illuminate the nature of prosodic strengthening, which is closely intertwined with the phonological system of a given language, not simply in a way to enhance the phonemic contrast between sounds in the language, but at the level of phonetic implementation of a phonological rule.

Third, there were some prosodic strengthening patterns that both the boundary and prominence factors have in common (for example, as reflected in /s/ frication duration, stop closure duration, VOT (only in #/CV/ syllables), vowel duration, and vowel intensity peak), converging on heightened phonetic clarities of speech outputs. Nevertheless, DIS and accent-induced strengthening patterns were differentially realized in some measures (as reflected in COG and RMS energy for /s/), supporting the view that the two aspects of prosodic structure may be encoded separately in speech production planning. Moreover, the two factors interacted with each other in such a way that phonetic clarities induced by accentuation appear to be even more heightened in the domain-initial, prosodically strong, position (as reflected in COG and RMS energy for /s/ and stop closure duration). This further implies that the two aspects of the prosodic marking are not independent, but they do interact with each other in a linguistically significant way that accent-induced strengthening is employed not to emphasize every accented word with the same degree, but to put more weight on the accented word that also reflects important positional information.

All in all, it is proposed that phonetic realization of a /s/-stop sequence is conditioned by an interaction of boundary and prominence factors, which is further modulated by the phonological system of a given language.

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