Stress Effects on CV Coarticulation and their Implications for Phonology

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1. Introduction

In this paper, I report on an experiment conducted to investigate the degree of coarticulatory effects of word-level stress on CV structures. The goal of this experiment is to determine if there is a difference in the degree of coarticulation between stressed and unstressed syllables at the word level.

Many phonetic studies have examined the acoustic and articulatory differences between stressed and unstressed vowels. Acoustically, a stressed vowel is typically identified by a higher fundamental frequency, greater intensity, greater duration and a different formant structure than an unstressed vowel (Brown Jr. & McGlone 1974, Engstrand 1988, Kent & Netsell 1971, etc.). Articulatorily, a stressed vowel involves a relative lowering of the jaw for low vowels, a greater opening of the lips and a movement of the tongue body to a more precise target position (De Jong et. al. 1993, De Jong 1995, Kent & Netsell 1971, Summers 1987, etc.). This paper investigates how such different manifestations of a stress contrast influence CV coarticulation by comparing the acoustic correlates of gestural overlap within stressed versus unstressed syllables. Specifically, this work explores how tongue body gestures of a vowel influence the constriction location in the vocal tract during the production of stop consonants by examining F2 variability across varying vowel contexts.

Most previous phonetic studies employed sentence stress, i.e. accent, and compared an accented syllable with an unaccented syllable (Engstrand 1988, De Jong et. al. 1993, De Jong 1995, Kent & Netsell 1971, and Summers 1987). As discussed in De Jong et al. (1993) and De Jong (1995), accented vowels, which have sentential or emphatic stress, are hyperacticulated: bigger jaw displacement for low vowel /a/ and more tongue retraction for back vowel /u/. They interpret the hyperarticulation as an enhancement of the phonemic distinctiveness of a segment in an accented syllable by reducing intergestural overlap. Therefore, they argue that accented syllables involve less gestural overlap, hence less coarticulation.

It has not been considered how lexical-level stress properties influence CV coarticulation, but on analogy with phrasal stress or accent, we might expect to find greater coarticulation between a consonant and a vowel in unstressed syllables within the word. If the absence of lexical stress conditions coarticulation, we might expect such coarticulation to develop into categorical place assimilation, and so expect an increased level of assimilation in stressless contexts. However, a review of the phonological literature on CV place assimilation does not support this hypothesis; there are very few examples of CV place assimilation only in stressless contexts.[1]

2. Assumptions and Hypotheses

I examine gestural coarticulation of a consonant affected by vowel gestures under the assumptions proposed by Recasens (1991). He claims that vowels are less vulnerable to coarticulation because they are produced by means of global vocal tract shapes which require articulatory control upon the entire tongue body configuration. On the other hand, consonants involve only local constrictions which leave other articulatory regions free to coarticulate. Therefore, we would expect a greater effect of a vowel on an adjacent consonant than that of a consonant on a vowel.[2]

A stop consonant has reliable place cues, the locus and F2 transitions into a flanking vowel. However, when a stop is articulatorily influenced by a flanking vowel, the locus is variant across the vowel contexts, as discussed by Kewley-Port (1982). Therefore, I hypothesize that the greater coarticulation in unstressed syllables will be manifested in a greater variance in F2 values in the vocalic regions of the syllables. Figure 1 displays the hypothetical F2 variation ranges of unstressed and stressed syllables across varying vowel contexts. More specifically, the range will be defined by the F2 of vowels in unstressed syllables: a greater range may result from various F2 values of the vowels as a consequence of a vowel's considerable coarticulatory effects. However, the range will be centered on a stop consonant locus in stressed syllables; the range may be an implementation of the approximate value of a stop locus as a result of less gestural overlap with adjacent vowels.

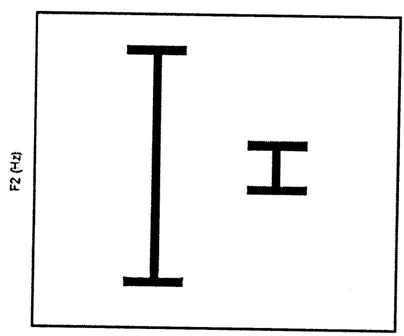

Figure 1. Hypothetical F2 variation range in unstressed and stressed syllables.

As discussed by Lindblom (1963) and Engstrand (1988), the transition duration is shorter in fast speech. It has been also claimed that a shorter transition results from a greater degree of overlap between a stop and a vowel (Browman & Goldstein 1989 and De Jong et al. 1993). Therefore, I hypothesize that unstressed syllables will involve a shorter duration of transition EITHER due to a greater degree of gestural overlap between a vowel and a consonant OR due to the intrinsically shorter duration of segments in unstressed syllables.

3. Experiment

3.1 Data

Nonsense Spanish words, /CVpo/ with /b, d, g/ and stressed and unstressed vowels, /i, e, a, o, u/ were recorded 6 times by three Spanish native speakers. Spanish was chosen because unstressed vowels are not categorically reduced in Spanish, allowing for a meaningful comparison of F2 values in stressed and unstressed syllables. English unstressed vowels are, by contrast, fully reduced in many contexts, it would not be appropriate to compare consonant and vowel coarticulation under stress contrasts. Only voiced stops were employed in the experiment since the voiced stops show more distinct formant transitions than voiceless stops (Kewley-Port 1982). The /CVpo/ tokens were recorded in 8-bit and 8KHz onto a Sparc station with the Sony F-VX30 microphone. The stimuli were read in a carrier sentence as follows:

A: ¿escriben _____ para mi?	'Do they write _____ for me?'
B: No, DICEN _____ para ti.	'No, they say _____ for you.'

The underlined part in B is the only source of data. Since a nuclear accent is assigned to an object noun in B, which is a target word in the sentence, the nuclear accent is intentionally put on DICEN so that the following object noun may not be affected by the phrasal stress. Pitch tracks show a flat low f0 in the target noun, while the preceding nuclear-accented DICEN displays HL.

3.2 Procedure

First, F2 values were measured at three points using Entropic's Waves program: at consonant release (hereafter C-release), at the F2 onset and at the steady state of a vowel. All measurements were carried out from spectra, compared with the corresponding waveform and spectrogram. A time window was used for sampling the spectrum to 6.5 ms. Since no noise-like jagged (burst) portion is seen for bilabial stops before the periodic waveforms of a vowel, the F2 values could not be measured at consonant release in /bVpo/ tokens. F2 variability was compared between stressed and unstressed syllables at two points, at C-release as well as at the onset of F2, although C-release alone can display sufficient information about vowels' coarticulatory effects on the preceding stops, since the C-release is farther from a vowel in timing. However, due to the fact that bilabial stops do not involve the C-release portion in Spanish, F2 variability solely at C-release would not show a general tendency for the three stop consonants associated with vowel's influences

Second, since the stressed and unstressed vowels are qualitatively different - but not categorically different as in English - and exhibit slightly different F2 values, e.g. between [e] and [é], I compared the F2 values at two points, at consonant release and at the beginning of F2 transition with the F2 values of the vowel steady state. This measurement is to identity the extent to which vowels influence consonant place of articulation in association with stress.

Third, I calculated the transition duration of F2: the time duration from the F2 onset to the initiation point of the steady vowel. However, I factored out syllables involving the alveolar stop with /o, u/ vowels and the syllables involving the velar stop with /a, o, u/ vowels, because those syllables do not show a distinct plateau of F2 regions due to the rapid tongue movement from high F2 to the low F2 of the following bilabial stop.

3.3 Results

Figure 2 shows a comparison of F2 onset range between stressed and unstressed syllables for speaker 1. Since I acquired exactly the same results for speakers 2 and 3, I present the results of only speaker 1.

The three panels in Figure 2 exhibit the F2 onset range involved in the syllables with bilabial, alveolar and velar stop consonants, respectively. The range of F2 onset values is slightly, but not significantly, more variant in unstressed than in stressed syllables with a bilabial and alveolar stops as obtained from Levene's test for equality of variance ($p = 0.05$). For syllables containing a velar stop, this does not seem to be the case: the F2 range seems to be more variant even though the variance is not significantly different. Moreover, F values in the equality of variance test are all below 1.

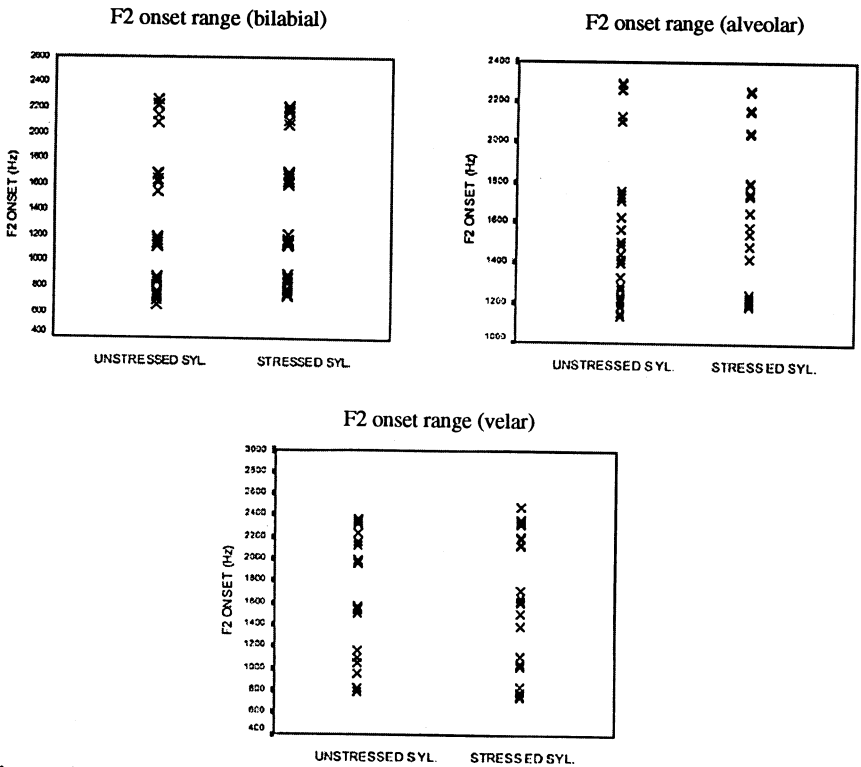

Figure 2 The range of F2 onset; the variability of F2 onset values is not statistically significant in stressed and unstressed syllables ($p = 0.05$) and all F values are below 1.

Figure 3 displays the F2 range at the alveolar and velar stop release in stressed and unstressed syllables. Again, there is no distinctively visible burst release in the bilabial voiced stop of /bVpo/ tokens in Spanish, and the F2 range at the bilabial consonant release cannot be shown in Figure 2. The left panel shows a comparison of the F2 in syllables with an alveolar stop, in which the F2 values are more variant in unstressed syllables than in stressed syllables. For the figure at the right, which represents the F2 range in syllables with a velar stop, this does not seem to be the case. However, the F2 range of unstressed syllables might be more variable if we exclude the highest value of F2 at around 2700 Hz in a stressed syllable, which could be a wrong measurement or an error. According to Levene's test, the variance of F2 values at stop release is not statistically different for unstressed and stressed syllables with both alveolar and velar stops ($p = 0.05$).

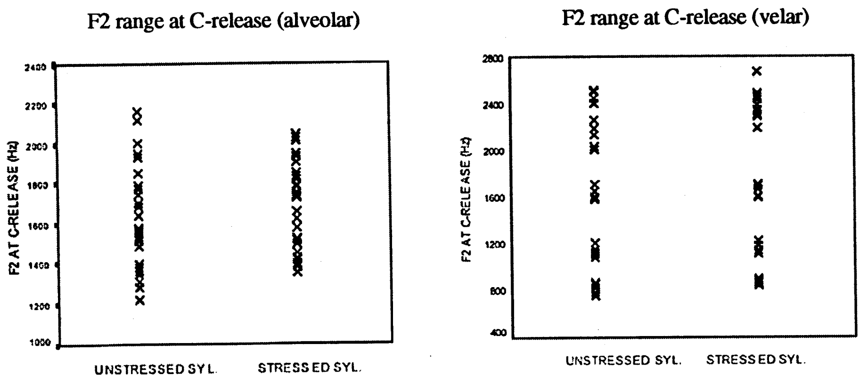

Figure 3 The range of F2 at consonant release; no significant difference in variability of F2 values is found between stressed and unstressed syllables ($p = 0.05$) and all F values are below 1.

Comparable results were obtained from the other two speakers in that the variation range of F2 at the consonant release and at the onset of transition is not statistically different between stressed and unstressed syllables ($p = 0.05$): the F values are all below 1.

The results indicate that the F2 values at the consonant release and at the onset of transition vary across the five vowel contexts regardless of stress. Therefore, the hypothesis that the range will be more variant in unstressed syllables than in stressed syllables is not supported. In other words, this test shows that there is no appreciable difference in stress effects on coarticulation between a vowel and a stop consonant in Spanish. It seems that stress information does not play a significant role in the degree of coarticulation between a vowel and a preceding stop consonant. Therefore, a possible interpretation could be made regarding temporal coordination of CV structures such that the overlap phasing between consonant and vowel gestures is not affected by word level stress.

Figures 4 and 5 show the correlation of a vowel's F2 values with F2 onset and with F2 at the stop release for speaker 1. Figure 4 exhibits the correlation between the onset of F2 and the F2 at the steady state of vowels in stressed and unstressed syllables. Correlation coefficients are 0.958 for unstressed syllables and 0.937 for stressed syllables ($p < 0.0005$), and the correlation both in stressed and unstressed syllables is statistically significant ($p = 0.01$). Therefore, F2 values between a vowel and the onset of transition are strongly correlated both in stressed and unstressed syllables.

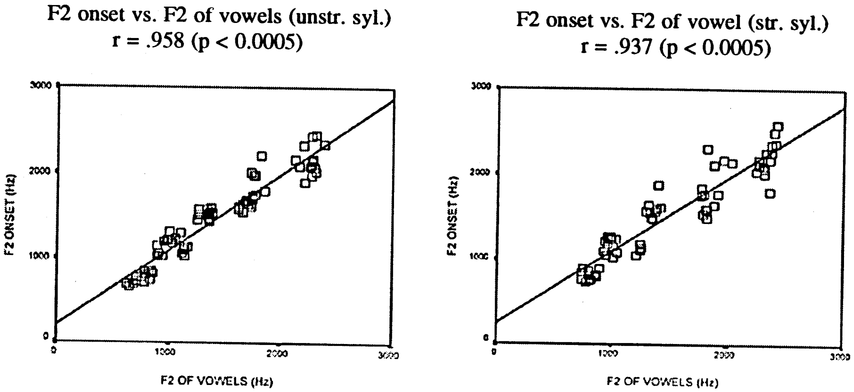

Figure 4 Correlation between F2 onset and F2 at the steady state of vowels in stressed and unstressed syllables. Correlation coefficients (r) are given ($p < 0.0005$), and the correlation both in stressed and unstressed syllables is statistically significant at the 0.01 level (2-tailed).

Figure 5 illustrates the correlation between F2 values at stop consonant release and F2 at the steady state of vowels. Although the correlation coefficient is higher in unstressed syllables, which is 0.924, than in stressed syllables, which is 0.866, both correlation values are statistically significant ($p = 0.01$). Consequently, this result also indicates a strong correlation between F2 at the steady state of a vowel and the consonant release.

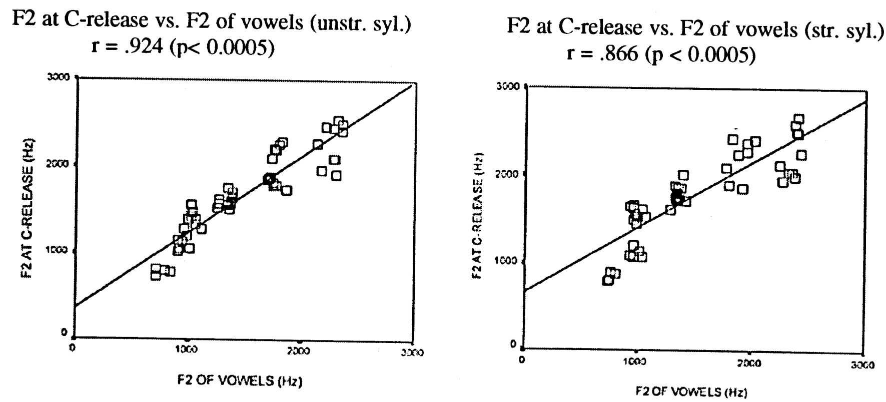

Figure 5 Correlation between F2 at stop release and F2 at the steady state of vowels in stressed and unstressed syllables. Correlation coefficients (r) are given ($p < 0.0005$), and the correlation both in stressed and unstressed syllables is statistically significant at the 0.01 level (2-tailed).

The other two speakers show the same correlation result as in Table 1 and all the correlation values are significant ($p = 0.01$). Therefore, a strong correlation between a vowel and onset of F2 and between a vowel and consonant release is supported.

	F2 onset vs. F2 of vowels ($p < 0.0005$)	
	unstressed syllables	stressed syllables
speaker 2	r = 0.899	r = 0.874
speaker 3	r = 0.904	r = 0.866
	F2 at C-release vs. F2 of vowels ($p < 0.0005$)	
	unstressed syllables	stressed syllables
speaker 2	r = 0.796	r = 0.786
speaker 3	r = 0.835	r = 0.794

Table 1 Correlation (speakers 2 & 3)

The correlation results indicate that there is no considerable difference in the degree of a vowel's influence on a preceding consonant's articulation for stressed and unstressed syllables. In other words, the results do not indicate that a stressed vowel is less likely to coarticulate with a consonant than an unstressed vowel due to its hyperarticulation or its achieving a more accurate target position in Spanish. Since F2 values at the consonant release and at the onset of transition are strongly correlated with vowels' F2 values both in stressed and unstressed syllables, the difference in the degree of coarticulation associated with lexical stress is not found in the present work. Therefore, word-level stress would not be a factor affecting gestural overlap between consonant and vowel gestures.

Mean values of F2 transition duration are calculated between the F2 onset and the initiation point of the steady state of vowels (excluding /a, o, u/ vowels in the syllables with a velar stop and /o, a/ in the syllables with an alveolar stop as mentioned in 3.2). Figure 6 indicates this transition duration of speaker 1 in unstressed and stressed syllables. The mean duration of stressed syllables is significantly longer than that of unstressed syllables ($p < 0.0005$). The other two speakers show the same result as speaker 1 in that the mean duration of a transition is significantly longer in stressed syllables than in unstressed syllables ($p < 0.0005$). This may be either (1) because more overlap between two gestures manifests short-timing transition, given the inter-target transition indicates the distance of two gestural targets or (2) because the short duration of an unstressed vowel brings about short transition. Since there is no distinct difference of CV gestural overlap invoked by lexical stress, the hypothesis (2) is supported. In other words, the short transitional duration in an unstressed syllable is not the manifestation of greater gestural overlap, but that of the intrinsically shorter duration of a segment in an unstressed context.

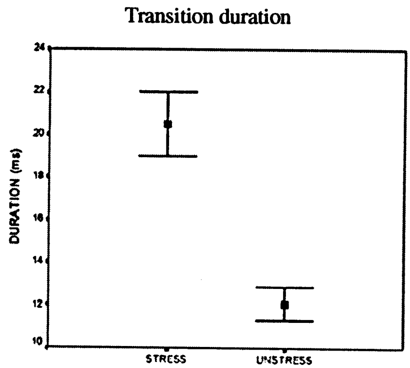

Figure 6 Mean duration of the F2 transition in stressed and unstressed syllables. Stressed syllables show 20.70ms, and unstressed syllables, 12.05ms. The two values are significantly different ($p < 0.0005$). The error bars represent standard error of means.

4. Discussion

I have presented some acoustic correlates of gestural overlap between a stop and a vowel associated with a stress contrast at the word level. I examined Spanish which does not involve a categorical reduction of an unstressed vowel and investigated the range of F2 variance at the consonant release and at the onset of F2 transition. The results show that F2 values are very slightly more variable, but not significantly, for unstressed syllables than for stressed syllables. The F2 range of a velar stop context is much greater than that for other stop contexts, but there is still almost no difference of the F2 range between stressed and unstressed syllables. In other words, word-level stress of a vowel does not seem to have much influence on the articulation of a preceding consonant, which implies that coarticulation between a vowel and a consonant is not significantly sensitive to word-level stress. If we take Browman & Goldstein's claim (1989) that coarticulation results from gestural overlap, the present work can be interpreted as saying that there is no considerable difference in the temporal phasing of consonant and vowel gestures in CV structures for stressed and unstressed syllables. Therefore, the results of this experiment do not support the hypothesis of greater gestural overlap in syllables that do not receive word-level stress.

The correlation results illustrate that consonant place cues are strongly correlated with a vowel's articulation, and also this significant relationship exists regardless of lexical stress. This finding also implies that vowel gestures extend to consonant articulation, which arises from gestural overlap, but the overlap in CV structures is found to be independent of stress.

The transition duration has been shown to be much longer in stressed syllables than in unstressed syllables. The shorter duration would simply result from an inherent characteristics of unstressed vowels. In other words, since the total duration of unstressed vowel is shorter, its transition should be shorter even if the same overlap phase is executed as in stressed syllables. This also implies that transition duration does not necessarily reflect on the degree of gestural overlap.

Previous studies explore coarticulation in accented and unaccented syllables with a phrase-level stress contrast, and find that there is greater gestural overlap in unaccented syllables. On the other hand, the present study investigates a comparison of CV coarticulation between stressed and unstressed syllables with a word-level stress contrast, and show the result that there is no significant difference of gestural overlap. These findings seem to be consistent with Netsell's claim: "the three peripheral systems (pulmonary, laryngeal and supraglottal) may or may not all participate in stress production, depending on the degree of the stress contrast" (cited in Kent & Netsell 1971: 42).

I suggest a general principle governing the stress degree system such that the low-level stress contrast may not be perceptually as great as the high-level stress contrast, and it might be due to the fact that low-level stress is to magnify the perceptual function of stressed syllables only through a single word.[3] In other words, perceptually less contrastive positions are more likely to be produced in favor of articulatory economy rather than perceptual salience, which may result in coarticulation both in stressed and unstressed syllables.

Accented syllables, on the other hand, should enhance great perceptual prominence so as to attract a listener's attention throughout the whole sentence. The high-level stress contrast might be carried out by a maximal differentiation in pulmonic pressure, articulatory/muscle strength, etc. In other words, perceptually salient accented syllables may tolerate articulatory cost, for example, by virtue of hyperarticulation: thus, coarticulation does not occur. Perceptually less salient unaccented syllables, however, may take advantage of articulatory economy; thus, coarticulation takes place. This might be only true in languages like Spanish where a low-level stress contrast is not qualitatively distinct along the segmental dimension; low-level stress shows a different contribution to gestural overlap from high-level stress.

5. Phonological implications and conclusion

If phonetic details are effectively reflected in phonological patterns (Ohala 1993), my results supplement the implication for phonology that consonant place assimilation affected by an adjacent vowel such as palatalization, labialization, and velarization should not be conditioned by lexical stress. My finding is consistent with the observation that the absence of stress is not a conditioning factor for phonological place assimilation as exemplified in languages like Akan (Schachter 1969, Boadi 1988), Czech (Kucera 1973), Eastern Ojibwa (Bloomfield 1957), Hungrarian (Siptar 1994), Kashmiri (Kelkar & Trisal 1964), Konkani (Misra 1989), Nupe (Smith 1967), Polish (Rubach 1981), Russian (Jones & Ward 1969), Sarcee (Cook 1978), Slovak (Rubach 1993), Swazi (Ponelis 1974), etc. However, to the best of my knowledge, there are very few languages showing examples of CV place assimilation in a stressless environment.

Now, I argue that the slight, not significant, difference in coarticulation between stressed and unstressed syllables may not give rise to a perceptually detectable difference which could develop into CV place assimilation only conditioned by stressless contexts, especially when a language does not show contrastive values between a stressed and an unstressed vowel such as a full reduction of the unstressed vowel. It might be possible that if a language involves a qualitative distinction between a stressed and an unstressed vowel as in English where unstressed vowels are fully reduced to schwa, the language may tend to maximize the contrast; perceptually salient stressed syllables are governed by perceptual salience maximization while less salient unstressed syllables are produced by satisfying articulatory economy requirements and, the CV sequences are modified by coarticulation. In fact, English is a language where palatalization is conditioned by lexical stress.[4]

Notes

[*] I would like to thank Jennifer Cole, Molly Homer, Jose Hualde and Khalil Iskarous for their helpful suggestions. I am especially grateful to Daniel Silverman for his valuable comments and discussion. All remaining errors are my responsibility, of course.

[1] CV place assimilation denotes such processes as palatalization, labialization and velarization of a consonant conditioned by an adjacent vowel.

[2] I may have to exclude a gestural coordination between a consonant involving tongue body gesture as a primary articulator (e.g. a pharyngealized consonant) and a vowel since both the consonant and the vowel are configured by a global vocal tract and might be competitively coarticulating each other.

[3] According to the grid representation of intonation (Liberman & Pierrehumbert, 1984), lexical stress attracts two grids, and a nuclear accent, which is assigned to emphatic stress word or sentence stress, is represented with four grids. In this sense, I term an accent "high-level stress" and lexical stress "low-level stress."

[4] For example, 'cónstitùte' [tu] – 'constítuent' [tSu] (See Borowsky 1986). I am not sure, however, that the languages which I listed above all do not show a categorical reduction of unstressed syllables.

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