Focusing, prosodic phrasing, and hiatus resolution in Greek*

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I investigate whether hiatus resolution in Greek (a) is a categorical rule, (b) applies within a certain prosodic domain, and (c) what effect focus exerts on this rule. The results suggest that the process is gradient, not categorical. Moreover, deletion of one of the two vowels creating hiatus occurs only for 25% of the data and there is no assimilation between the two vowels at all for 30% of the data. For the remaining 45% of the data there is assimilation in varying degrees. Vowels around strong boundaries and vowels in focused environments show greater resistance to assimilation than those around weak boundaries and non-focused environments. A strong positive correlation was found between duration and the degree of assimilation: Vowels with long duration resist assimilation more than vowels with short duration. There is also a significant influence of the quality of the input vowels both on segmental duration and the degree of assimilation.

1. Introduction

Recent studies have shown the effects of prosodic phrasing on segments. For example, final lengthening before prosodic boundaries is a well known process, and so is the strengthening of segments in phrase-initial positions (Jun 1993; Keating et al. in press; Pierrehumbert and Talkin 1992). Prosodic phrasing has also been shown to affect coarticulation between segments: Cho (2001; 2002; in press) found greater resistance to coarticulation across stronger boundaries than across weaker ones. In addition, focus has been found to affect segments: A focused word shows expanded pitch range and lengthening (Frota 2002 for a typology of focus realization; Jun and Fougeron 2000 and references therein; Jun and Lee 1998).

This is an experimental study which concentrates on the influence of prosodic contexts on *hiatus* resolution in Greek. Hiatus, two immediately adja-

cent vowels, is often avoided in casual speech. In this paper only *external* (cross-word) hiatus cases will be examined. In (1) [ao] creates hiatus: *megala onomata* surfaces with [a] deleted.

(1) megàla onòmata → megàl onòmata
'big names'

Cross-linguistically hiatus is avoided through different strategies (Casali 1997). In the Greek phonological literature, hiatus resolution has been treated as a categorical rule (Condoravdi 1990; Fallon 1994; Hadzidakis 1905; Kaisse 1977; Nespor and Vogel 1986). Greek researchers agree that external hiatus is optionally resolved in fast speech, usually by deletion of the first vowel (V1). According to these analyses, which are impressionistic, hiatus resolution depends on the quality of the hiatus vowels and on the syntactic relation between the carrier words. However, there is disagreement on how extensive the hiatus resolution process is, what the domain of each proposed rule is, and which vowels are affected in each domain.

The experimental evidence presented in this paper suggests that the output of hiatus is variable and gradient. Cross-linguistically, several sandhi processes have been shown to be gradient. For example, vowel assimilation in Igbo, as analyzed in Zsiga (1997), is a process very similar to the Greek phonological description of vowel deletion in hiatus environments. Zsiga convincingly shows that the phenomenon, described in phonological studies as categorical, is in fact gradient. Gradient assimilation is accounted for within Articulatory Phonology (Browman and Goldstein 1986; Browman and Goldstein 1989; Browman and Goldstein 1992): articulatory gestures for two segments overlap to a greater or lesser extent. In Igbo, this partly depends on prosodic phrasing. Korean Lenis Stop Voicing has also been shown to have gradient output (Jun 1995). The gradient nature of this rule was also accounted for within Articulatory Phonology, by showing the correlation between the duration of lenis stop closure and the degree of voicing; that is, it was shown that the shorter the closure duration of the stop, the more likely it was to be voiced.

Turning to Greek, Pelekanou and Arvaniti (2001) in an acoustic study of several sandhi processes in Greek also examined external hiatus. The deletion of V1 predicted in the phonological literature occurred only in 35% of their data, in 26% there was no deletion at all, and for the remaining 39%, the outputs were gradient, including reduction, coalescence, and diphthongization. In many cases more than one of these outputs were observed for

the same pair of words. Pelekanou and Arvaniti conclude that vowel deletion is best viewed as gradient overlap of articulatory gestures which can be perceived as 'deletion' when overlap is complete, and as different degrees of partial overlap when gradient outputs range anywhere between total deletion and no deletion at all. The domain of vowel deletion reported in Pelekanou and Arvaniti is a small prosodic phrase, called the *intermediate phrase* in Greek ToBI (Arvaniti and Baltazani 2000; Arvaniti and Baltazani 2004). The evidence I present supports the conclusion in Pelekanou and Arvaniti and sheds more light on the effects of prosodic structure on hiatus by exploring the importance of prosodic phrasing as well as the effect of focus on hiatus.

The results suggest that, first, vowel deletion in hiatus environments in Greek is less common than reported in the phonological literature, confirming the Pelekanou and Arvaniti results. The most common hiatus output is V1V2 variable assimilation. Second, the extent of V1V2 assimilation correlates with their duration, which in turn is affected mainly by prosodic phrasing and occasionally by focusing: vowels that have lengthened are less prone to assimilate than vowels that have not. That is, the hiatus resolution process is gradient, not categorical. The degree of V1V2 assimilation in hiatus outputs covers the continuum between deletion on one side and total lack of assimilation on the other.

The prosodic organization of Greek laid out in GRToBI is assumed here, that is, a hierarchical system with three prosodic levels, in descending order, the Intonational Phrase (IP), the intermediate phrase (ip), and the Prosodic word (PrWd). A strong prosodic boundary is present across IPs and boundary strength diminishes for the lower levels. V1V2 were placed in sentences with these three levels of prosodic phrasing separating them.

1.1. Prosodic strength hypothesis

Cross-linguistically phrase final lengthening is stronger at higher prosodic boundaries (Cooper and Paccia-Cooper 1980; Edwards, Beckman and Fletcher 1991; Klatt 1975; Wightman et al. 1992). More recently, Cho (2001; in press) in an articulatory study found more resistance to V-to-V coarticulation across strong prosodic boundaries. In accordance with these results, the first hypothesis of the experiment is that in Greek the duration and the quality of the hiatus vowels are affected by the strength of the boundary between them: Stronger boundaries induce greater resistance of vowels to shorten or assimilate.

It is unclear, however, whether assimilation is blocked by boundaries as such or by lengthening regardless of the presence of boundaries. In a study of the acoustic characteristics of Greek vowels, Fourakis, Botinis and Katsaiti (1999) found that focused vowels are longer and the vowel space is more expanded in focus conditions than non-focused ones. In addition, Baltazani and Jun (1999) found that words after a focused item in Greek are de-accented and prosodic boundaries are deleted. These facts combined allow the use of focus-induced lengthening to test whether less assimilation occurs in the absence of strong boundaries. If resistance to assimilation occurs whenever segments are lengthened, then we should find correlation between less assimilation and lengthening due to focus alone without the confounding factor of strong prosodic boundaries. The second hypothesis of the experiment, then, is that V1V2 duration and quality are affected by focus: focused vowels resist shortening or assimilation more than non-focused ones.

2. Method

2.1. Material and speakers

In a production experiment subjects read sentences containing eight different hiatus vowel pairs: [ae], [ao], [oa], [ia], [ua], [eo], [oe], and [ou]. Greek has a five vowel system [a, e, i, o, u] (Joseph and Philippaki-Warburton 1987; Koutsoudas and Koutsoudas 1962; Mackridge 1985). The particular pairs in this experiment were chosen because the words they occurred in sounded natural across all the prosodic contexts. One pair of words for each vowel pair was created (henceforth carrier words), with V1 at the end of the first word and V2 at the beginning of the second. Table 1 shows the eight carrier word pairs with hiatus vowels underlined.

Table 1. The eight carrier word pairs used in the experiment. Each one, containing one of the eight vowel pairs, was embedded in seven different prosodic environments.

1	[ae]	*diávas<u>a é</u>gera* read-pst-1s in time 'I read in time'
2	[ao]	*megál<u>a o</u>rámata* big-pl vision-pl 'A grand vision'

3	[oa]	*diavázo astinomiká* read-pres-1s detective-novels 'I read detective novels'
4	[ia]	*ápiri amerikána* inexperienced American 'Inexperienced American'
5	[ua]	*(I mamá tu) Andrónikou anevéni* (the mother of) Andronikos-gen go-up-3s 'Androniko's mother is going up'
6	[eo]	*katedafísoume olókliro* demolish-3p all 'We will demolish (it) whole'
7	[oe]	*aftokínito érhete* car come-3s '(The) car is coming'
8	[ou]	*nóstimo uzáki* tasty ouzo 'Tasty ouzo'

The carrier words were embedded in seven prosodic contexts. Three tested different strengths of prosodic boundary: Prosodic Word (PrWd), intermediate phrase (ip), and Intonational Phrase (IP). The remaining four contexts tested the effect of focus. Carrier words relative to focus were post-focal (postF), pre-focal (preF), or focused (w1f and w2f). Table 2 gives an example of the contexts for [ou]. Sentence A illustrates PrWd boundary between the words *nostimo uzaki* 'tasty ouzo'. The same two words are separated by ip and IP boundary in B and C respectively. The carrier words are post focal in D and pre-focal in E. Sentence F shows word 1 and G word 2 in focus.

Table 2. The seven prosodic contexts for [ou]. Brackets show prosodic boundary. V1V2 are underlined and focus is shown by small caps.

A	*Tha sou etoimáso éna nóstimo*$]_{Wd}$ *uzáki me mezé.* will for-you prepare-1s one tasty ouzo-dim with tidbits 'I'll prepare tasty ouzo with tidbits'
B	*An éxei mezé nóstimo,*$]_{ip}$ *uzáki pínoun óloi.* If has tidbits tasty ouzo-dim drink-3p all 'If the tidbits are tasty, everyone drinks ouzo'
C	*Tha fáo mezedáki an ínai nóstimo.*$]_{IP}$ *Uzáki den píno.* Will eat-1s tidbits-dim if is tasty ouzo-dim not drink-1s 'I'll have tidbits if they're tasty. I won't drink ouzo'

D *Tha sou etoimaso éna nóstimo uzáki, den boró na su arnithó*
will for-you prepare-1s one tasty ouzo-dim not can to refuse-1s
'I WILL prepare tasty ouzo for you, I can't refuse you'

E *Tha sou etoimáso éna nóstimo uzáki me meze.*
will for-you prepare-1s one tasty ouzo-dim with tidbits
'I'll prepare tasty ouzo WITH TIDBITS for you'

F *Tha sou etoimáso éna nostimo uzáki, óxi san tis Annas*
will for-you prepare-1s one tasty ouzo-dim not like Anna's
'I'll prepare TASTY ouzo for you, not like those that Anna makes'

G *Tha sou etoimáso éna nóstimo uzaki, óxi bíra*
will for-you prepare-1s one tasty ouzo-dim not beer
'I'll prepare tasty OUZO for you, not beer'

Four Athenian Greek speakers, one male and three females ranging in age between 18 and 40, repeated each sentence three times, creating a corpus of 652 tokens (8 V-pairs X 7 Prosodic conditions X 4 speakers X 3 repetitions). Each speaker was recorded separately in a quiet room.

2.2. Measurements

The duration and formant frequencies (F1 and F2) of the vowels in hiatus were measured. *Pitchworks* and *PCquirer* (Scicon) speech analysis programs were used for the measurements.

All duration measurements reported are those of the vowel *pair*: for pairs with a pause between them, the duration of V1 and V2 were added and the silence excluded. F1 and F2 were measured at a stable part near the middle of each vowel, when the two vowels were separate. When there was no break between V1 and V2 two measurements were taken, the first one at a stable part around 1/4 to 1/3 of the way into the vowel pair and the second at a stable part around 1/3 to 1/4 before the end.

The outputs are classified into four categories, shown in Table 3. One-vowel outputs are called *deletion* if the output is in a position (in the F1xF2 vowel space) typical for either vowel and *merger* otherwise. Two-vowel outputs are called *no assimilation* if they occur in their typical positions and *partial assimilation* if either vowel occurs in a non-typical position.

I use the Euclidean distance between the vowels in the F1F2 space[1] to quantify V1V2 assimilation. Smaller distance means more assimilation. These results are reported in section 3.

Table 3. Classification of hiatus outputs according to the hiatus resolution process.

OUTPUT	TYPICAL FORMANTS	NON-TYPICAL FORMANTS
1 vowel	Deletion	Merger
2 vowels	No assimilation	Partial assimilation

3. Results

3.1. Duration

As a reference for the duration of Greek vowels, data from Fourakis, Botinis and Katsaiti (1999) are shown in Table 4. Duration was measured in that study in stressed, unstressed, focused, and unfocused conditions, in fast and slow tempos. Table 4 presents single unstressed vowel durations, because the vowels in my study were unstressed (except V2 in pairs [ae] and [oe]). Moreover, the vowels in the present study were produced in normal tempo, so the average duration between fast and slow will be used for comparison here.

Table 4. Durations (in ms) of unstressed Greek vowels produced in slow and fast tempo from an acoustic study in Fourakis, Botinis and Katsaiti (1999).

Vowel	Slow	Fast	Average
[i]	44	36	40
[e]	57	51	54
[a]	78	69	73.5
[o]	67	58	62.5
[u]	54	40	47

Figure 1 shows durations from the present study in striped bars and in Fourakis, Botinis and Katsaiti in solid bars (vowel pair duration was calculated by adding the averages for single vowels from Table 4). Mean durations are provided under the graph. It is not clear how similar prosodic contexts in the two studies are because no intonational realization details were provided in that paper. Because of this, averages across all prosodic conditions were taken.

The average V1V2 duration in the present study is almost the same as the sum of two single "typical" vowels. Of course, as the error bars show,

durations from different prosodic positions within each vowel pair vary considerably: in some prosodic contexts V1V2 duration is as short as a single vowel and in some it is much longer than two single vowels. Table 5 shows the durations for the eight vowel pairs in each of the seven prosodic positions examined. Pooled durations are given in each cell and standard deviations are included in brackets.

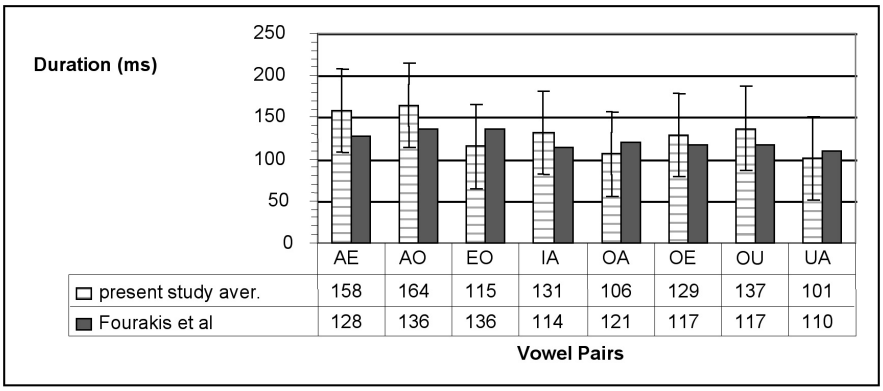

Figure *1*. Durations in the present study and in Fourakis, Botinis and Katsaiti (1999).

An analysis of variance tested the effect of prosodic condition (PrWd, ip, IP, postF, preF, w1F, w2F) as well as the type of vowel pair ([ae], [ao], [eo], [oe], [ua], [oa], [ia], [ou]) on duration. Both factors were significant: Prosodic position ($F[1, 6] = 56.553$, $p < .0001$) and Vowel Pair ($F[1, 7] = 14.591$, $p < .0001$). Post-hoc tests show that for all vowel pairs, the longest duration was found for vowels straddling a strong prosodic boundary, either that of an intermediate phrase (ip) or that of an Intonational Phrase (IP): these two prosodic positions, IP and ip, are significantly longer than all the rest. No other significant differences were found for the remaining prosodic positions.

Vowel pairs were significantly longer around strong prosodic boundaries, supporting the first hypothesis. No significant effect of focus on duration was found, refuting the second hypothesis. Vowel pairs in focus positions were longer than those in non-focus positions, but the difference was not significant. Table 5 shows three clusters in the duration values: one with the strong boundary positions (the only one showing significant difference), one comprising w1F and w2F, and a third cluster comprising the rest, all phrase

medial positions. This clustering more or less corresponds to the initial experimental setup. It is not clear whether the failure of the lengthening in focus positions to reach significance is due to the small number of participants in this study.

Table 5. Duration for the eight vowel pairs in the seven prosodic positions: Prosodic word boundary (PrWd), intermediate phrase boundary (ip), Intonational Phrase boundary (IP), post focal position (postF), pre-focal position (preF), focus on the first word (w1F), focus on the second word (w2F).

Prosodic Condition	[ae]	[ao]	[eo]	[ia]	[oa]	[oe]	[ou]	[ua]
PrWd	159 (25)	123 (10)	78 (15)	102 (21)	72 (21)	94 (16)	135 (13)	83 (24)
Ip	217 (50)	246 (22)	179 (11)	186 (32)	240 (96)	93 (16)	178 (13)	165 (24)
IP	249 (60)	233 (25)	199 (56)	193 (53)	163 (46)	205 (37)	152 (13)	131 (44)
postF	101 (15)	127 (3)	61 (14)	112 (25)	62 (17)	87 (19)	112 (12)	67 (9)
preF	108 (25)	123 (5)	62 (17)	108 (25)	62 (19)	94 (17)	116 (11)	90 (8)
W1F	124 (43)	143 (33)	138 (61)	102 (23)	69 (2)	107 (27)	122 (4)	72 (8)
W2F	150 (39)	157 (11)	87 (27)	117 (23)	77 (14)	220 (38)	142 (40)	98 (43)

The formant frequency measurements reported in section 3.2 show the influence both of the prosodic context and of the input vowels on V1V2 assimilation.

3.2. Formant frequencies

Section 3.2.1 shows which hiatus resolving strategy (deletion, merger, partial assimilation, and no assimilation) was used for the different vowel pairs and prosodic positions tested; 3.2.2 shows the influence of prosodic context and input vowel quality on the output; finally, 3.2.3 gives more evidence for gradience.

3.2.1. Output classification

As a reference for the formant values of Greek vowels, data from Fourakis, Botinis, and Katsaiti (1999) were used. These vowels were produced within sentences, just like in the present study, so the formant values between the two studies are fairly comparable. An important difference between the two studies is that whereas the Fourakis, Botinis and Katsaiti experiment had only male participants, the current experiment included three females and one male. In Table 6 the male speaker formant values in the present experiment in the IP condition are quite similar to those in the Fourakis, Botinis and Katsaiti study. Those produced by the female speakers in the IP condition are lower and more front than those produced by males, schematically shown in Figure 2.

Table 6. Top row: Average F1, F2 formant values in the Fourakis, Botinis and Katsaiti (1999) study (all male speakers); middle row: the male speaker of the present study; bottom row, the female speakers of the present study.

[i]		[e]		[a]		[o]		[u]	
F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
305	2025	472	1680	680	1315	468	1097	327	1069
366	2098	522	1700	635	1325	487	1077	389	1000
366	2430	620	2070	780	1650	562	1235	487	1100

V1V2 tended to remain in their "typical" positions the most in the strong boundary conditions; formant frequencies in the remaining prosodic positions tended to shift towards one another. Details about assimilation in the different prosodic contexts are given in the following section. For now, the main point is that the formant frequency values in the IP condition will be considered the norm and values in all other prosodic positions will be compared to them. Due to the difference in formant frequencies between males and females, the comparison between the typical values and the centralized ones was made separately for males and females.

Table 7 shows the percentage of each hiatus resolving strategy defined in section 2.2, broken down by vowel pair. Almost half of the outputs show neither deletion nor total lack of assimilation, but intermediate degrees of assimilation.

The quality of input vowels affects the hiatus resolution process used. More specifically, for vowel pair [ia] there are no tokens in the deletion category and very few in the merger category. For [oa] deletion is rare, with

merger the most frequent output. For the remaining vowel pairs, deletion occurs around 30% of the times. In the no assimilation column, the average shown in the TOTAL row, 30%, is very near the percentage for each vowel pair. In the partial assimilation column, there are three values that differ from the average: [ia] and [ua] have more outputs than average in this category, while [oa] has extremely few.

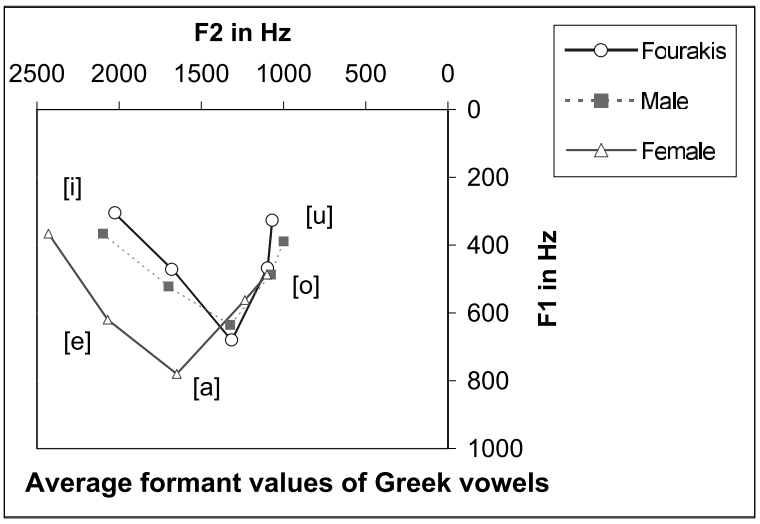

Figure 2. The formant values found in the Fourakis, Botinis and Katsaiti (1999) (all males) and those found for the male and female speakers in the present study

Table 7. Percentage of the different types of output across input vowel pairs.

Vowel Pair	Deletion	Merger	Partial Assimilation	No Assimilation
[ae]	32	4	29	31
[ao]	39	14	18	29
[oa]	11	57	3	29
[ia]	0	7	61	31
[ua]	25	0	36	39
[eo]	29	21	14	36
[oe]	32	25	21	21
[ou]	39	11	25	25
All 8 pairs	26	17	26	30

Table 8 shows the percentage of outputs in each hiatus resolving category, broken down by prosodic positions.

Table 8. Percentage of the different types of hiatus output in each prosodic position.

Prosodic condition	Deletion	Merger	Partial Assimilation	No Assimilation
PrWd	31	22	41	6
Ip	17	3	6	75
IP	0	0	3	97
postF	41	25	28	3
preF	34	31	31	3
w1F	34	19	34	12
w2F	25	22	37	17
All Conditions	26	17	26	30

The hiatus resolution process is not uniform across prosodic positions, that is, the prosodic position a specific vowel pair is found in influences the hiatus resolution process. More specifically:

- In the no assimilation column, values are widely dispersed from the average: no assimilation is the most common output around strong prosodic boundaries, and a rare output around weak prosodic boundaries, and in unfocused positions. Furthermore, no assimilation occurs in approximately one fifth of the outputs with focus, w1F and w2F, which is considerably more often than in the non-focus, phrase medial positions.
- In the deletion column, the distribution is again uneven. Deletion never occurs in the IP condition and relatively seldom in the ip condition. For the remaining prosodic positions, the distribution of deletion outputs is between 30–40%, with the exception of positions with focus on the second carrier word, w2F.
- As for the resolution processes in the two middle columns, there are low numbers in the ip and IP conditions and for the remaining prosodic positions, the distribution of merger and partial assimilation is fairly even.

Two major findings emerge from the results in this section. First, the claim made in the phonological literature that the most frequent hiatus output in Greek is V1 deletion is not supported. Instead the results here support the findings presented in Pelekanou and Arvaniti (2001). Almost a quarter of the outputs belong in the deletion category (V1 deletion mostly), and a

quarter each belong in the merger, partial assimilation, and no assimilation categories.

Second, the degree of V1V2 assimilation is influenced by the quality of these vowels as well as the prosodic position the pair is embedded in.

No unifying generalization can be made regarding which hiatus resolution strategies apply for which vowel pairs. The percentage of no assimilation is fairly constant around 30% for all vowel pairs, but for the remaining three hiatus resolution processes, each vowel pair displays its own pattern of hiatus resolution.

In the phonological literature several vowel quality properties have been claimed to affect deletion as hiatus resolution strategy[2]. The report that high vowels do not delete is verified by the data in the present study only for [i], not for [u], which deletes 25% of the time. The report that a round V1 does not delete in adjective-noun pairs, is not verified by the data, because [o] deletes 39% of the times in the pair [ou], although embedded in such an environment. The report that a V1 higher in the sonority hierarchy [o > a > u > i > e] than V2 does not delete in verb-adverb pairs, is not verified either, because [a] deletes before [e] 32% of the time.

As far as merger (coalescence) is concerned, Casali (1997), in an influential cross-linguistic typological study of hiatus resolution, notes that this strategy is common when V1 is lower than V2 and rare for the reverse. No such tendency was found in the present study. The merger rate for [oa] is high, 57%, although [o] is higher than [a].

The reasons behind the difference in the process of hiatus resolution for each vowel pair remain elusive. A larger scale study may reveal some generalization.

The effect of prosodic contexts on hiatus resolution has not been systematically examined in a quantitative study before. Results show that assimilation is blocked across strong prosodic boundaries, like those at the edge of intermediate phrases (ip) and Intonational Phrases (IP). Moreover, in phrase-medial positions some amount of assimilation is almost always the case. The assimilation-blocking effect of focus on the carrier words is much weaker than that observed for strong boundaries (not statistically significant as we will see in section 3.2.3) but stronger than that for phrase-medial positions. Finally, the rates of deletion, merger, and partial assimilation are approximately equal in every prosodic context except for the strong (IP, ip) boundaries.

In summary, the most robust effect on hiatus resolution is exerted by strong boundaries. A weak effect of focus is only seen for the no assimilation

strategy: In contexts with focus on one of the carrier words (i.e., w1f, w2f), more outputs showed total lack of assimilation than in the phrase-medial contexts (i.e., post-F, pre-F, PrWd). In all other hiatus resolution categories (i.e., deletion, merger, and partial assimilation) prosodic positions related to focus are not much different from the phrase-medial prosodic positions.

3.2.2. Assimilation across prosodic positions

In this section I present the V1V2 Euclidean distance in each prosodic position and the correlation between this distance and duration. First, Table 9 shows the V1V2 distance. The numbers on the left column under each vowel pair give the absolute V1V2 distance (pooled across speakers). The numbers on the right column present the 'normalized' distance, which is the distance of the vowel in the given prosodic position expressed as a proportion of the distance in the IP condition in the column (thus 1 in the IP condition). This was done to facilitate comparison across vowel pairs.

Table 9. Euclidean V1V2 distance across vowel pairs in each prosodic condition. The first column provides the distance in absolute values and the second column provides the distance in each prosodic position as a proportion of the distance in condition IP.

	[ae]		[ao]		[oa]		[ia]		[ua]		[eo]		[oe]		[ou]	
PrWd	240	0.47	152	0.3	110	0.3	587	0.59	401	0.52	183	0.5	133	0.25	184	0.74
Ip	498	0.97	477	1	406	1.1	863	0.87	613	0.79	583	1.5	82	0.15	220	0.89
IP	512	1	466	1	355	1	996	1	778	1	389	1	534	1	248	1
postF	291	0.57	123	0.3	76	0.2	600	0.6	267	0.34	178	0.5	107	0.2	158	0.64
preF	217	0.42	131	0.3	117	0.3	511	0.51	432	0.56	171	0.4	191	0.36	166	0.67
w1F	231	0.45	138	0.3	88	0.3	637	0.64	294	0.38	419	1.1	170	0.32	160	0.65
w2F	257	0.5	201	0.4	114	0.3	584	0.59	330	0.42	165	0.4	274	0.51	168	0.68

An analysis of variance tested the effect of prosodic position and the types of vowel pair on Euclidean distance. The within-subject factors considered were Prosodic Position (PrWd, ip, IP, postF, preF, w1F, w2F) and Vowel Pair (ae, ao, eo, oe, ua, oa, ia, ou). Both showed significant effects, Prosodic Position ($F[1, 7] = 25.1214$, $p < .0001$) and Vowel Pair ($F[1, 7] = 40.4224$, $p < .0001$). Post hoc comparisons show that distances across an IP and an ip boundary were indeed significantly greater than those in the remaining prosodic positions. No other prosodic position differences reached significance.

As for the vowel pairs, post hoc comparisons show that distances for the [ia] pair were significantly greater than those in the remaining vowel pairs, those for [ua] the next greatest, and no other significant differences were found.

Table 10 shows the correlation between distance and duration for each vowel pair for each speaker. The values compared were averages across prosodic positions.

Table 10. Correlation between duration and the Euclidean distance for each vowel pair across prosodic positions for the four speakers.

Vowels	Speaker 1	Speaker 2	Speaker 3	Speaker 4
[ae]	0.80	0.89	0.90	0.87
[ao]	0.99	0.80	0.96	0.98
[oa]	0.81	0.94	0.59	0.71
[ia]	0.94	0.86	0.92	0.79
[ua]	0.86	0.76	0.99	0.66
[eo]	0.98	0.89	0.83	0.93
[oe]	0.83	0.47	0.98	0.67
[ou]	–0.13	–0.19	0.80	0.81

For most of the vowel pairs, there is high correlation, over 0.8, between duration and distance. Except for two cases, the correlation is positive, meaning that as duration increases, so does the resistance of a vowel pair to assimilation.

The findings in this section show once more the robust inhibiting effect of strong prosodic boundaries on assimilation. The distance between the two vowels in the strong boundary positions is significantly greater than that in all other prosodic positions. A less robust assimilation inhibiting effect, which didn't reach statistical significance, was found for focus on a word carrying a hiatus vowel. In other words, the hypothesis that focus will block assimilation was not supported. Finally, phrase medial positions, where prosodic boundaries are weak, allowed for the greatest degree of assimilation.

Combining the results of this section with the previous one, it is necessary to stress that although these outputs were classified into four different hiatus resolution categories, these categories do not have sharply defined borders, since the statistical results showed no significant difference for most of the distances. The outputs in the no assimilation category – which in the majority are the outputs in the IP and ip conditions – are the only exception, being significantly different from the rest. Of course there are some 'prototypical' outputs of deletion, no assimilation, and so on, but these constitute the minor-

ity. If the four hiatus resolution processes defined in this study are seen as a continuum from no assimilation to deletion, then the measurements showed that outputs are spread all over this continuum and the borders between one category and its neighbor were never clear but had to be artificially imposed upon the data. In other words, this is a gradient process, not a categorical one. Gradience is evident not only across prosodic positions but also within them, as will be shown in the next section, 3.2.3.

The degree of assimilation between the two vowels in a pair also varied as a function of the input vowels. The statistical results show that vowel pairs [ia] and [ua] are different from the remaining pairs, showing the least amount of assimilation and also different from one another, [ia] assimilating less than [ua]. No significant effect of the remaining vowel pairs was found.

Finally, a high positive correlation was found between duration and the Euclidean distance between V1 and V2. It seems that in addition to the effect of boundaries, duration affects the assimilation between the two vowels. Although no statistical support was given to the initial hypothesis that focusing affects the degree of assimilation, the high correlation between segmental duration and assimilation suggests that lengthening in the absence of boundaries does influence the assimilation process.

3.2.3. Assimilation within prosodic positions

Speakers produced three repetitions per prosodic position and vowel pair. For part of the data the degree of assimilation varies across the three repetitions within the same prosodic position.

For example, Table 11 shows formant values for [ia] in two prosodic conditions, IP and postF, produced by speaker 1. The values for each repetition are shown separately. F1 values for [i] and [a] are shown in columns two and three, respectively; F2 values are shown in columns four and five. The last column shows V1V2 Euclidean distance.

For the IP condition, formants in all repetitions are close to typical. For the postF condition, the output in repetition 3 is different from the remaining two: the distance between the two vowels is smaller because [a] has moved to a much higher and more front position than it is typical for it and [i] has moved to a much more back position. Both vowels have moved towards the center but still are distinct from each other: a partial assimilation output. In repetitions 1 and 2, the formant frequencies show that the vowels occupy

slightly more centralized positions (especially [a] is around 100 Hz more front) than is typical for them but, according to the classification in this paper, these are no assimilation outputs, qualitatively and quantitatively different from the output in repetition 3.

Table 11. Formant values of [i] and [a] in the vowel pair [ia] in prosodic conditions IP and postF produced by speaker 1. Values in each repetition are shown separately.

Speaker 1 [ia] Condition IP	F1 [i]	F1 [a]	F2 [i]	F2 [a]	Euclidean Distance
Repetition 1	342	799	2328	1656	813
Repetition 2	338	828	2393	1585	945
Repetition 3	417	809	2512	1508	1078
Speaker 1 [ia] Condition postF	F1 [i]	F1 [a]	F2 [i]	F2 [a]	Euclidean Distance
Repetition 1	416	687	2328	1785	607
Repetition 2	401	714	2522	1784	802
Repetition 3	410	563	2112	1807	341

Table 12 shows how much variability of the type shown in the example above occurred within prosodic conditions. In general, 13% of the data display such variability. Table 12A shows variability in prosodic conditions and 12B variability in vowel pairs.

Table 12. The percentage of variability among the repetitions is shown in each prosodic position (A) and in each vowel pair (B).

A.

Prosodic Position	Variability
PrWd	13%
ip	13%
IP	6%
postF	21%
preF	18%
W1F	8%
W2F	11%
AVERAGE across prosodic positions	13%

B.

Vowel Pair	Variability
[ae]	11%
[ao]	11%
[oa]	14%
[ia]	8%
[ua]	12%
[eo]	14%
[oe]	15%
[ou]	14%
AVERAGE across V pairs	13%

The greatest amount of variability occurs in phrase-medial positions, PrWd, postF, and preF. There is less variability in the two focus positions, w1F and w2F, and the least amount of variability is found in strong boundary position IP. Contrary to the general pattern observed so far of ip and IP boundaries influencing segments in a similar way, in this case there is considerably more variability found around intermediate phrase boundaries than around IP boundaries.

As for the variability across the vowel pairs, in Table 12B, only [ia] is obviously different from the rest: it has outputs with the least amount of variability. The remaining vowel pairs cluster around the average of 13%.

For one eighth of the data, the amount of assimilation between the vowels varies across the three repetitions. The greatest amount of variability occurs in phrase-medial positions and the least in strong boundary positions. One noteworthy exception to this generalization is the high degree of variability around intermediate phrase boundaries. In all other respects, as was repeatedly shown throughout this study, the positions around both intermediate and Intonational phrase boundaries induce the same behavior for vowels: they impede assimilation and facilitate lengthening. This is one instance where we see a difference between the two kinds of boundary, and this nicely illustrates the difference in strength between the two otherwise very similar prosodic environments – there is more plasticity around intermediate phrase boundaries than around Intonational Phrase ones.

As for variability across vowels, only for vowel pair [ia] is there a link between variability and the amount of assimilation found: less assimilation correlates with less variability, just as noted for IP boundaries. However, no such pattern was observed for the pair [ua] which showed the second lowest degree of assimilation.

In summary, the results suggest once more that the hiatus resolution process is gradient. I would like to stress that stating that the hiatus resolution process is not categorical does not contradict the fact that prosodic context influences this process: the prosodic position effect is a tendency, not an absolute.

4. General discussion and conclusion

Several conclusions can be drawn from the results of this experiment. First, it is evident that hiatus resolution in Greek cannot be described as a categorical rule: the same speaker, in the same prosodic position, produced different

outputs, with varying degrees of assimilation between the two vowels. Even though there is a clear cut difference between total lack of assimilation and the remaining hiatus resolution processes, we cannot speak of categorical rules, as whenever assimilation happens, it does so in varying degrees.

Second, several factors influence the amount of V1V2 assimilation. Vowels around strong boundaries show significantly greater resistance to assimilation than those around weak boundaries. Moreover, vowels show a non-significant trend to assimilate less around focused environments than around non-focused ones. Connected to these findings, I showed that segments have shorter duration around weaker boundaries than around stronger ones and in non-focus environments than in focused ones. Although we cannot argue for a causal link between the assimilation results and the duration results, there is strong positive correlation between segmental duration and the degree of assimilation: Vowels with long duration display more resistance to assimilation than vowels with short duration. The combination of these results makes clear the need to investigate further the effects that lengthening due to focus has on assimilation, to reveal whether lengthening alone, without the confounding factor of prosodic boundaries, is what inhibits assimilation. This study failed to establish statistically significant effects of focus on the hiatus resolution process. Further investigation is necessary to confirm this result.

The acoustic effects of varying degrees of assimilation cross-linguistically have been described in the literature as results of variable overlap between the articulatory gestures for the two hiatus vowels. It has been claimed that more time allows articulators to reach their target positions, but when time is compressed articulators do not have time to reach the target and only reach intermediate positions approximating the target. As a result, gestures are compressed by overlapping with each other more, that is, articulators do not reach their target, and each gesture lasts a shorter time. Although the results of this study could certainly accommodate such an explanation, it should be borne in mind that this was an acoustic study, not an articulatory one, and no hard evidence can be provided for or against an explanation within Articulatory Phonology.

Finally, one of the questions left unanswered in is how the quality of the input vowels influences hiatus resolution. The results show a significant influence of the input vowels both on segmental duration and the degree of assimilation. Several vowel properties were examined in section 3.3 in connection to this question, among them vowel height, sonority hierarchy, vowel roundness, and relative height between V1 and V2, but no single gen-

eral property can account for these results. A larger scale study may reveal generalizations that the present study failed to detect.

In summary, we have shown that the process of hiatus resolution in Greek is gradient, not categorical. Moreover, the degree of assimilation between hiatus vowels in Greek and their duration are affected by their prosodic position, with less assimilation and more lengthening found around strong boundaries and focus.

Notes

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1. This distance is the square root of the sum of the squares of the difference between the vowel formant frequencies (ED= $\sqrt{((F1V1–F1V2)^2+(F2V1–F2V2)^2)}$). I thank one of the reviewers for suggesting this measure.
2. All three phonological rules for deletion mentioned here were employed in Kaisse (1977).

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