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A Longitudinal Investigation of Vowel Acquisition

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A longitudinal study investigated change in the vowel systems of five adult native Spanish speakers learning English. It focused on 11 vowels of English as uttered in CVC words and in various sentential contexts. Vowel productions from each speaker were measured for the acoustic parameters of F1, F2 and duration. These acoustic parameters were then analyzed via classification matrices of discriminant analysis and compared over time. Findings indicate that the vowels of nonnative speakers change in ways that reflect dialectal and diachronic changes. Specifically, we see instances of split, merger and shift as described by Labov (1994). It is also the case, however, that changes occur that are unique to second language (L2) acquisition. This study provides evidence that the intermediate phonological systems arising during L2 acquisition should be viewed not only in terms of the target but as unique systems of contrasts. It also provides evidence that changes are not necessarily unilateral; movement in one area of the system can affect other areas of the system. These findings are relevant to the way in which we view, teach and assess the pronunciation of an L2 vowel system.

INTRODUCTION

In the study of second language (L2) acquisition and cross-linguistic production and perception, many models have been proposed to account for learners' pronunciation of L2 sounds. In an attempt to determine which model best accounts for the complex facts, it is often the case that we focus on particular aspects of pronunciation, on particular subsets of the phoneme inventory, or on particular learning paradigms that will best distinguish between models or hypotheses. The methodology for studying L2 phonological acquisition is often a three-step process: 1) form a hypothesis, 2) find a subset of the phonological system that has characteristics to test the hypothesis, and 3) determine whether the actual productions by L2 learners on that subset support the hypothesis. The results of such studies have undoubtedly brought us closer to understanding L2 phonological acquisition in terms of both production and perception. Yet, we are left with a crucial question. Do all the sounds or sound contrasts that fall into the same production or perceptual pattern behave the same way within an individual speaker? In her study of cross-linguistic perception, Escudero (2000) suggests several directions for future research. She specifically mentions the need to study category formation and perception of other sounds in the system. She also suggests the need for longitudinal studies of one year or more to determine the stability of the patterns and the sequence of development. These suggestions are clearly relevant to L2 production as well.

This study examines the development of phonological systems or subsystems over time. It is a descriptive study of change in the non-diphthongized vowel systems of L2 learners. Its purpose is to observe and describe change from two perspectives. The first perspective is that all change is relevant regardless of its nature. This perspective is based on the concept of Interlanguage (IL). Since interlanguage is the unique system of a learner unlike the native or target language (Selinker, 1972), it is possible that the IL can change but still not approximate the target. Thus, in this study, the learners' vowels were first described independently of the target via a comparison of a system at one point in time to *itself* at another point in time. The second perspective of change is based on the idea that successful phonological acquisition entails movement of the system towards the target norms. Thus, change was also observed via a direct comparison of a learner's system to the target system. Similarities and differences between each learner's system and the target system were then compared across time.

METHODS

Participants for this study consisted of five nonnative speakers and two native speakers of English. The five non-native speakers all spoke Spanish as their native language. Three of them were from Colombia, one was from Guatemala, and one was from Peru. Their ages ranged from 20 to 42 years old, and length of residency at the onset of the study ranged from six months to twelve years. Four of the non-native speakers were male and one was female. All of the non-native speakers were enrolled in at least one English as a Second Language (ESL) class at Nassau Community College at the time their first recordings were taken, but only two were registered in a pronunciation class.

The native speakers consisted of one male speaker and one female speaker. At the onset of the study their ages were 34 and 38 years old respectively. They were both born in New York and had lived there all of their lives. They were monolingual English speakers. Both studied Spanish in High School, but neither could converse in any language other than English. The native speakers were used to provide a baseline to evaluate change over time of the non-native speakers.

Procedures and Materials

The portion of the study reported here included a sentence reading task. This task was designed to elicit eleven target vowels: [i, ɪ, e, ɛ, æ, ʌ, u, ʊ, o, ɔ, ɑ]. Target vowels appeared in three monosyllabic English words of the structure CVC, where each C was a stop (Table 1). Each monosyllabic word was then repeated five times with each occurrence of a word being in a unique sentential context.

Table 1. Target Words

[i] *keep, peek , bead*	[ɪ] - *pick, pit, kid*
[e] - *take, gate, paid*	[ɛ] - *get, pet, bed*
[æ] - *cat, pat, bad*	[Λ] - *cut, cup, but*
[u] - *boot, coop, tube*	[ʊ] - *put, took, could*
[o] - *coat, boat, code*	[ɔ] – *talk, caught, taught*
[ɑ] - *pot, cop, top*	

The entire data set resulted in 15 utterances of each vowel[1] (three words multiplied by five repetitions of each word) and a total of 165 different sentences (15 tokens of each vowel multiplied by 11 vowels).

Acoustic Measurement and Statistical Analysis

Vowels were measured for the acoustic parameters F1, F2, and duration. Duration measures for these CVC words were taken from the release of the first stop gap to the closure of the final stop gap. Formants were measured at the 25%, 50% and 75% points. This means that the duration of the vowel was calculated and then frequency measurements were taken one quarter of the way into the vowel (i.e. the 25% point), one half of the way into the vowel (i.e. the 50% point) and three quarters of the way into the vowel (i.e. the 75% point). This paper focuses on the F1 and F2 measurements from the 50% point because these were clear across all speakers and were highly consistent when random samples of the data were re-measured.

Acoustic measurements were analyzed via discriminant analysis; this is a multiple regression technique that examines a set of variables or predictors that serve to distinguish a set of categories. Independent parameter values are weighted to maximally distinguish separate categories. For this investigation, individual speakers were treated as separate case studies. The 11 *intended* vowels (American English vowels designated for the lexical items) served as the categories; parameter values (F1, F2 and duration) of the vowels *actually uttered* served as input to the model. The discriminant analysis essentially took the acoustic parameters of all vowels entered for an intended group and found a centroid for that group. It then determined how near or far the acoustic parameters for each uttered vowel were from that centroid. If the acoustic parameters of a spoken vowel were close to the centroid of the intended category, the discriminant analysis characterized them as *correct* matches. If the acoustic parameters of a spoken vowel were far from the centroid of the intended category (or closer to the centroid of an unintended category), they were characterized as being mismatched. In this respect, *intended* simply refers to the vowel phoneme that linguists consider to be in the particular word being pronounced. For example, in the word *keep* linguists consider the vowel phoneme to be /i/. Therefore /i/ is the intended category. It does not imply any knowledge on the part of the speaker as to what should be produced in a given English word. The output of the discriminant analysis is a classification matrix as illustrated in Figure 1 and Table 2. Figure 1 shows the F1, F2 plot of a *native speaker* producing instances of the intended vowel /i/ in the words *keep*, *peek* and *bead*. Table 2 shows how the discriminant analysis categorized each vowel uttered. Notice that 13 of the 15 vowels uttered in the words *keep, peak*, *bead* matched the centroid of the vowel /i/. Two instances were closer to the centroid of the vowel /ɪ/. The confusion matrix represented in Table 2 indicates this as 86.6% correct match for the vowel /i/ to its intended category.

Discriminant classifications were used in two types of analyses corresponding to the two perspectives of change discussed earlier. The first analysis considered the vowels of a nonnative speaker as a separate system and did not compare them to any external criteria. This allowed observation of change within a learner's system independent of native speaker norms. The second type of analysis used the centroids of a native speaker's vowels (male to male and female to female) as the criteria for evaluating the vowels uttered by a nonnative speaker. This made it possible to evaluate a learner's system in direct comparison to the target language.

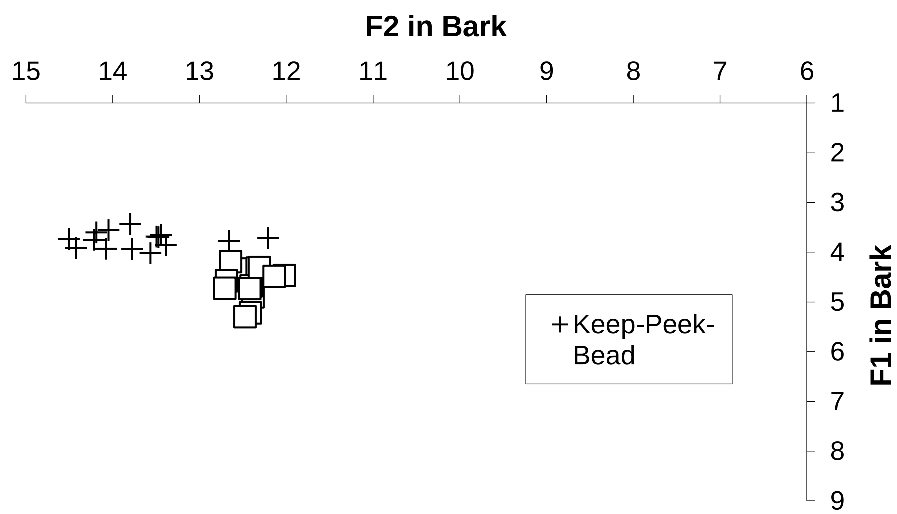

Figure 1. F1/F2 plot of native speaker producing words with /i/ and /ɪ/. The F1/F2 plot of a native speaker of English producing 15 words that contain the vowel /i/ and 15 words that contain the vowel /ɪ/. Note that F1 and F2 measurements have been converted to Bark from Hz. The Bark scale ranges from 1-24 and is a measure of frequency based on the critical bandwidths of hearing.

Table 2. Sample Classification Matrix for /i/ and /ɪ/

Intended Vowel	% correct	Classification				
		i	ɪ	e	ɛ	æ
i	86.66666	13	2	0	0	0
ɪ	73.3	0	11	2	2	0

NOTE: Classification matrix of a native speaker of English producing 15 items that contain the vowel /i/ and 15 items that contain the vowel /ɪ/. The data are the results of a discriminant analysis with F1 and F2 as the only input parameters.

RESULTS

To begin, we first look at the results of the native speakers. The native speakers in this study were essential for establishing baseline measurements for presenting a realistic picture of the target vowel system on these particular lexical items in these sentences, as evaluated by this particular statistical analysis[2]. The findings regarding the native speakers could be a separate paper, but a brief summary is given below.

1. Native speakers do not have perfect category matches of vowels.
2. Category matches within a single lexical item were better than matches across lexical items.
3. Native speakers exhibit allophonic variation that affects category matches.
4. Native speakers are not completely stable over time.

Evidence for these conclusions can be seen in Table 3 which shows the percent of correct category matches for the first native speaker[3] at Time 1.

Table 3. Overview of Category Matches at Time 1 for a Native Speaker

Percent Matched on F1, F2 and Duration		
Target Vowel	**Across Three Lexical Items**	**In a Single Lexical Item**
i	93.3 (14/15)	100 (5/5)
ɪ	33.3 (5/15)	100 (5/5)
e	92.8 (13/14)	100 (5/5)
ɛ	85.7 (12/14)	100 (5/5)
æ	53.3 (8/15)	100 (5/5)
ʌ	53.3 (8/15)	100 (5/5)
u	73.3 (11/15)	100 (5/5)
ʊ	66.6 (10/15)	100 (5/5)
o	60 (9/15)	80 (4/5)
ɔ	66.6 (10/15)	80 (4/5)
ɑ	100 (13/13)	100 (5/5)
Total %	70	96.3

NOTE: Percentage of correct category matches of one native speaker at one point in time with all three parameters entered into the discriminant analyses. This table also compares the percent of category matches of vowels uttered across lexical items as compared to vowels uttered in a single lexical item.

The first column in Table 3 shows the percent correct for each vowel uttered 15 times across three different lexical items (e.g. /i/ in *keep, bead* and *peek;* /ɪ/ in *pick*, *bit* and *kid*, and so forth). One can immediately see that, native speakers do not have perfect category matches for any of the vowels. The second column shows the results of the discriminant analyses of each vowel uttered only five times and in only one lexical item (e.g. / i **/** in *keep*; /ɪ/ in *pick*, and so forth). The category matches for the vowels are far better when uttered in only one lexical item. Expectations are that native speakers have clearly distinguished, if not perfectly distinguished, vowel groups. In fact, in much of the early research on vowels this is the case. Those studies, however, measured vowels in only one context (as in the classic hVd study by Peterson and Barney, 1952). This study and others like it have shown that the more varied the context, the less discrete the groupings become. One can also see that some vowels showed better category matches than others. The vowels /i/ and / ɑ /, for example, had consistently high category matches across the native speakers. The vowels /o/ and /ɔ/ had consistently lower category matches across the native speakers[4]. Additionally, the vowels /æ/ and /u/ showed clear allophonic variation, which in turn affected the classification percentages. When the lexical item *bad* was included in the analysis, the percentage of correct matches for the vowel /æ/ was only 53%. This number raised to 100% when *bad* was excluded (i.e. when it occurred in the items *pat* and *cat* only). This is likely due to the New York City pronunciation of raised /æ/ in certain contexts. Likewise, the vowel /u/ in the item *tube* caused a lower percent of correct category matches in this group because of the fronting of /u/ with preceding alveolars (see also Hillenbrand, Clark and Neary, 2001 for similar results). One final note about the native speakers is that they were not perfectly stable over time. Categories did not change by more than four matches across the period of one year in either of the native speakers. More importantly the groupings remained stable in that there was no evidence of vowel groups being added being added or eliminated.

Before turning to observations of change in the nonnative speakers, it should be noted that most of the nonnative speakers initially showed a five-vowel pattern when pronouncing the American English vowels (at least with respect to F1 and F2 plots). One speaker, however, showed few clear vowel groupings. She was the least advanced learner and was most likely struggling with the sentence elicitation task. Although it is not possible to report all of the data here, Table 4 provides an example of the initial category matches for one nonnative speaker. Note that the percent of correct category matches are shown both independently of and in direct comparison to the native speaker.

Table 4. Overview of Category Matches at Time 1 for a Nonnative Speaker

	Independently of the Native Speaker		**Matched to the Centroids of the Native Speaker**	
Target Vowel	**Across Three Lexical Items**	**In a Single Lexical Item**	**Across Three Lexical Items**	**In a Single Lexical Item**
i	0 (0/10)	60 (3/5)	60 (6/10)	80 (4/5)
ɪ	100 (15/15)	60 (3/5)	20 (3/15)	20 (1/5)
e	73.3 (11/15)	100 (5/5)	80 (12/15)	100 (5/5)
ɛ	64.2 (9/14)	100 (4/4)	35.7 (5/14)	100 (4/4)
æ	73.3 (11/15)	80 (4/5)	66.6 (10/15)	40 (2/5)
ʌ	46.6 (7/15)	60 (3/5)	66.6 (10/15)	40 (2/5)
u	77.7 (9/14)	60 (3/5)	50 (7/14)	60 (3/5)
ʊ	64.2 (9/14)	60 (3/5)	42.8 (6/14)	80 (4/5)
o	86.6 (13/15)	80 (4/5)	13.3 (2/15)	40 (2/5)
ɔ	33.3 (5/15)	60 (3/5)	26.6 (4/15)	0 (0/5)
ɑ	21.4 (3/14)	100 (5/5)	21.4 (3/14)	0 (0/5)
Total %	58	74	44	50

NOTE: Percentage of correct category matches of one nonnative speaker at one point in time with all three parameters entered into the discriminant analyses. This table compares the percent of category matches of vowels uttered across lexical items as compared to vowels uttered in a single lexical item. This table also evaluates the nonnative speaker's vowels independently of and in direct comparison to the native speaker's vowels.

The question of course is whether or not these vowel groups changed over time. Before describing change, two points must be made. First, this study looked at whether the relationship between phonemically relevant pairs changed over time[5]. We could ask, hypothetically, if the percent of category matches for /i/ changed over time, but the answer would meaningless unless we also looked at how it changed in relation to the other vowels, especially /ɪ/.

The second point is that this study did not begin with a specific hypothesis, but rather was intended to be descriptive. As changes emerged it became immediately apparent that many of them fell into patterns of linguistic change proposed earlier by Labov (1994). Labov referred to the major patterns of linguistic change as split, merger and shift. The next section describes specific instances of change observed in the nonnative speakers with respect to these major patterns.

Split

The first type of change observed in the nonnative speakers was *split*. According to Labov (1994), split is the process whereby a preexisting phoneme divides into distinct phonemes. This can occur when two allophones become distinctive upon the loss of a conditioning environment or it can occur when existing word classes divide in what Labov refers to as a *lexical split.* An example of change considered to be split can be seen in a nonnative speaker pronouncing target words containing the vowels /i/ and /ɪ/. This particular split involves the duration parameter and shows change when a nonnative speaker's vowels are analyzed independently of a native speaker's vowels. Table 5 shows that at Time 1, 24 of the 25 words uttered were closest to a single centroid and grouped together as a single vowel. By Time 3, seven of the vowels have become distinct (Figure 2).

The nonnative speaker initially had only one vowel with no distinction between the vowels /i/ and /ɪ/. After one year, the speaker used duration to make the vowels different. The speaker still has not associated the correct word with the correct target vowel.

Table 5. Split by Duration of /i/ and /ɪ/

	Time 1		**Time 2**		**Time 3**	
Target Vowel	**Match /# of Tokens F1/F2**	**Match /# of Tokens F1/F2 Duration**	**Match /# of Tokens F1/F2**	**Match /# of Tokens F1/F2 Duration**	**Match /# of Tokens F1/F2**	**Match /# of Tokens F1/F2 Duration**
i	-----	-----	-----	-----	i (2)	i (4)
N=10	ɪ (10)	ɪ (10)	ɪ (10)	ɪ (10)	ɪ (8)	ɪ (6)
% correct	0	0	0	0	20	40
ɪ	ɪ (14)	ɪ (15)	ɪ (15)	ɪ (14)	ɪ (15)	ɪ (12)
N=15	-----	-----	-----	i (1)	-----	i (3)
	e (1)	-----	-----	-----	-----	-----
% correct	93	100	100	93	100	80

NOTE: Discriminant classifications of a nonnative speaker producing /i/ and /ɪ/. Note that the word *match* refers to how individual vowels uttered matched the centroid of the nonnative speaker's own productions, indicating that this evaluation is independent of the native speaker norms. Columns are divided by time and then subdivided by which input parameters were used.

/i/

(7 at Time 3)

↗

/ɪ/

(24 at Time 1)

↘ /ɪ/

(18 at Time 3)

Figure 2. Illustration of split by duration

This case of split is interesting for two reasons. First, it supports the idea of interlanguage, a system unto itself unlike the native language or the target language. These duration differences indicate that a distinction was being learned but it was not the same distinction that the native speakers had. Second, it shows a relationship between perception and production. We know from previous studies that nonnative listeners use duration to distinguish some sounds even when native listeners do not. Bohn (1995) found that while English listeners relied almost entirely on spectral cues to identify the stimuli on the English *beat-bit* continuum, German and Spanish speakers relied heavily on duration cues and Mandarin speakers relied almost exclusively on duration cues (p. 299). This nonnative Spanish speaker relied on duration to split a single vowel grouping of /i/ and /ɪ/ into two vowel groups (whereas the native speakers in the study made a spectral distinction between these vowels). Although we do not have perception data on these particular Spanish speakers, it is interesting to see the similarities between their production and previous perception studies.

Although a few other cases of split were found, it did not occur frequently. Labov (1994) notes that split is a relatively rare linguistic change. Briére (1966) found that *divergence* (when a single sound in the native language must split into two contrastive sounds in the target language) is one of the more difficult patterns to acquire. In this study, split was often accompanied by a merger between another pair thereby preserving the number of original phonemes in the learner's system. Furthermore, the cases of split observed did not always match the native speakers' norms.

Merger

The second type of change observed in the nonnative speakers was *merger*. According to Labov (1994) merger is the process whereby a phoneme moves in the F1/ F2 space but surrounding vowels do not move. The vowel that is moving essentially encroaches into the space of another vowel and the two become one. Labov contrasts splits and mergers in the following way: Splits involve movement into an *unoccupied* space and *create* distinction; mergers involve movement into an *occupied* space and *eliminate* distinction. Table 6 shows a merger when a nonnative speaker's pronunciation of the target vowel /Λ/ was compared to the centroid of a native speaker's productions. Notice that at Time 1, the nonnative speaker has some utterances that actually matched the native speaker's centroid for /Λ/. By Time 3 they have virtually disappeared and almost all match the centroid of the native speaker's /ɑ/.

Table 6. Formant Merger of /ʌ/ and /a/

	Time 1		**Time 2**		**Time 3**	
Target Vowel	**NS Match /# of Tokens F1/F2**	**NS Match /# of Tokens F1/F2 Duration**	**NS Match /# of Tokens F1/F2**	**NS Match /# of Tokens F1/F2 Duration**	**NS Match /# of Tokens F1/F2**	**NS Match /# of Tokens F1/F2 Duration**
ʌ	ʌ (4)	ʌ (5)	-----	-----	-----	ʌ (1)
N=9	ɑ (5)	ɑ (4)	ɑ (8)	ɑ (8)	ɑ (9)	ɑ (7)
	-----	-----	ɛ (1)	ɛ (1)	-----	ɛ (1)
% correct	44	55	0	0	0	11

NOTE: Discriminant classifications of a nonnative speaker producing target words with the vowel /ʌ/. NS match refers to how many of the vowels uttered by the nonnative speaker are near the native speaker's centroid for /ʌ/. Columns are divided by time and then subdivided by which input parameters were used.

Shift

The third type of change observed in the nonnative speakers was shift. Shift refers to a simple movement of a vowel in the F1/F2 space which neither creates nor eliminates phonemic distinction. Table 7 shows an example of shift when the nonnative speaker's production of /e/ and /ɛ/ were compared to a native speaker's centroids.

Table 7. Formant Shift of a Mid Front Vowel Grouping

	Time 1		Time 2		Time 3	
Target Vowel	**NS Match /# of Tokens F1/F2**	**NS Match /# of Tokens F1/F2 Duration**	**NS Match /# of Tokens F1/F2**	**NS Match /# of Tokens F1/F2 Duration**	**NS Match /# of Tokens F1/F2**	**NS Match /# of Tokens F1/F2 Duration**
e	e (9)	e (12)	e (4)	e (11)	e (5)	e (7)
	ε (6)	ε (2)	ε (11)	ε (3)	ε (10)	ε (8)
N=15	-----	ɪ (1)	-----	ɪ (1)	-----	-----
% correct	60	80	26.6	73.3	33.3	46.6
ε	ε (5)	ε (5)	ε (12)	ε (11)	ε(13)	ε (10)
	e (7)	e (6)	e (1)	e (2)	e (1)	e (4)
N=14	ɪ (2)	ɪ (3)	ɪ (1)	ɪ (1)	-----	-----
% correct	36.7	35.7	85.7	78.5	92.8	71.4

NOTE: Discriminant classifications of a nonnative speaker producing target words with the vowels /e/ and /ε/. *NS match* refers to how many of the vowels uttered by the nonnative speaker are near the native speaker's centroids for /e/ and /ε/. Columns are divided by time and then subdivided by which input parameters were used.

At Time 1, these vowels were poorly distinguished, but the majority of the tokens matched the native speaker's centroid for /e/. By Time 3, the vowels were still poorly distinguished, but the majority matched the native speaker's centroid for /ε/. This change is considered to be shift because a single vowel grouping did not split or merge; rather moved collectively to a different position in the F1, F2 space (as illustrated in Figure 3).

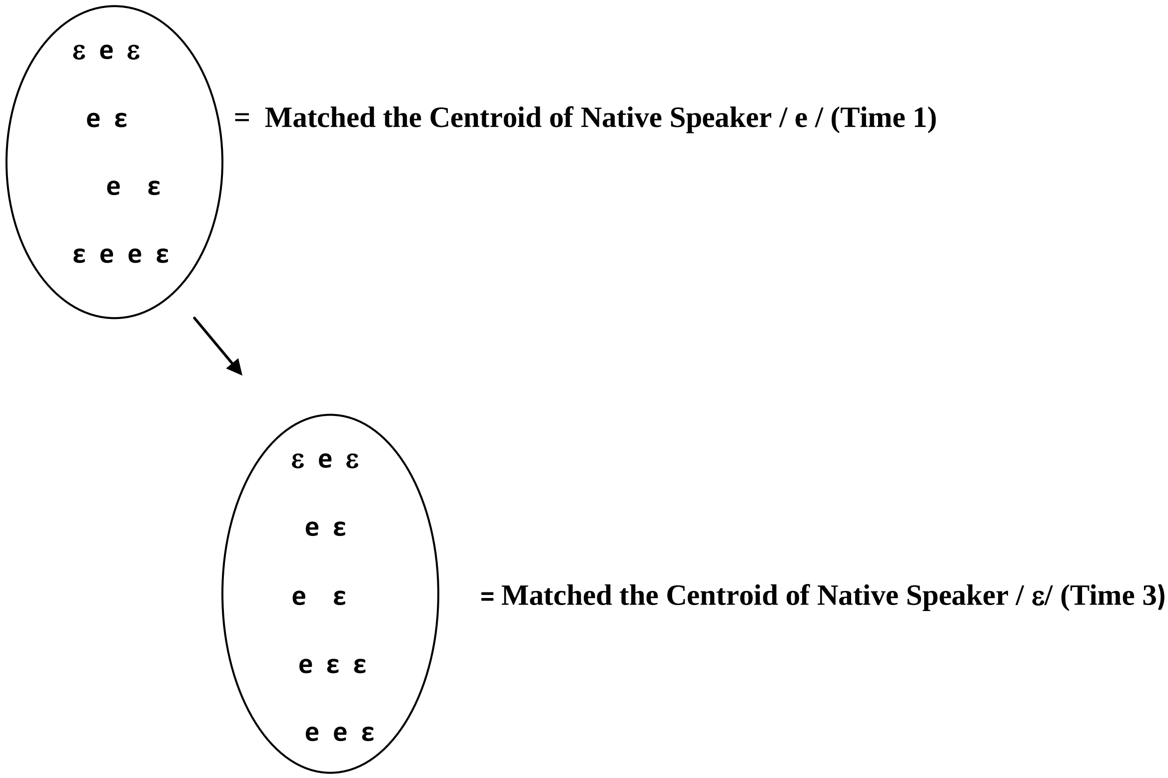

Figure 3. Shift of /e/ to /ε/. Shift of a mid front vowel grouping. Note that at Time 1, the majority of the utterances matched the native speaker's centroids for /e/. By Time 3, the majority of utterances matched the native speaker's centroid for /ε/.

DISCUSSION

This study has looked at L2 acquisition in a subsystem of the entire phonology as opposed to looking at individual sounds or learning paradigms. It also attempted to describe change over time independently of and in direct comparison to the target language. Findings indicate that change exhibited by L2 learners are in many cases similar to those observed in dialectal and historical change (namely splits, mergers and shifts)[6].

Additional findings of the study have implications for research and teaching. First, since contrastive pairs that seemingly share characteristics do not exhibit the same types of change, L2 acquisition should not be studied in terms of pairs extracted from the entire system. Likewise, since changes in the system are not always unilateral teachers should use whole system exercises and not minimal pair type exercises alone. This is especially true since there was a general tendency among the speakers in this study to maintain the original number of vowels in the native language system when pronouncing the target language system. Evidence of this was seen in cases where a split in one area was accompanied by a merger in another. Additionally, since change occurred in the interlanguage system that did not necessarily match native speaker norms, L2 acquisition should not be studied solely with respect of movement towards target but in terms of movement or change in general. Researchers and language teachers should evaluate all learning not just that which achieves the target. Finally, since native speakers overlap, change and do not show perfect category matches for vowels across lexical items, researchers and teachers should acknowledge the actual input as opposed to an idealized input.

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NOTES

[1] Various items were excluded from each speaker's data if they were judged to have been misread, could not be measured, or otherwise not analyzable. All data tables therefore show both percentages and raw scores.
[2] Results of vowel studies vary with respect to the context in which the vowels are couched (Bradlow, 1995; Hillenbrand, Clark and Neary, 2001), the point or points at which the vowels are measured, and the particular dialect of the speakers (Hillenbrand, Getty, Clark &Wheeler, 1995).
[3] For all the data obtained for the native and nonnative speakers please refer to Gulinello (2009).
[4] Perhaps this is due to the New York pronunciation of the vowel /ɔ/ or perhaps other parameters are needed to distinguish these vowels.
[5] A limitation of the study is the incompatibility of methodologies and theoretical frameworks. This study exemplifies such an incompatibility. The methodology collected acoustic data (F1, F2 and duration measurements) and analyzed them via a multiple linear regression technique called discriminant analysis This method of analysis requires each phoneme to be viewed as an atomic unit devoid of internal structure, a requirement that is in direct conflict with virtually all modern phonological theories. Phonological theories view features, not phonemes, as the atomic units. In particular, this study is an attempt to view the evolution of learner's vowel inventories as changes in a system of contrasts, a perspective which directly entails a featural analysis. The reader should understand that this gap is an artifact of the choice of discriminant analysis as a statistical method, not a theoretical claim on the part of the author. I am grateful to Charles Cairns for pointing this out.
[6] The acquisition of the orthography presents other unique patterns of change which, for space considerations, cannot be addressed here

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