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Effects of prosodic and segmental context on /g/-lenition in Spanish

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This paper reports on an acoustic experiment to investigate prosodic and segmental factors governing the degree of spirantization of intervocalic /g/ in Castilian Spanish. Significant variation in the degree of /g/-spirantization, measured here in terms of relative acoustic energy, is found to be conditioned by stress and the quality of the vowels adjacent to /g/. Spirantization is typically characterized as a process of weakening or articulatory reduction, and the experimental findings are considered in light of the view that reduction results from speech economy and/or gesture overlap. The observed effect of stress on spirantization is consistent with existing research that correlates gesture strength with the strength of the prosodic position in which the gesture occurs. The experimental results also indicate significant effects of vowel quality on the degree of spirantization, which conflict in part with the analysis of spirantization as a general phenomenon of intervocalic speech reduction. The findings suggest that a complete account of the variation in degree of spirantization must include consideration of the dynamics of the movement between specific consonant and vowel gestures.

1. Introduction

A widely-known feature of Spanish is the lenition of the voiced obstruents /b,d,g/ in intervocalic position, a process also referred to as spirantization. Phonological and phonetic discussions of spirantization in Spanish and other languages typically characterize it as a process of weakening or articulatory reduction (Browman & Goldstein 1991; Harris &Lindsey 1995:69; Kenstowicz 1994:35; Kirchner 1998). Spirantization is sometimes also viewed as an assimilation of stricture (or sonority) from adjacent vowels, especially in those cases where the spirant is flanked by vowels on both sides (Ladefoged 1997:604; Lass:1984:181-3; Weismer 1997:210). Phonological analyses within the generative tradition (eg., Goldsmith 1981; Harris 1969; Mascaró 1984, 1991) also treat spirantization as a process of assimilation, in which the spirant acquires the [+continuant] feature of the flanking vowels. Our goal in this paper is to gain a better understanding of spirantization in Spanish by investigating the factors that govern variation in the degree of spirantization as they relate to the mechanisms of speech production that give rise to articulatory reduction and assimilation.

A number of works on Spanish phonetics and phonology have noted that spirantization is subject to a certain amount of variability within a given dialect or idiolect (Amastae 1986, 1989, 1995; Zamora & Guitart 1982:102; Barrutia & Terrell 1982:61). Consequently, spirantization is best characterized in terms of contexts that favor the continuant or non-continuant realization of /b,d,g/, and not as an obligatory, categorical phonological rule (Mascaro 1991). But there is another type of variability in spirantization, and that is variation in the degree of spirantization. The continuant allophones of /b,d,g/ have been described by Quilis (1988: 221-224) as ranging from narrow fricative segments to approximants with vowel-like qualities, a description which is based on visual inspection of spectograms and auditory impression.

The data in (1) present typical examples of the contexts where spirantization occurs. The voiced obstruents /b,d,g/ are realized as continuants [β, ð, ɣ] respectively, in intervocalic position, both word-internally (1a) and across word boundaries (1b).

(1)	a.	sabe	[sáβ̞e]	's/he knows'
		lado	[láð̞o]	'side'
		lago	[láɣ̞o]	'lake'
	b.	la bala	[laβ̞ála]	'the bullet'
		para dos	[paɾað̞ós]	'for two'
		mala gota	[malaɣ̞óta]	'bad drop'

Acoustic analysis reveals that the continuant allophones [β, ð, ɣ] have very little high-frequency non-periodic energy, and are thus better defined as approximants than as fricatives or spirants (Romero 1995).[1] Both in the present study an in our earlier pilot study on Spanish spirantization, we find that there is considerable variation in the amount of overall energy contained in the consonant region of intervocalic /b,d,g/, with tokens ranging from a complete stop to a vocalic glide. Consider the spectogram in figure 1 of the phrase *pide todo* 'ask for everything'. This phrase contains two instances of /d/ in intervocalic position, each following a word-level stressed vowel. The /d/ in *pide* has the small amount of acoustic energy characteristic of a voiced stop, while the /d/

[1] Although Quilis describes continuant allophones that are narrow fricatives, we find very few tokens that fit that description in our data.

in todo has much more energy, and is in fact difficult to distinguish visually from the regions of the flanking vowels.[2]

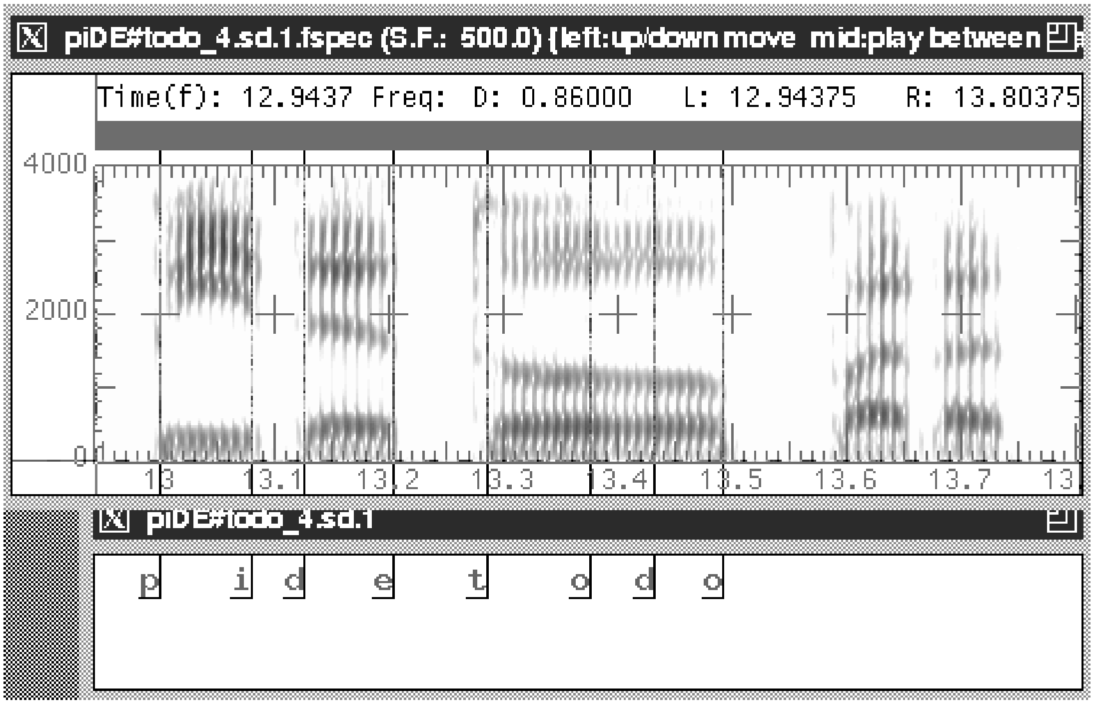

Figure 1: Variation in the realization of intervocalic /d/ in a single utterance.

The qualitative aspect of variation in spirantization goes unreported in nearly all published work on Spanish phonology and phonetics. The majority of investigators rely instead on a simple binary distinction between continuant and non-continuant allophones.[3]

2. Sources of variation

Under the view that spirantization results from the mechanisms of speech production that govern reduction and assimilation, we are led to consider two possible sources for variation in the degree of

[2] This example, culled from our earlier pilot study, is shown here because it illustrates variation in the spirantization of /d/ in the speech of a single speaker, within a single utterance. Similar variation can be seen for each speaker in the experiment reported here, by comparing /g/ tokens across stimuli; there is no single stimulus item that contains more than one token of /g/. In Figure 1, the segmentation indicated by the spectrogram labeling is aided by auditory impression, and in this case constitutes only a rough placement of the transitions between /d/ and the adjacent vowels.
[3] An exception is Romero (1995), who argues for a finer distinction than the traditional binary one, since he distinguishes approximant and fricative allophones. The latter are identified in realizations of sequences of the type /sb/ in certain Andalusian dialects.

spirantization: prosodic and segmental context. Prosodic structure has been found in recent work to play a role in conditioning the magnitude of an articulatory gesture. Speech gestures have been shown to be affected by their position in the word and phrase, relative to accent and initial and final edges. For example, Byrd (1996) and Browman & Goldstein (1992), among others, have shown that speech gestures in word-initial position differ in magnitude from gestures in medial and final positions. Similar findings obtain for gestures in phrase and sentence initial position (Fougeron & Keating 1996, 1997). With respect to accent, Beckman & Edwards (1994), and Beckman, Edwards & Fletcher (1992) show that jaw and lip movements are often larger and faster in syllables that bear word stress or nuclear accent than in unaccented or reduced syllables. Pierrehumbert & Talkin (1992) demonstrate similar results for laryngeal gestures, which are found to be of greater magnitude in positions of prosodic strength at the word and phrase levels. In another case, deJong (1996) argues that flapping in English results from reduction of the consonant closing gesture in unstressed positions following the nuclear accent. These findings collectively indicate that articulatory gestures are greatest in domain-initial positions relative to non-initial position, and in positions of word-level stress and phrasal accent relative to the corresponding unstressed or unaccented positions. If spirantization is correctly viewed as a reduction in the magnitude of a consonant constriction, i.e., a type of articulatory reduction, we then expect to find the greatest degree of spirantization in intervocalic positions that are prosodically weak at the word or phrase level, and less spirantization, ie., more stop-like realizations of /b,d,g/, in intervocalic positions that are prosodically strong.

Segmental context may also influence the degree of spirantization, under two hypotheses about speech production. First, the hypothesis of articulatory economy (Kohler 1990, 1991; Lindblom 1983, 1990) indicates that a consonant closing gesture will involve the minimal displacement possible from the articulatory configuration of adjacent vowels, so long as the gesture still results in a perceptually salient consonant. Second, the hypothesis of gestural overlap (Browman & Goldstein 1989, 1990; Fowler & Saltzman, 1993) states that gestures for adjacent segments may overlap, especially in cases where the segments make conflicting demands on shared articulators.[4] Overlap gives rise to gesture blending, which can result in a perceived assimilation in some cases, or gesture reduction in others. One hypothesis regarding spirantization is that it results

[4] This discussion summarizes Farnetani's (1997) overview of this and other models of coarticulation.

from the opening or “sonorization” of the consonant closing gesture due to overlap with the more open gesture of the vowel.[5]

The present study of Spanish spirantization explores variation in the degree of spirantization through an acoustic analysis in which spirantization is quantified in terms of relative acoustic energy in the consonant region. In this study we focus exclusively on intervocalic /g/, giving detailed consideration to the kinds of segmental and prosodic factors that can influence this particular consonant closing gesture. We relate our findings to an earlier study of ours on Spanish spirantization that included /b/ and /d/ in addition to /g/, which did not however examine segmental context in detail. Given the limited scope of the present study, our findings speak only to the mechanisms involved in velar spirantization; however, in future research we plan to extend the study to examine conditioning factors for the dental and bilabial consonants as well. The experiment described below looks for conditioning effects of three factors on the amount of energy in intervocalic /g/:

- The position of stress relative to /g/: ˈVgV *vs*. VˈgV
- The quality of the preceding vowel: igV, egV *vs*. ugV, ogV *vs*. agV
- The quality of the following vowel: Vgi, Vge *vs*. Vgu, Vgo *vs*. Vga

3. Experimental Methods

3.1 Materials

The acoustic analysis of intervocalic /b,d,g/ is based on speech data collected from three subjects, 1 female and 2 males, all native speakers of Castilian Spanish. Each subject read a list of 59 words containing intervocalic /g/, produced in a carrier phrase, in a normal conversational style and speech rate. Instructions were given in Spanish by one of the experimenters, who also demonstrated the desired conversational speaking style. The word list was balanced for the location of stress: half of the words had stress on the vowel immediately preceding /g/ (ˈVgV), while the other half had stress on the vowel immediately following /g/ (VˈgV). The words also varied in the quality of the vowels preceding and following /g/. Each of the vowels five /i,e,o,u,a/ occurs in positions both preceding and following /g/. The front vowels /i,e/ were classed together in constructing the stimuli set, as

[5] deJong (1995) discusses this hypothesis as an account of English flapping, but rejects it based on conflicting evidence from articulatory data.

were the non-low back vowels /u,o/. There were roughly equal numbers of words with the vowel preceding /g/ from each of the three vowel classes: /i,e/ (21), /u,o/ (21) and /a/ (17). Similarly, there were roughly equal numbers of words with the vowel following /g/ from the same classes: /i,e/ (18), /u,o/ (20), /a/ (21). Each word was repeated three times, for a total of 177 tokens per speaker.

3.2 Procedures

Speakers were recorded directly onto a Sun Sparc10, using the Entropic ESPS/Waves+ recording facility. Recording sessions were conducted under quiet conditions. Speech was sampled at 8kHz and segmentation of the target consonants and flanking vowels was done using ESPS/Waves+, based on waveform, spectrogram and listening.

The digitized speech segments were analyzed to produce an energy measurement for each target consonant. The energy measurement is a ratio of the time-averaged energy of the consonant (an RMS measure) to the time-averaged energy of the whole word. The ratio measure was done to normalize for differences in overall volume of individual utterances.[6]

4. Results

The energy measurements obtained from the entire data set reveal significant variation for each of the three speakers, illustrated in Figure 2 with a chart of the range of energy values, collapsed over all conditions, for each speaker. The findings from this experiment are consistent with our earlier pilot study on Spanish spirantization, where we also found significant variation in the degree of spirantization for all three voiced obstruents, /b,d,g/, in the speech of 5 speakers of Castilian Spanish.

Three results are obtained from our analysis relevant to the factors that condition variation in the degree of spirantization. First, comparing /g/ in words with stress on the preceding vowel against words with stress on the following vowel shows that for each speaker, the tokens of /g/ in post-stress position have significantly more energy than /g/ in pre-stress position (Student's t-test, two-tailed, $p < .05$), as seen in Figure 3. This finding shows that the production of intervocalic /g/ is influenced by prosodic context. Specifically, /g/ preceding a stressed vowel is stronger, in the sense of having a

[6] Other normalization strategies were also evaluated, in which the consonant energy was normalized against the energy in the preceding vowel, the following vowel or the stressed vowel. The results were relatively stable across these various measures.

more complete closure, than /g/ preceding an unstressed vowel. In other words, the presence of a following word-level stress inhibits spirantization of /g/.[7]

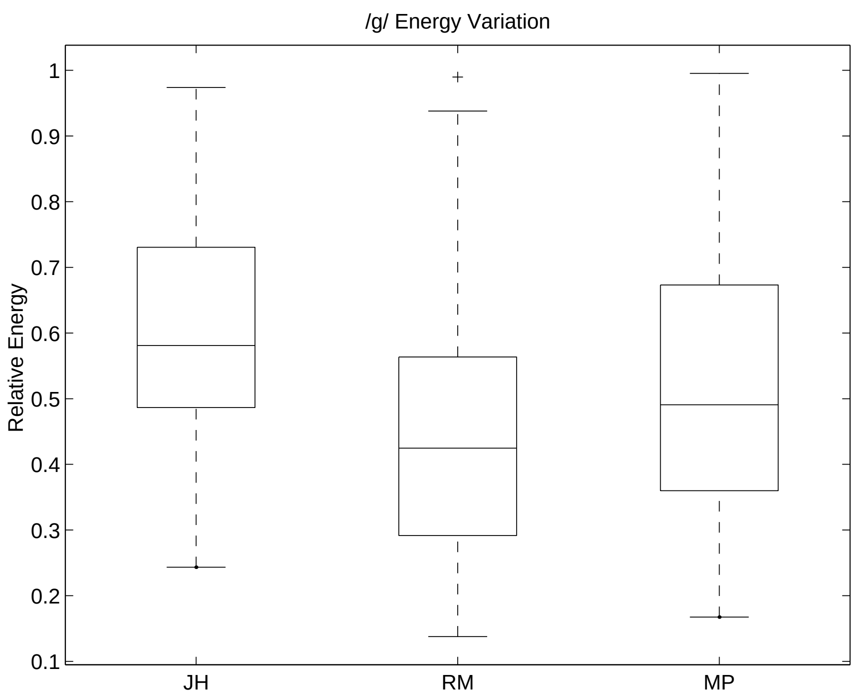

Figure 2: Range of variation in relative /g/ energy values by subject. Energy values calculated as a ratio of RMS energy in the /g/ interval over the time-averaged energy of the whole word. In this and subsequent boxplots, the box encloses 50% of the data around the median (from the lower quartile to the upper quartile), while the top and bottom brackets extending from the box show the maximum and minimum values, respectively. Outliers are shown as tick marks beyond the value of the maximum or minimum. The median is indicated by the line through the box.

[7] The word-level stress in these data was also the nuclear phrase-level stress in most of the utterances.

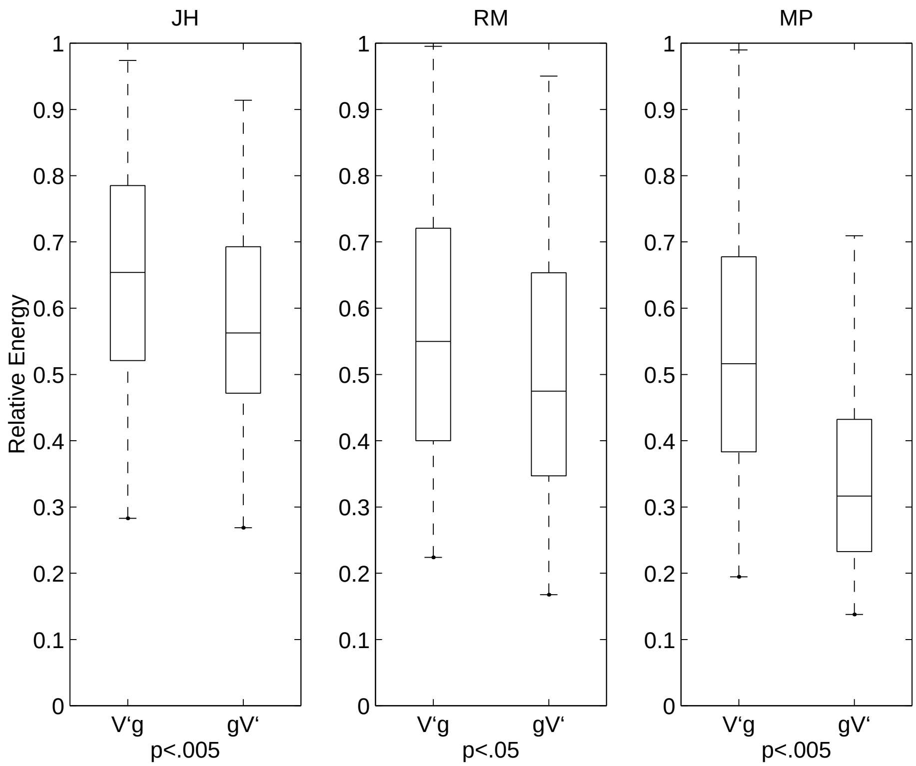

Figure 3: Effects of location of stress. A comparison of /g/ energy in positions following and preceding a stressed vowel, for three speakers.

The second result obtained from the data concerns the quality of flanking vowels in conditioning the energy of /g/. Data from two speakers, JH and RM, show significantly lower-energy /g/ in the context of the low vowel /a/ than in any other vowel context (Student's t-test, two-tailed, $p<.05$). The examples of waveforms from [aɣa] and [uɣu] sequences produced by speaker RM in Figure 4 illustrates this difference.

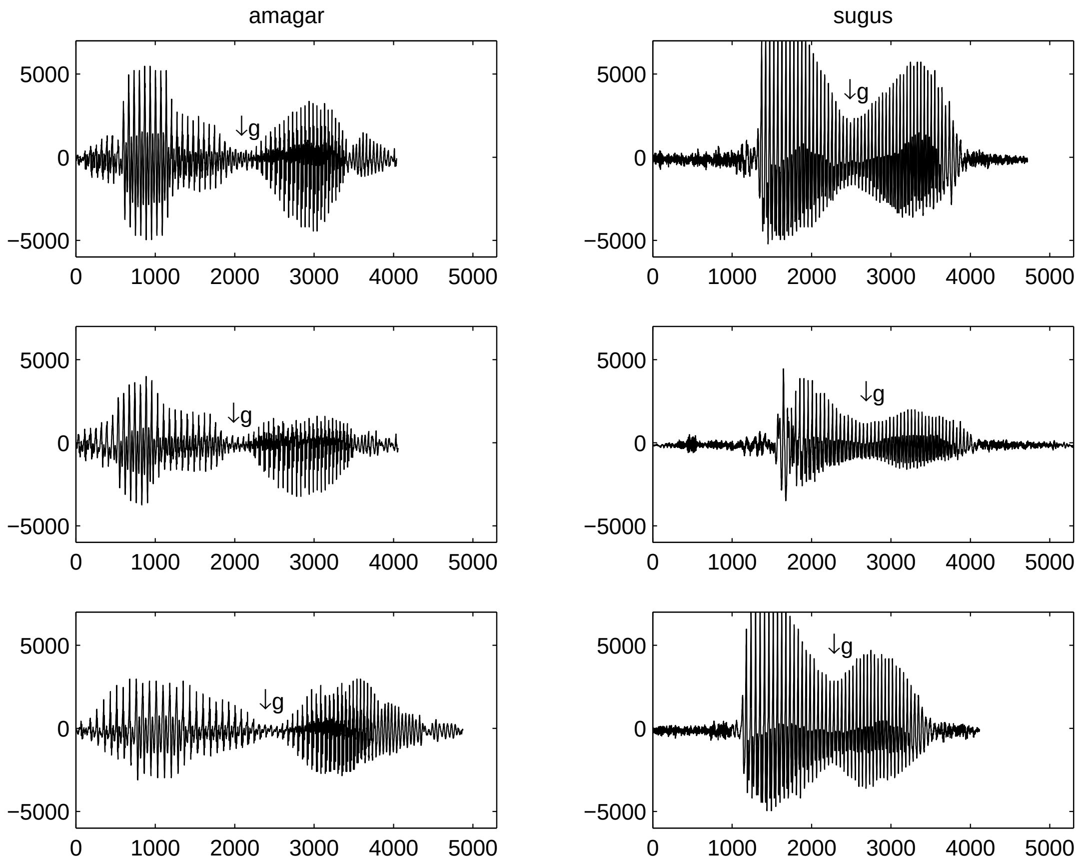

Figure 4: Waveform comparison of /g/ in the context of /a/ and /u/ vowels by speaker RM. The left three panels show [aɣa] from three different tokens of the word *amagar*. The right three panels show [uɣu] from three different tokens of the word *sugus*.

The third speaker, MP, showed no significant difference in the energy of /g/ in low vowel contexts compared to other vowel contexts. Figure 5 shows the comparison between /g/ in the context of /a/ and /u,o/ vowels. Comparisons of /a/ contexts with /i,e/ contexts reveals no consistent patterns across speakers. The effect of /a/, the maximally open vowel, in minimizing spirantization is unexpected in light of the view of spirantization as a process of sonorization.

The third result obtained was that for all three speakers /g/ has significantly greater energy in the context of the non-low back vowels /u,o/ than in the context of the front vowels /i,e/ (Student's t-test, two-tailed, $p < .05$), as shown in Figure 6. This effect of /u,o/ cannot be attributed to their lesser height relative to /i,e/, because the lowest vowel of all, /a/, conditions the least energy in adjacent /g/.

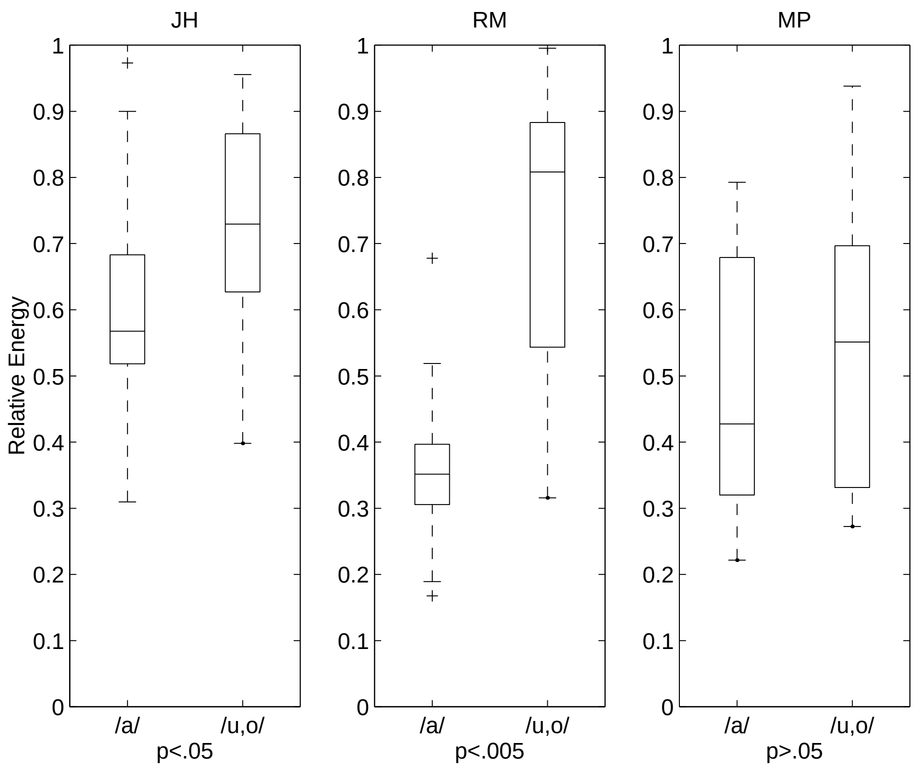

Figure 5: Effects of adjacent /a/ vs. /u,o/. A comparison of the distribution of /g/ energy measurements in [aɣa] tokens with /g/ energy measurements in [uɣu], [oɣo], and [uɣo] contexts (collapsed), for three speakers.[8]

[8] No tokens of familiar words containing an [o⊗u] sequence were found, and hence such items are not included in the stimuli set.

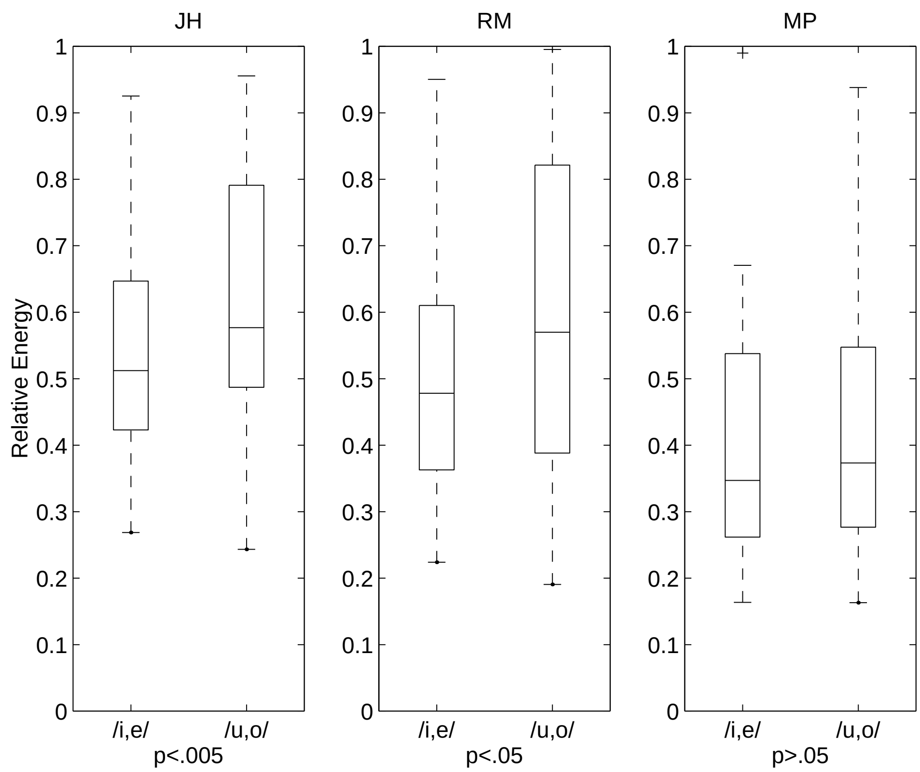

Figure 6: Effects of adjacent /i,e/ vs. /u,o/. A comparison of the distribution of /g/ energy measurements in [iɣi], [eɣe], [iɣe] and [eɣi] tokens (collapsed) with /g/ energy measurements in [uɣu], [oɣo], and [uɣo] contexts (collapsed), for three speakers.

The effect of vowel backness is found to be greatest when both flanking vowels are from the same class, /i,e/ or /u,o/. A similar but weaker effect of vowel backness is found for all three speakers in forms where the flanking vowels are not identical, as shown in Figure 7. When the following vowel is front, /g/ has less energy than when the following vowel is non-low and back, independent of the quality of the preceding vowel. The difference is statistically significant for JH and RM (Student's t-test, two-tailed, $p<.05$), and non-significant but in the same direction for MP.

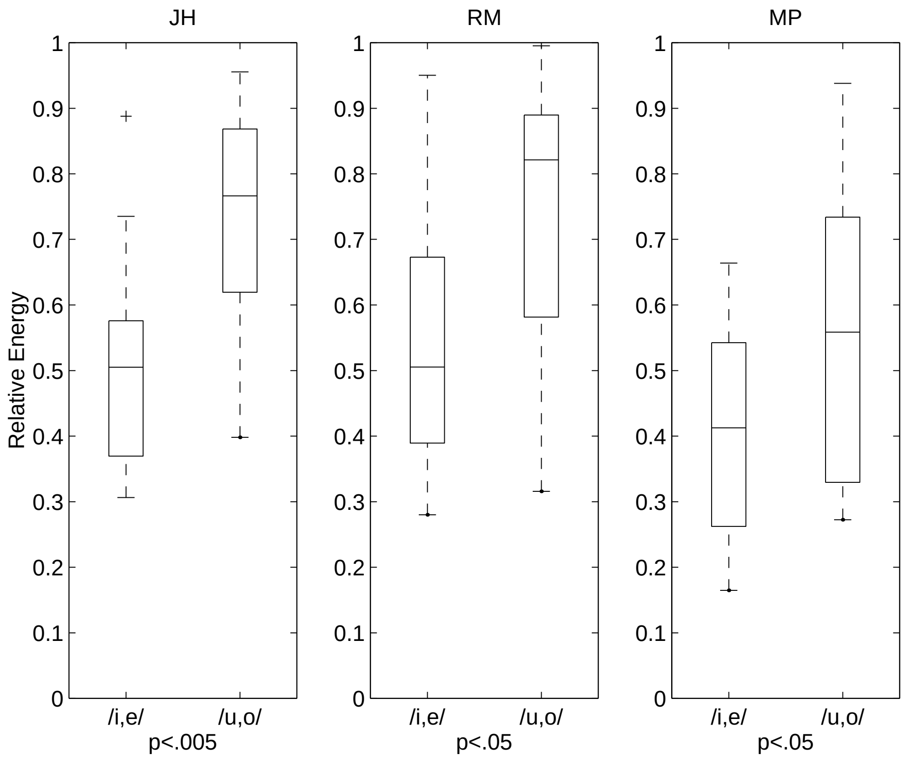

Figure 7: Effects of /i,e/ vs. /u,o/ following /g/. A comparison of the distribution of /g/ energy measurements in all tokens of [Vɣi] and [Vɣe] (collapsed) with /g/ energy measurements in [Vɣu] and [Vɣo] (collapsed).

5. Discussion

Summarizing the results presented above, we find that spirantization is affected both by prosodic structure and the quality of flanking vowels. The greatest degree of spirantization is found in contexts following (as opposed to preceding) a stressed vowel, or with flanking /u,o/ vowels. Spirantization is significantly less preceding a stressed vowel, or with flanking /i,e/ and /a/ vowels. In this section we consider the prosodic and segmental conditioning effects in turn.

The inhibitory effect of a following stress on /g/-spirantization found in our data is parallel to the finding of DeJong (1996), who shows that English Flapping is similarly inhibited by a following stressed (ie., accented) vowel. DeJong interprets his results as an indication that the intervocalic flap is syllabified with the following unstressed vowel, eg., V.PV|, and that Flapping is the consonantal analogue to vowel reduction in unstressed syllables. A similar interpretation is possible for Spanish, namely that spirantization is enhanced by unstressed syllable reduction in syllable structures such as V.ɣV|, although it bears noting that the effect of unstressed syllable reduction is different in the two languages: in Spanish the onset consonant ([ɣ] in our data) undergoes a much greater reduction than the following unstressed vowel, which is not subject to nearly the same degree of reduction as an unstressed vowel in English. The inhibitory effect of following stress on spirantization is also consistent with the results of Beckman & Edwards (1994) and Beckman, Edwards & Fletcher (1992) for jaw and lip movements, and with the results of Pierrehumbert & Talkin (1992) for laryngeal gestures. In all of these cases, gestures are found to have greater magnitude in prosodically strong positions (e.g., the onset to an accented/stressed syllable), with reduced gestures occurring in the corresponding prosodically weak positions (e.g., the onset to an unaccented/unstressed syllable).

The conditioning effect of stress is one indication that spirantization is sensitive to prosodic structure. Further evidence was found in our earlier pilot study, where we observed that spirantization is largely inhibited in utterance-initial position. The stop-like realizations of /b,d,g/ that we observed in utterance-initial position are consistent with traditional phonological descriptions of Spanish, and showed much less variation in constriction degree compared to intervocalic tokens. Our observations are also consistent with the findings of Fougeron & Keating (1996,1997) that the initial position of a sentence or phrase conditions a greater magnitude of articulatory gestures. With respect to word-initial position, our earlier study did not provide evidence for the finding reported in Byrd (1996) and Browman & Goldstein (1992) that articulatory gestures are stronger in this position, also. Rather, we found that spirantization has the same effect on intervocalic /b,d,g/ regardless of whether the VCV sequence is word internal or occurs across a word boundary, as in V#CV.

Our data reveal two conditioning effects of the quality of vowels flanking /g/. Spirantization of /g/ is inhibited when it is flanked on both sides by the low vowel /a/, when it is flanked on both sides by a front vowel /i,e/, or when it is followed by /i,e/. These inhibitory effects of vowel quality on spirantization were an unexpected finding based on a view of spirantization as resulting either from economy-driven articulatory reduction, or from gestural overlap. The economy hypothesis requires that the consonant closing gesture be executed with the minimal displacement from the adjacent vowels. Since the constriction location of /a/ is farthest among all vowels from the constriction location for /g/, we would expect that the closing gesture for /g/ will be effected less completely in the context of flanking /a/ vowels. Our data reveal the opposite pattern. Similarly, since the movement between /i/ or /e/ and a palatalized /g/ is greater than the movement between (non-palatalized) /g/ and /u/ or /o/, we expect on the basis of economy that /g/ constriction will be more complete in the context of /u,o/. Again, our results conflict with this expectation, showing more complete constriction in the context of the front vowels /i,e/ than the back vowels /u,o/. Our findings are in conflict with the findings of Lindblom, Pauli and Sundberg (1975), whose bite-block experiment shows that apical consonants in VCV utterances are produced with a tongue body configuration requiring the least movement from the adjacent vowels. The vowel quality effects found in our data are similarly unexpected under the analysis of spirantization in terms of gesture overlap. In particular, the overlapping of /g/ with an adjacent /a/ is expected to result in the maximal reduction of the /g/ closing gesture, contrary to our findings. The open jaw position of /a/ is expected to exert the greatest opening effect on the /g/ closing gesture, compared to vowels produced with less open jaw positions. The gesture overlap analysis is perhaps more consistent with the inhibitory effects of flanking /i,e/ vowels on spirantization, relative to flanking /u,o/. There is complete sharing of the articulators involved in /g/ and /u,o/ productions, and less sharing with /g/ and /i,e/. Since gesture overlap increases as gestures are increasingly shared between adjacent targets, the expectation is for greatest overlap, and hence greatest spirantization of /g/ in the context of adjacent vowels with a dorso-velar constriction.

The asymmetry between /u,o/ vowels on the one hand, which condition greater degrees of spirantization, and /i,e/ and /a/ vowels on the other hand, which condition lesser degrees of spirantization, has a parallel in the articulatory dynamics of VgV sequences. Movement between /g/ and /i,e/ or /a/ vowels involves a change in the overall position of the tongue body, while there is virtually no change in tongue body position for movements between /g/ and /u/ or /o/. We suggest that the effect of adjacent vowel quality on constriction degree for /g/ is a consequence of the dynamics of tongue body movement. Movement of the tongue body is necessary to produce a consonant closing gesture, whether the movement is in the horizontal dimension, the vertical dimension, or both. When the tongue body position is changed in the movement between /g/ and an adjacent vowel, the closing gesture for /g/ is most fully realized. But when no overall change in the tongue body position is required, as in the movement between /g/ and adjacent /u/ or /o/, then the closing gesture for /g/ is not effectively realized. In support of this view, we note that in a number of tokens from our data, it appears that the /g/ is produced as an unrounded velar glide when flanked by /u,o/ vowels, and is barely or not at all distinguishable from the vowels based on auditory impression. This account of vowel quality as a conditioning factor for spirantization suggests that different vowel quality effects will be found for the dental and bilabial spirants due to differences in the dynamics of the VCV gestures involved. We plan to pursue this hypothesis in future research.

Acknowledgments

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