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New vowels in an existing space:
evidence from Italian production of English /æ/

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Introduction

Bohn and Flege (1992) discuss the acquisition of L2 vowels that are dissimilar from those in the L1. It appears that the presence of a proximate vowel category in the L1 interferes with learners' ability to correctly produce L2 vowels, while the absence of a proximate vowel category in the L1 will trigger the creation of such category and subsequent improvement in that vowel's production. The English vowel [æ] is considered by Bohn and Flege to fit in with the second of these types, at least for German L1 speakers, being different enough from German vowels to prompt the creation of the new vowel category.

The goal of this study is to describe the acoustic characteristics of an Italian L1 speaker's production of English /æ/, to compare these characteristics (F1 and F2 frequencies) with those of the speaker's native language vowels and those of native speakers of English. With close attention paid to the geometry of acoustic vowel space, the speaker's behavior is modeled in a constraint-based theory.

The research questions central to this paper are as follows:

RQ1: What are the acoustic properties of a native Italian speaker's production of /æ/ relative to the native English speaker's vowel system?

RQ2: What generalizations may be made regarding the native Italian speaker's English vowel space compared with that of the native speaker of English and how are these generalizations best modeled in a constraint-based theory?

Given the first of these questions, three possible behaviors are foreseen.

a. the speaker subsumes English /æ/ into an existing vowel category, most likely the proximate vowel /ɛ/
b. the speaker produces a target-like /ae/
c. the speaker creates a new vowel category for English /æ/

Note that the speaker may also demonstrate a pattern of variation in production of English /æ/, neither consistently subsuming the vowel into his existing categories nor creating a new category, and that some variation will naturally be present in the speech of controls. Therefore, this study looks for significant and consistent departures from the target acoustic features.

The second of the research questions involves generalizations about the factors influencing shape of the L2 vowel space given a different L1 space.

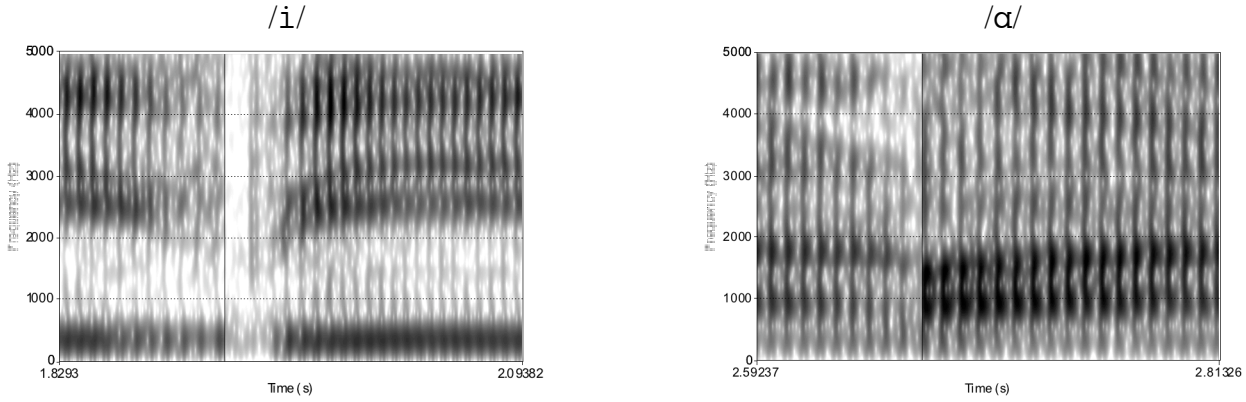
It will be shown that the Italian speaker, proficient in English as a second language, depicts a behavior regarding /æ/ in which he effectively produces a target-like vowel, departing in no significant manner from native English speaker data. An examination of the properties of the Italian vowel inventory, along with the data gathered here, will aid in positing the reorganization of constraints necessary for this speaker's ultimate attainment of the target-like vowel.

The structure of this paper is as follows. Section 1 provides relevant background on the acoustic characteristics investigated in the experiment. Section 2 compares the acoustic characteristics of English and Italian vowels and the shape of the vowel spaces in each language. Section 3 outlines the methodology used, including subject information, data elicitations, and analysis. Section 4 presents the results of this study. Finally, in Section 5, the implications of the findings are discussed and a theoretical model based on acoustic constraints is constructed to account for the observed data.

1. Phonetic background

Of particular usefulness in describing vowel sounds are formant values. Formants, as described by Fry (1979) are the resonant frequencies in a system (more frequently used are the peak values of these resonant frequencies). One way to determine resonant frequency is by locating high amplitude energy peaks along a continuum of frequencies. These peaks, in a spectrum (amplitude by frequency) manifest themselves as dark bars in a spectrogram (amplitude by frequency over time). Thus spectral analysis may be accomplished and vowel formant values obtained quite easily, due to their salience. Figure 1 illustrates this salience in spectrograms

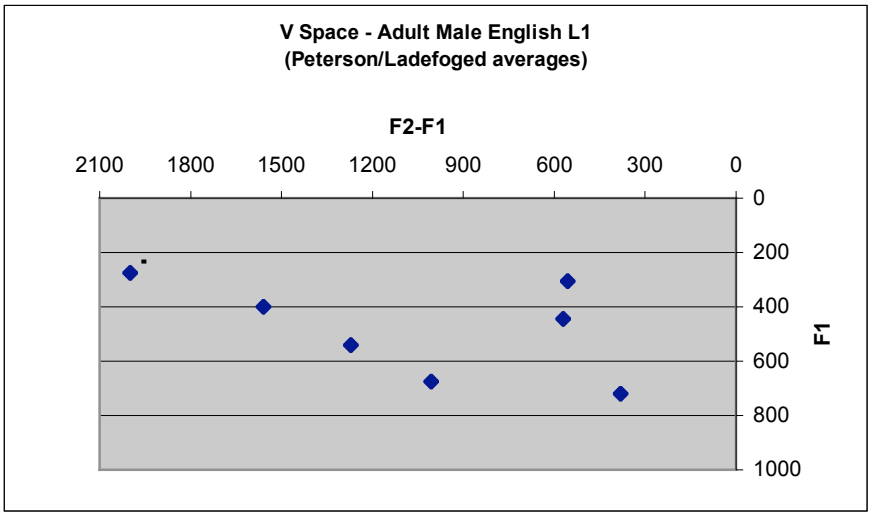
Figure 1. Spectrograms of vowels /i/ and /ɑ/.



Such prominence also serves as a perception aid, with vowels usually identified on the basis of their first two formant values (F1 and F2), and the dispersion of, or distance between, these two figures (F2-F1). Because of the highly variable nature of the human vocal tract, the normalization of vowel formants is an elusive task, and speakers generally rely on the relative distance between the first two formant values in identifying, discriminating, and categorizing vowels.

It is perhaps easiest to depict the tight correspondence between acoustic and articulatory properties of vowel sounds with a graphic. Figure 2 graphs F2-F1 values along the x-axis and F1 values along the y-axis for a number of English vowels (from Peterson, 1952 and Ladefoged, 1975).

Figure 2. Scatter plot of English vowels



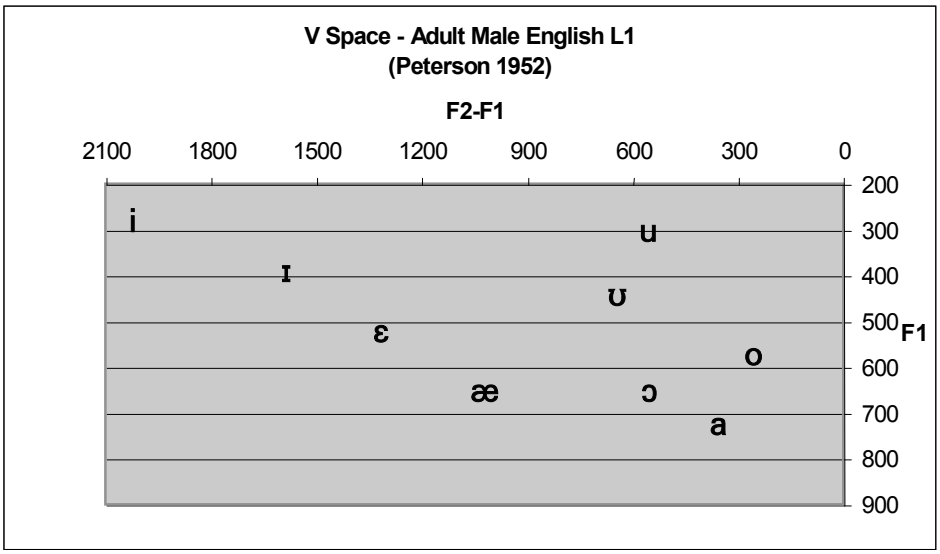
It should be clear from Figure 2 that F1 has something to say about vowel height, while F2-F1 dispersion is a very good indicator of front/backness. Because individual formant values are based on the resonant frequencies of various parts of the vocal tract, they will vary inversely with the length of the portion of vocal tract to which they are associated. F2-F1 dispersion will vary inversely with the degree of backness – a low dispersion marking a front vowel, a mid-range dispersion marking a central vowel, and a high dispersion marking a back vowel.

This study will pay close attention to F1 and F2-F1 dispersion values in the analysis of L2 vowel production.

Note further that the vowels in Figure 2 serve as the outer boundaries of a "vowel space," that is, the general range of F1 to F2-F1 dispersion in the given language. This

vowel space has much to say regarding the types of vowels in a language's phonetic inventory. English, with its abundance of vowels, would have a vowel space looking like that in Figure 3.

Figure 3. The English vowel space.



Normalization of formant values is a difficult task. Therefore, exact frequencies and the differences among them are not the focus of this study. Instead, the goal is to assess general trends in vowel production on the part of the Italian speaker, comparing average formant values with those of native English speaker averages, those of the Italian subjects' other neighboring vowels.

With this brief overview of the relevant phonetic features of vowels, the vowel systems of English and Italian may be examined more closely.

2. Contrastive analysis of English and Italian vowel systems

Three generalizations are immediately observed in comparing the English and Italian vowel systems. First, Italian's vowel inventory is slightly more limited than that of English; second, English shows a lack of the tense mid vowels; and third, Italian conspicuously lacks the central vowels found abundantly in English, organizing its vowels at the perimeter of the vowel space. It is the last of these differences that are most relevant to the current study.

Tables 1 and 2 below list the formant values for Italian and English, respectively. Italian data are from Fava and Caldognetto (1976); English data are from Peterson (1952), as Ladefoged omits two of the central vowels crucial to the analysis here. All data are taken from adult male native speakers of the respective languages.

Table 1. Formant values for English vowels.

	i	ɪ	ɛ	æ	ɜ	ʊ	ʌ	u	a	ɔ
F1	270	400	530	660	1350	440	640	300	730	570
F2	2300	2000	1850	1700	490	1100	1200	850	1100	850
F2-F1	2030	1600	1320	1040	860	660	560	550	370	280

Table 2. Formant values for Italian vowels.

	i	e	ɛ	a	u	o	ɔ
F1	300	395	540	765	325	445	560
F2	2140	2000	1870	1240	715	775	885
F2-F1	1840	1605	1330	475	390	330	325

For those vowels which English and Italian share, only slight differences are noted in formant values. However, what is clear from the tables above is that the English vowel inventory demonstrates a gradual shift from high to low in F2-F1 dispersions while Italian dispersions jump from higher to lower values (note the absence of F2-F1 dispersions in the range of about 500 Hz to 1300 Hz in Table 2).

It is precisely the vowels with mid-range F2-F1 dispersions that are the central vowels in English. That is, they are neither clearly [+back] nor [-back]. Figures 4 and 5 plot the vowel inventory by F2-F1 and F1 values and demonstrate the exploitation of the entire vowel space by English, and the conspicuous absence of central vowels in Italian.

Figure 4. Plot of English vowel system.

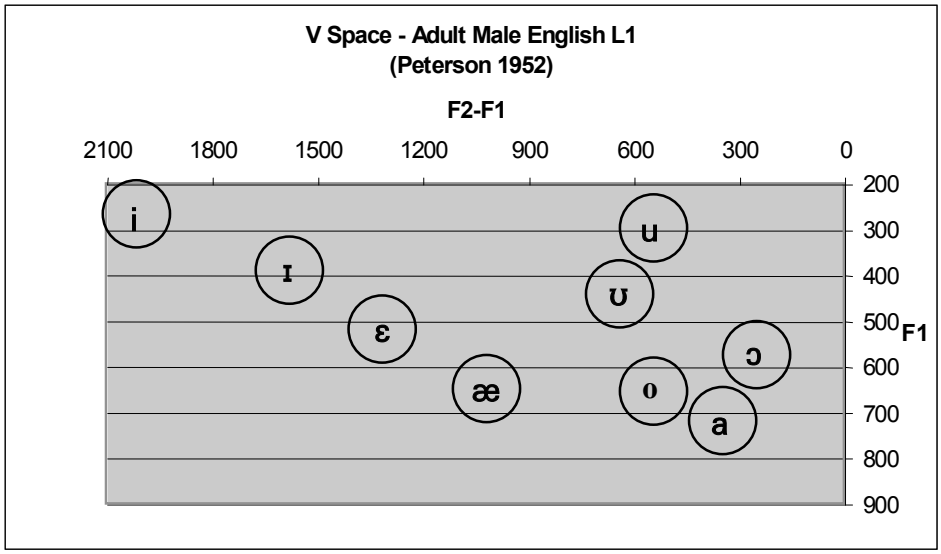
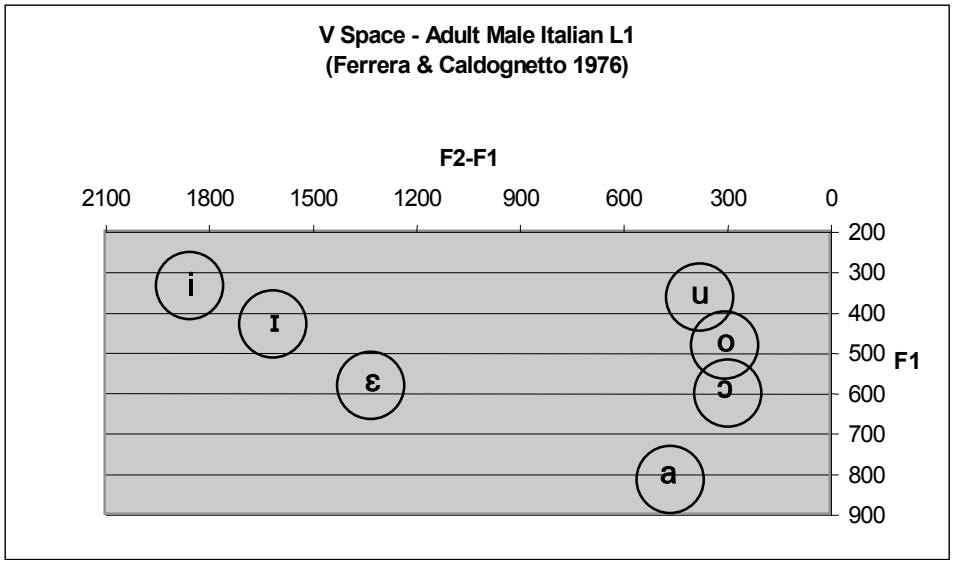


Figure 5. Plot of Italian vowel system.



This brief background will enable generalizations to be made about Italian speakers' treatment of English's central vowels.

3. Methodology

As this is a pilot study, data was collected from one participant, a native speaker of Florentine Italian who is highly proficient in English as a foreign language, having approximately 16 years of English experience, with ten of those years being spent in the U.S.

The data collected from this speaker consist of a range of vowels, both English and Italian, spoken in CVC contexts and included in and English or Italian carrier phrase "Now I say ___" or "Adesso dico ___". Appendix A lists the elicited tokens in detail. The subject was asked to repeat each word in the appropriate carrier phrase a total of three times.

In addition to the CVC words, the subject was asked to read [hVd] tokens in order that an English vowel space might be constructed for the speaker. These tokens and their transcriptions are listed in Table 3.

Table 3. [hVd] tokens.

vowel	token	IPA
i	'heed'	[hid]
ɪ	'hid'	[hɪd]
ɛ	'head'	[hɛd]
ɛj	'hayed'	[hɛjd]
æ	'had'	[hæd]
ʌ	'HUD'	[hʌd]
u	'who'd'	[hud]
ʊ	'hood'	[hʊd]
ɑ	'hod'	[hɑd]

A few of the elicited tokens not relevant to the present study, particularly those containing the vowel [ɑ] that is orthographically represented by 'o', were found to be

problematic, most likely due to orthographic interference. As these tokens have no direct bearing on the analysis of [æ], they are ignored. No errors were made in the elicitation.

All data was collected using a Marantz portable tape recorder and a unidirectional microphone. Data was digitized at a 22kHz sampling rate and analyzed using PRAAT acoustic software. For each vowel in the [CVC] and [hVd] contexts, F1 and F2 values were measured at a steady-state portion of the vowel, and F2-F1 dispersion was calculated from these values.

Other than providing data for graphing of the subject's vowel spaces, much of the formant data collected for vowels other than [æ] and its immediate neighbors is largely irrelevant.

4. Results and analysis

The results from the CVC and [hVd] tasks were not entirely compatible. The average formant values of vowels produced by the Italian speaker in the CVC task differed only slightly from the Peterson values, as shown in Table 4.

Table 4. Subject's production of [æ] and [ɛ] compared to Peterson averages

	subject		Peterson		Δ (subj-Peterson)	
	æ	ɛ	æ	ɛ	æ	ɛ
F1	688	643	660	530	28	13
F2	1783	1890	1700	1850	83	40
F2-F1	1095	1247	1040	1320	55	-73

The subject's production of [æ] shows a clear similarity to the data recorded by Peterson. Somewhat compatible similarities are obtained comparing the subject to formant values documented by Ladefoged (1975), as in Table 5, although in this comparison the subject's production of [æ] is farther from the target.

Table 5. Subject's production of [æ] and [ɛ] compared to Ladefoged averages

	subject		Ladefoged		Δ (subj-Ladefoged)	
	æ	ɛ	æ	ɛ	æ	ɛ
F1	688	643	690	550	-2	97
F2	1783	1890	1660	1770	123	120
F2-F1	1095	1247	970	1220	125	27

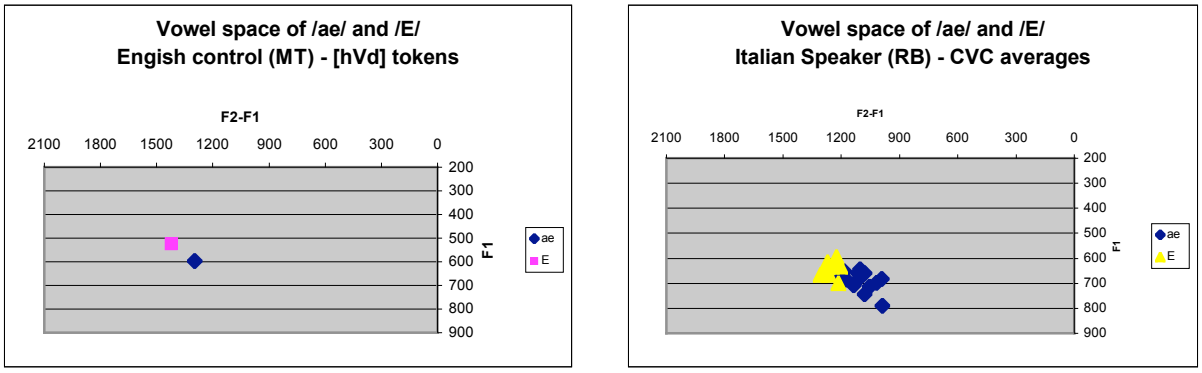
Finally, the subject's formant values can be compared to a native English control:

Table 6. Subject's production of [æ] and [ɛ] compared to English control

	subject		English control		Δ (subj-control)	
	æ	ɛ	æ	ɛ	æ	ɛ
F1	688	643	596	523	108	120
F2	1783	1890	1894	1946	-111	-52
F2-F1	1095	1247	1298	1423	-203	-176

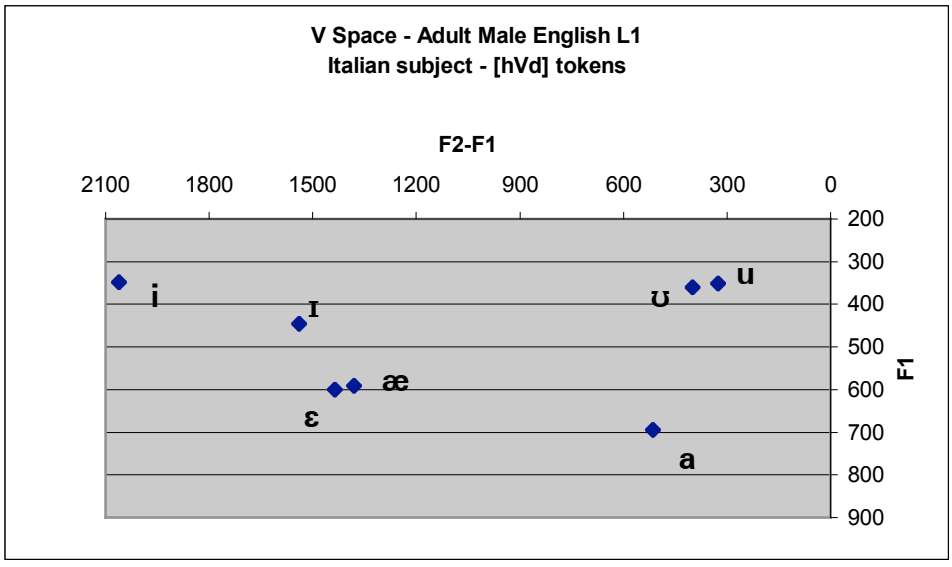
Furthermore, the graphs in Figure 6 display a roughly similar placement in the vowel space of [æ] and [ɛ] by both the Italian speaking subject and English control:

Figure 6. [æ] and [ɛ] location in the vowel space.



However, if we graph the results of the Italian speaker's [hVd] tokens, we get a different picture. Note the conspicuous absence of central F2-F1 dispersion values and the proximity of /æ/ and /ɛ/ in Figure 7.

Figure 7. Italian subject vowel space from [hVd] tokens.



Thus the results are somewhat contradictory: the CVC tokens show an apparent similarity with the target formant values for English /æ/, and provide no evidence of absorption of /æ/ into the mid-front vowel category. However, the [hVd] elicitations reflect the expected gap in the vowel space due to the lack of mid-range F2-F1 dispersion values. It is likely that an increase in the subject pool and a refinement of the elicited tokens may resolve this contradiction in the findings, but it must be noted that data collected from multiple subjects may prove to show so much variance as to complicate analysis substantially.

5. Implications and theoretical model

The data generally point to the conclusion that the subject does not fail to produce a target-like /æ/, subsuming the non-native vowel sound into an existing proximate category, but in fact succeeds at producing the target with little variation from the native speaker data. It is therefore necessary to construct a theoretical model that explains the adoption of the non-native vowel.

As outlined in Section 2, the Italian vowel inventory lacks any vowels in the central space defined by mid-range F2-F1 dispersions – exactly where /æ/, /ɜ/, /ʌ/, /ə/, (and perhaps also /ʊ/) are located. In other words, Italian vowels are either clearly [+back] or [-back], with no middle ground. To explain this one might posit a highly-ranked markedness constraint in Italian against central vowels, or, in acoustic terms, against mid-range F2-F1 dispersions (approximately 800Hz to 1200Hz):

***MID F2-F1: no F2-F1 dispersion values in range of 800-1200 Hz**

There are a few justifications for this markedness constraint. First, if a language has central vowels it will also have front and back vowels, but we will not find languages with only central vowels (data from Handbook of the International Phonetic Association, 1999). Second, those languages whose phonemic inventory includes both [+/- back] and central vowels will have fewer of the latter. Third, the importance of the [+/-back] feature is often found in morphophonological phenomena such as vowel harmony, while little, if any, role is played in such processes by central vowels. Finally, from a perceptual standpoint, the phonologies of language will tend toward the 'ends' of a front/back spectrum in order to aid perception.

A brief survey of formant values in American English, Italian, German, and Swedish shows that a very limited number of vowels in these languages actually have F2-F1 dispersions in the mid range. The vowels are /æ/, /ɜ/, and /ö/ (and perhaps /y/). The data in Table 7 illustrate this.

Table 7. Formant dispersions in four languages

	i	ɪ	e	ɛ	y	æ	ö	ɜ	ʊ	ʌ	u	ɑ	o	ɔ
	high F2-F1					*mid F2-F1*			*low F2-F1*					
English	2030	1600		1320		1040		860	660	560	550	370		280
Italian	1840		1605	1330							390	475	330	325
German	1534		1271		1225		969				733	708	588	
Swedish	1935		1905		1800	1095	1350					537	300	

Also note that none of the cardinal vowels, in either a three-vowel (iɑu) or five-vowel (ieɑou) system, has an F2-F1 dispersion in the middle range of 800-1200 Hz.

The difference, then, between target-like production of /æ/ and some non-target-like output, will hinge on the ranking of the *MID F2-F1 constraint relative to the following faithfulness constraints in the grammar.

IDENT F1: **no significant variance from F1 value of input**
IDENT F2: **no significant variance from F2 value of input**
IDENT F2-F1: **no significant variance from F2-F1 value of input**

But there is another consideration to be made. Non-target production may fall into one of two categories: either the speaker may absorb the new vowel into an existing L1 category, or he may create a new vowel. Again, a new constraint is necessary:

***NEW:** **no segments not in the L1 inventory**

The interaction of these constraints in a simple way will yield each of the three possible outcomes mentioned earlier: absorption, novel production, and target-like production.

All three can be achieved simply by floating the cluster of markedness constraints, *MID F2-F1 and *NEW, below the faithfulness constraints. Tableaux in (8-10) illustrate this.

Table 8. Absorption of /æ/ into Italian vowel category

input: /æ/ 675, 1680, 1005	*MID F2-F1	*NEW	IDENT F1	IDENT F2-F1
☞ Italian /ɛ/ 540, 1870, 1330			*	*
`IL new vowel 675, 1900, 1225		*!		
English /æ/ 675, 1680, 1005	*!			

At this level, the markedness constraints against central vowels and non-native vowels outrank all faithfulness constraints, yielding /ɛ/ as the winning candidate.

Table 9. Creation of new V in Interlanguage

input: /æ/ 675, 1680, 1005	IDENT F1	*MID F2-F1	*NEW	IDENT F2-F1
Italian /ɛ/ 540, 1870, 1330	*!			
☞ IL new vowel 675, 1900, 1225			*	
English /æ/ 675, 1680, 1005		*!		

In the next stage, the two markedness constraints have floated down in the ranking, resulting in faithfulness to one of the first two formant values (note it cannot be determined whether IDENT F1 or IDENT F2 is appropriate; thus the former was chosen arbitrarily) outranking them. This ranking produces some new non-central vowel.

Table 9. Creation of new V in IL

input: /æ/ 675, 1680, 1005	IDENT F1	IDENT F2-F1	*MID F2-F1	*NEW
Italian /ɛ/ 540, 1870, 1330	*!			
IL new vowel 675, 1900, 1225		*!		
☞ English /æ/ 675, 1680, 1005			*	

Finally, at a level of higher proficiency, the markedness constraints have floated lower than faithfulness to dispersion, resulting in a new, central, and target-like vowel as the winning candidate.

Due to the possibility of small amounts of variation in formant values, faithfulness constraints must be satisfiable even if formants in the output do not match input exactly. How much variation is to be allowed while still satisfying these constraints is left for future investigation, but some gradience in constraint definitions will certainly be necessary.

Furthermore, with only one highly-proficient subject in the current study, the rankings in Tables (8-10) are merely hypothesized. A wider range of subjects, to include proficiency levels at the elementary, intermediate, and advanced stages, are needed to confirm these constraint rankings.

Concluding remarks

This study has collected and analyzed the speech of a native Italian speaker proficient in English for the purposes of assessing the production of English /æ/, a vowel that has no acoustic counterpart in the Italian vowel system. It has been shown that the speaker succeeds in producing a target-like /æ/, and that such production may necessitate the re-ranking of certain markedness constraints that are hypothesized to rank highly in Italian based on the robust lack of central vowels in that language. Further data must be collected to test the optimality theoretic model put forth here, and this should include speech samples from Italian L1 subjects at varying ranges of proficiency in English, as well as from speakers of other languages lacking central vowels.

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