VOWEL QUALITY EFFECTS ON HIATUS RESOLUTION IN SPANISH

Irene Barberia

1. Introduction

Hiatus Resolution refers to the various strategies that languages use in order to avoid two adjacent heterosyllabic vowels at the phonetic output. These strategies include vowel reduction, diphthongization, coalescence and deletion as the most common reported in the literature. From the point of view of production, Hiatus Resolution (henceforth HR) can be explained by the crosslinguistic preference for CV syllables. It has also been claimed that speakers apply HR strategies in a gradient manner, basing their choice of the strategy on patterns of prosodic lengthening (Simonet 2005). From a perception point of view, the avoidance of adjacent vowels is motivated by a perceptual reduction of vowel distinctions in weak contexts, which triggers changes in the vowels, in order to neutralize (or, at least, reduce) those distinctions (Fourakis 1991, Aguilar 2003, Sands 2004). Hiatus Resolution in Spanish is a phonetic phenomenon favored in contexts of reduced perceptibility, such as unstressed syllables in connected speech. The factors that affect HR are numerous and of a diverse nature: phonetic, phonological and usage-based.[1] This paper explores the effects on HR in Spanish of one of these factors: vowel quality.

Phonologically, Spanish sequences of non-high vowels within word boundaries are heterosyllabified, as in *teatro* 'theater' ([te. a.tro]). But when a high vowel is involved, then (i) either the high vowel bears stress and hiatus takes place, as in *teoría 'theory'* ([te.o. ri.a]) or (ii) the high vowel is unstressed and diphthongization occurs, as in *peinar* 'to comb' ([pej. nar]). Across word boundaries, vowel sequences are always heterosyllabified, regardless of vowel height or stress. However, the actual phonetic realizations of non-identical vowel sequences differ from the phonological expectations. For instance, the vowel sequence /ea/ in the word pair *est<u>e a</u>sunto* ('this subject') can be pronounced in hiatus ([es.te#a. sun.to]), with vowel reduction ([es.te̯#a. sun.to]), diphthongization ([es.tja. sun.to]) or with deletion of one vowel ([es.ta. sun.to]). These are all strategies that Spanish uses in order to resolve hiatus sequences at the phonetic level.

[1] For a literature review on the effects of the different factors favoring HR in Spanish refer to the following: Aguilar (1999, 2003), Aguilar & Machuca (1995), Alba (2005), Casali (1997), Dauer (1983), Hualde & Chitoran (2003), Jenkins (1999) and Quilis (1981).

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Assuming Ladefoged's (1993) account for vowel sonority, less sonorous vowels undergo HR more easily than more sonorous vowels, all other factors being equal. Then, it seems logical to question which of the two vowels in the sequence (V1 or V2) is a better target to undergo changes when HR strategies apply. A study by Esgueva (1999) on deletion of vowel sequences suggests a preference for corner vowels (/a, i, u/) to prevail in hiatus sequences over mid vowels (which become the target for HR), and also back vowels to prevail over front vowels. Unfortunately, Esgueva does not provide specific explanations for his results. However, Aguilar (1999) proposed a correlation between duration and vowel quality in a study on hiatus/diphthong alternation. Added to that, in her later study Aguilar (2003) analyzing the production of sequences /a/ + /a, e, i/ in unstressed positions (in order to neutralize the effect of stress) by Spanish speakers, she shows a gradation of preference for different strategies of hiatus resolution based on the quality of the vowels in the sequence: *non-high* > *identical* > *high* for monosyllabification strategies (these include reduction of non-high vowels and diphthongization); *identical* > *high* > *non-high* for coalescence and deletion.

Taking Aguilar's (2003) as a departure, a larger experimental study was conducted to analyze the use of HR strategies in Spanish, including all possible non-high vowel combinations. The results of part of that experiment, those involving a production task, are presented here. This paper focuses on the effects of vowel quality on the resolution of non-high vowel sequences in Spanish.

2. Hiatus Resolution strategies

The results of the acoustic experiment presented in this paper are based on the duration and frequency (F1 and F2 values) measurements of the vowel sequences produced by native speakers. Measurements of these two acoustic correlates are used to define the various strategies that speakers use in Spanish to resolve hiatus.

2.1. Hiatus

Along the lines of Martínez-Celdrán (1984: 221), vowels in hiatus are defined in the literature as two "autonomous vowels", nuclei of adjacent syllables: acoustically, each vowel maintains its own well defined formant values and the transition from one vowel to the other is shown by an abrupt change in the spectrogram, especially in the F2 value. Throughout the data analysis, instances of hiatus exhibit the durational values of two full vowels and stable formant frequency values.

In the experiment, hiatus is rarely produced as defined above, since vowel assimilation in F1 and/or F2 is usually found. In these cases, however, vowel sequences are considered in hiatus, because it shows a durational value that corresponds to two vowels.

2.2. Acoustic diphthongization and gliding

During the speech act, durational reduction may imply a syllabic reorganization of the speech sounds. If there is not enough time to produce both vowels in the sequence completely, at least one of the vowels is durationally reduced. When the reduction in the duration of a vowel is significant, the vowel may lose its syllabicity and it will merge into the syllable of the other vowel in the sequence. Acoustically, according to Martínez-Celdrán (1984), the glide in a diphthong has lost its autonomy and its formants look like an appendix of the syllabic nucleus (1984: 222). This occurs to non-high vowels, as defined below:

> Acoustic diphthongization: $[V_1.V_2] \rightarrow [.\underset{\frown}{V}_1V_2.]$ or $[.V_1\underset{\frown}{V}_2.]$
>
> Significant durational reduction of a nucleic vowel in a vowel sequence. It may also lead to a certain degree of qualitative assimilation to the other vowel in the sequence.

Shifting the formant values of a reduced non-high vowel in the sequence to those of [j] or [w] results in a qualitative change of the vowels into glides. By enlarging the articulatory distance between the two vowels in the sequence, a better perception of the two vocalic sounds under durational reduction is assured. When the vowel suffering qualitative and durational changes rises to a glide, gliding occurs.

2.3. Coalescence and deletion

A further reduction in the duration of the vowel sequence leads to the production of a single vowel instead of two. In such contexts, the speaker may (i) either delete completely one of the vowels in the sequence or (ii) produce a different vowel instead of the sequence. Usually in the latter case, this vowel maintains features of the original vowels in terms of F1 and F2 values. When both vowels merge into a new one, partially assimilating each other, coalescence occurs.

> Coalescence: $[V1.V_2] \rightarrow V_3$
>
> Resyllabification of a hiatus into a single syllable, the resulting vowel is a combination of the F1/F2 values of the original vowels.

Deletion, on the contrary, is used in order to produce a single vowel from the original two vowels in the sequence. This eliminates traces of formant values of the target vowel.

> Deletion: $[V_1.V_2] \rightarrow [V_1]$ or $[V_2]$
>
> Resyllabification of a hiatus into a single syllable, resulting in the deletion of one of the original vowels.

Table 1 summarizes the acoustic characterization of the different ways vowel sequences were produced in the production task, including all possible HR strategies.

		Phonetic representation	Duration	Frequency	V_1-to-V_2 transition
Hiatus	Hiatus	$[V_1.V_2]$	Two vowels	Stable, clearly defined formant values for both vowels.	Abrupt and short
	Vowel assim.	$[V_1.V_2]$	Two vowels	Stable formant values for two vowels. The assimilated vowel shows F1 and/or F2 values closer to the values of the adjacent vowel.	Abrupt and short
	Vowel rising	$[V_{+high}.V_2.]$ or $[V_1.V_{+high}]$	Two vowels	Stable formant values for two vowels. One of the vowels shows formant values of a high vowel.	Abrupt and short
HR strategies	Acoustic diphthong.	$[.\underset{\frown}{V}_1V_2.]$ or $[.V_1\underset{\frown}{V}_2.]$	More than one vowel but less than two	Stable formant values for one vowel. Reduced vowel shows formant values close to the original vowel.	Smooth
	Vowel gliding	$[.GV_2.]$ or $[.V_1G.]$	More than one vowel but less than two	Stable formant values for one vowel. The reduced vowel shows formant values close to those of a high vowel.	Smooth
	Deletion	$[V_1]$ / $[V_2]$	One vowel	Stable formant values for either the first of second vowel only.	No transition
	Coalescence	$[V_3]$	One vowel	Stable formant values for one vowel, showing an F1 value of the V1 and F2 value of V2, or vice versa.	No transition

Table 1

Acoustic description of the strategies of hiatus resolution

3. Experimental procedures

The experiment consists of a production task performed by 8 native speakers of Spanish. They were 4 male and 4 female native speakers of northern varieties of Peninsular Spanish, from the communities of the Basque Country, Galicia, Castile-Leon and Catalonia. Their ages at the time of the experiment were between 25 and 30 years old, except for one of the female speakers, who was 42. At the time of the experiment, all of them were first or second year graduate students at the University of Illinois at Urbana-Champaign. Prior to that, they had lived in their place of origin in the Spanish communities mentioned above.

Subjects were asked to perform a reading task and their production was recorded for later analysis. The corpus for the production task consisted on a list of sentences that had words and word pairs (henceforth *tokens*) containing all possible combinations of non-high vowel sequences in Spanish: /ae/, /ao/, /ea/, /eo/, /oa/ and /oe/. A total of 43 tokens containing the vowel sequences were created with controlled syllabic structure. All the tokens varied in syllable length, from two to four syllables. The syllables containing the vowel sequences were unstressed and were adjacent to a stressed syllable. Each token was embedded into a sentence in order to provide a natural context for the production, given the fact that it was a reading task and not spontaneous speech. The tokens were placed regularly towards the middle of the sentence, avoiding placing them right before a pause or at the end of an intonational boundary.

Subjects were asked to read the list of sentences containing the tokens three consecutive times. The sentences were preceded by three filler sentences at the beginning and followed by three filler sentences at the end. The filler sentences allowed the subjects to familiarize themselves with the reading list and to adapt their rhythm for the recording session, in order to keep a similar structure to that of the sentences for the analysis; filler sentences were not included in the analysis, in order to avoid interacting effects. The complete reading set of 43 sentences (plus 6 filler sentences), read three consecutive times by each subject, made a total of 129 tokens containing vowel sequences for each subject analysis.

Subjects were trained to produce a more or less constant speech rate throughout their reading task, with a production speed that would be fast enough to allow hiatus resolution strategies to take place. The reading speed was close to *connected speech*, following Llisterri (1992). Subjects were asked to maintain that rhythm throughout the reading task. The purpose of the training was to get the reading to sound as natural as possible and closer to a spontaneous style rather than a reading style.

The recording was carried out in a sound-treated room at the phonetics laboratory of the University of Illinois at Urbana-Champaign. This acoustic experiment was conceived to record the subjects' production of those vowel sequences, which were, a posteriori, categorized into the different strategies of hiatus resolution and analyzed for the effect of vowel quality. The reading task lasted an average of ten minutes for each subject. The production data (subjects' recordings) was recorded with a professional-quality equipment (micro: head-mounted Shure SM10A; recording, CSL 4300B Kay Elemetrics; sampling rate 44.100Hz).

4. Results

Since vowels are acoustically defined according to their duration and formant frequencies (Martínez-Celdrán 1984, Quilis 1993), hiatus resolution strategies are based on the characterization of those acoustic features. Thus, the objects of analysis in this experiment are *duration* and *frequency*. Duration refers to the possible durational reduction in the production of the vowel sequences, due to the application of hiatus resolution strategies. In the analysis of the production of each token, the duration of the vowel sequence was measured. Each subject repeated the production task three times; therefore, three productions were measured for each token. An average of those values was used in the statistical analyses. Measurements of F1 and F2 of the vowel sequences were also obtained. Although the actual formant values are not reported in a specific section within this paper, they were used as a criterion to classify the vowel sequences within the different categories of hiatus resolution strategies.

All measurements in the production experiment were manually obtained from waveform, spectrogram and spectra exploration using the *Praat* software for speech analysis (by Paul Boersma and David Weenink, *www.fon.hum.uva.nl/praat*, version 4.6.20). There were cases were formant measurements were difficult to obtain; in such cases, the formant tracking algorithm from Praat was used. For contexts where measurements were unclear, a second opinion from a phonetician was used to obtain a more accurate description. The statistical analyses run on the recorded data result from one-way ANOVA tests, conducted using SPSS 15.0 for Windows.

4.1. Vowel height

Tables 2 and 3 below display the results for the occurrence of the various strategies of hiatus resolution based on the height of the vowels in V1 or V2 positions. The results in table 2 show a significant preference for hiatus when the first vowel in the sequence is a low vowel. This result is consistent with those in table 3: hiatus and acoustic diphthongization show a higher percentage of production when V2 is a non-low vowel. In addition to that, there is a significant preference for coalescence when V2 is a low vowel. Unlike for coalescence, the results for deletion are not significant, but they suggest a similar preference (table 3). The results in tables 2 and 3 suggest a trend that divides into similar preferences of use hiatus and acoustic diphthongization on the one hand, and coalescence and deletion on the other. This division is further supported by the results recorded for vowel frontness and backness.

Table 2

V1 height: percentage of strategies produced

Strategy	V1=low	N	V1=non-low	N	*p*-value	F-value
Hiatus	15%	312	10%	643	.014*	F(1,953) = 6.011
Ac. diph.	18%	312	20%	643	.472	F(1,953) = .517
Gliding[2]	2%	312	1%	643	.241	F(1,953) = 1.379
Coal.	38%	312	44%	643	.084	F(1,953) = 2.990
Del.	27%	312	26%	643	.602	F(1,953) = .272

[2] Regarding gliding, the results do not show significant data and the choice of that strategy was limited to tokens that had a palatal consonant right after the vowel sequence. They are not relevant in the rest of the analysis either.

Table 3

V2 height: percentage of strategies produced

Strategy	V2=low	N	V2=non-low	N	*p*-value	F-value
Hiatus	7%	358	15%	597	<.001*	F(1,953) = 12.591
Ac. diph.	14%	358	22%	597	.002*	F(1,953) = 9.354
Gliding	1%	358	1%	597	.412	F(1,953) = .674
Coal.	49%	358	38%	597	.001*	F(1,953) = 11.065
Del.	29%	358	25%	597	.158	F(1,953) = 1.992

4.2. Vowel frontness

The results of the effects of vowel frontness are shown in tables 4 and 5 below. Most of them were not significant. However, the significant results reflect the effect of frontness in the choice of strategy of HR. Concerning the vowel in V1 position (table 4), deletion shows a greater percentage of production when V1 is a non-front vowel. Table 5 also shows only a significant difference: acoustic diphthongization is produced less often when V2 is a front vowel. However, again, a trend for a division is suggested based on the overall results: hiatus and acoustic diphthongization occur more often if V2 is non-front, whereas coalescence and deletion have a greater percentage of occurrence if V2 is a front vowel.

Table 4

V1 frontness: percentage of strategies produced

Strategy	V1=front	N	V1=non-front	N	*p*-value	F-value
Hiatus	12%	354	11%	601	.605	F(1,953) = .267
Ac. diph.	21%	354	18%	601	.416	F(1,953) = .663
Gliding	1%	354	1%	601	.395	F(1,953) = .724
Coal.	44%	354	40%	601	.272	F(1,953) = 1.209
Del.	21%	354	29%	601	.011*	F(1,953) = 6.485

Table 5

V2 frontness: percentage of strategies produced

Strategy	V2=front	N	V2=non-front	N	*p*-value	F-value
Hiatus	11%	245	12%	710	.690	F(1,953) = .159
Ac. diph.	13%	245	21%	710	.004*	F(1,953) = 8.212
Gliding	2%	245	1%	710	.077	F(1,953) = 3.144
Coal.	44%	245	41%	710	.397	F(1,953) = .717
Del.	30%	245	25%	710	.135	F(1,953) = 2.233

4.3. Vowel backness

The effects of backness on the strategies of HR are displayed in tables 6 and 7 below. Table 6 shows significant results for hiatus, gliding and deletion strategies. Hiatus and gliding show a greater percentage of occurrence when V1 is a non-back vowel, this difference being highly significant (p= .002); on the contrary, deletion is preferred when the first vowel in the sequence is a back vowel. The results in table 7 suggest a correspondence with those in table 6, since hiatus and acoustic diphthongization are more common when V2 is a back vowel whereas gliding, coalescence and deletion occur more often if V2 is non-back.

Table 6

V1 backness: percentage of strategies produced

Strategy	V1=back	N	V1=non-back	N	*p*-value	F-value
Hiatus	7%	289	14%	666	.002*	F(1,953) = 9.322
Ac. diph.	19%	289	19%	666	.903	F(1,953) = .015
Gliding	0%	289	2%	666	.036*	F(1,953) = 4.396
Coal.	43%	289	41%	666	.544	F(1,953) = .369
Del.	31%	289	24%	666	.033*	F(1,953) = 4.585

Table 7

V2 backness: percentage of strategies produced

Strategy	V2=back	N	V2=non-back	N	*p*-value	F-value
Hiatus	17%	352	9%	603	<.001*	F(1,953) = 15.442
Ac. diph.	29%	352	14%	603	<.001*	F(1,953) = 32.874
Gliding	0%	352	2%	603	.015*	F(1,953) = 5.923
Coal.	33%	352	47%	603	<.001*	F(1,953) = 16.983
Del.	21%	352	29%	603	.006*	F(1,953) = 7.713

5. Discussion on the results

Although the data discussed in the previous section does not reveal many significant results, they do suggest a trend that divides the different strategies of HR into two categories. Regarding vowel height, more instances of hiatus occur when the low vowel is in the first position in the vowel sequence, as displayed in table 2; this is supported in table 3, since hiatus as well as acoustic diphthongization occur with a greater percentage if V2 is not a low vowel (therefore, the low vowel has to be in V1 position). Regarding vowel frontness, the results in tables 4 and 5 suggest that deletion occurs more often if V1 is not a front vowel (table 4); and if V2 is a front vowel, then coalescence and deletion are the preferred strategies (table 5). The only significant results in table 5 show a lower preference for acoustic diphthongization when V2 is a front vowel, which supports the idea of a categorical division between hiatus and acoustic diphthongization on the one hand, and coalescence and deletion on the other. Each of these groups is used under similar conditions, according to the results in section 4. The results on backness displayed in tables 6 and 7 also support this categorical division: hiatus is chosen more often to resolve hiatus, when V1 is non-back (table 6); that is, hiatus (and acoustic diphthongization) is preferred when V2 is a back vowel (table 7). On the contrary, if V1 is a back vowel, deletion is preferred (table 6); that also corresponds to the fact that when V2 is non-back, then coalescence and deletion are chosen as preferred strategies (table 7).

Given that six vowel combinations (/ae/, /ao/, /ea/, /eo/, /oa/ and /oe/) were considered in this experiment about Spanish, the results suggest a hierarchy of preference for targeting a specific vowel (V1 or V2) within the vowel sequence, when HR applies. On the one hand, more instances of hiatus are maintained if V1 is the low vowel /a/, less if it is the front vowel /e/ and even less if it is the back vowel /o/. On the other hand, when V2 is a back vowel, hiatus and acoustic diphthongization show the greatest percentage of occurrence, whereas coalescence and deletion show the lowest. These results are indeed relevant since they suggest a partition among the various strategies of hiatus resolution into two main groups; i.e. hiatus and acoustic diphthongization, containing two vowels in the sequence, and coalescence and deletion, which have monophthongized the sequence. Finally, coalescence shows the highest percentage of occurrence when V2 is the vowel /a/. This is an interesting result suggesting that centralization of the vowel sequence (since /a/ is a low central vowel) is preferred in raising sonority sequences (/ea/ and /oa/) than in falling sonority sequences (/ao/ and /ae/).

The overall results show the existence of vowel quality effects on the different strategies of HR. They do not show that more sonorous or more marked vowels resist better hiatus resolution. But they do suggest that a categorical division may exist in the continuum of HR strategies.

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