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The discriminability of nearly merged sounds

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ABSTRACT

In a near-merger, speakers produce two contrasting words differently, without reliably being able to discern the contrast in their own speech or in the speech of others. Acoustic measurements typically reveal small differences between the elements of near-merged minimal pairs along several acoustic dimensions. We argue that statistical evaluation of the potential distinctiveness of these near-merged elements must simultaneously take into account all of these dimensions. For this reason, discriminant analysis is used to assess the differences between near-merged/il–ɪl/, /el–ɛl/, and /ul–ʊl/ for five Utah speakers. In contrast with independent univariate analyses of variance of F1, F2, f_0, and spectral slope, the multivariate discriminant analyses suggest that all three contrasts are preserved by all five speakers. However, homophones like *heel* and *heal* are not distinguished by the discriminant analyses. Discriminant analysis is thus a powerful technique for assessing whether a reliable basis exists for the claim that two potentially contrastive items are in fact distinctive.

The phenomenon of near-merger in language change has gained increasing attention in recent years, but it is still not very well understood. In near-mergers, two sounds which were originally distinct appear at one synchronic language stage to have merged completely; however, at a later stage the two sounds are again distinct. The paradigm case of such a near-merger is that of Early Modern English reflexes of Middle English */ɛ̄/ (as in *meat*), which

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first appears to have merged with reflexes of */ā/ (as in *mate*), but which in Modern English has merged instead with reflexes of */ē/ (as in *meet*) (Faber, Di Paolo, & Best, 1994; Harris, 1985; Labov, 1974). The most plausible diachronic account is that the original merger was an illusion (similarly, Nunberg, 1980). Indeed, in present-day near-mergers, as reviewed by Labov, Karen, and Miller (1991) and by Labov (1994:Part C), it is often the case that speakers are demonstrably unaware of small, but reliable acoustic differences that they equally demonstrably produce. As Labov noted, near-mergers present a challenge for linguistic theory, in that it is unclear how such seemingly imperceptible differences could be learned. Yet, if such differences are learned and if they are observed, it must be that the speakers for whom they are observed did in fact learn them—they must have been perceptible to these speakers at some point in the process of language acquisition (see Faber, Di Paolo, & Best, 1995, for details). In the present article, our interest lies in the development of an appropriate framework to describe the small, but reliable differences among speech sounds of the sort that characterize near-mergers.

In an earlier study (Di Paolo & Faber, 1990), we examined the near-merger of tense and lax vowels before /l/ in younger speakers in the Salt Lake Valley of Utah.[1] For many, although not all, speakers in this area, formant differences between the vowels in, for example, *heel* and *hill* were at best minimal, at least in formal word-list style (laboratory speech).[2] Nor were there consistent differences in duration or in f_0. There were, however, consistent, albeit small, differences in spectral slope, amplitude level of f_0 (L0) minus amplitude level of F1 (L1), which we referred to as VQI. The tense vowels had more prominent f_0 relative to F1 than the lax vowels. Just as differences in formant frequency reflect articulatory differences in the configuration of the supralaryngeal vocal tract, differences in spectral slope in vowels with the same formant frequencies reflect differences in laryngeal configuration (Ladefoged, 1983; Stevens, 1988, 1989). The tense vowels are breathy, while the lax vowels are creaky. In other words, the glottis is open for a larger proportion of the duty cycle in tense vowels than in lax vowels. Our suggestion was that these differences in spectral slope suffice to distinguish tense from lax vowels before /l/ in Utah.

Like most studies of vowel acoustics, our previous study simply equated vowel distinctiveness with distinctiveness along a single measurable dimension. This is not a necessary equation. If we posit a multidimensional vowel space whose axes represent, perhaps, F1, F2, f_0, spectral slope, and duration, it is possible to imagine two vowel nuclei which occupy distinct regions of this space, but are not well separated along any one of its axes. In such a case, the two vowels would be distinct; however, ordinary analysis techniques, techniques that treat the multiple dimensions of the vowel space in quasi-independent fashion, would not uncover this distinctiveness. In the current study, we use discriminant analysis, a statistical technique for assessing the extent to which multiple parameters serve to distinguish groups of items (Klecka, 1980). This technique has previously been applied to linguistic data by Port and Crawford (1989) in a study of German final devoicing; Sussman (1991), Sussman, McCaffrey, and Matthews (1991), and Fowler (1994) in studies of English stop consonant place of articulation; and Johnson, Ladefoged, and Lindau (1993) in a study of vowel production. Port and Crawford measured vowel duration, final stop closure duration, stop burst duration, and number of glottal pulses in the final stop closure in three minimal pairs differing in underlying stop voicing produced by five German speakers. In separate ANOVAs for each measure, only stop burst duration varied significantly according to underlying stop voicing. Nevertheless, the optimal discriminant function utilized all of the measured variables with the exception of number of glottal pulses in the final stop closure. That is, variables, which by themselves did not differentiate the two categories (i.e., final "voiced" and "voiceless" stops), did contribute to a multidimensional differentiation of the categories. As Port and Crawford stressed, this simultaneous reference to multiple weak cues may provide a better analog to actual speech perception than traditional analysis in terms of single strong cues.

In the present study, we extend our previous research on the distinction between tense and lax vowels before /l/ in Utah English. In our previous research (Di Paolo & Faber, 1990), we suggested that, on the basis of acoustic measurements and a perceptual labeling study, small differences in spectral slope sufficed to distinguish cognate tense and lax vowels before /l/. In the present study, we assess multidimensional vowel contrast by means of discriminant analysis. In the earlier study we did not include any cases in which contrast was not expected; therefore, we had no way of determining whether our techniques were too sensitive. In the present study, we include a number of pairs of homophones in order to provide a baseline of clear lack of contrast.[3] This inclusion of homophones provides us with a criterion for assessing phonetic distance. If *heel* and *hill* are acoustically more distinct than *heel* and *heal*,[4] this will lend support to a model of sound change in which small, but significant differences serve to preserve a contrast while some acoustic parameters are changing. If, on the other hand, the distinction between *heel* and *hill* is comparable to that between *heel* and *heal*, such a view of sound change will not be supported.

In addition, our previous study treated F1, F2, f_0, and spectral slope as independently controlled acoustic parameters, when, of course, they are not. While F1 and F2 may each reflect different aspects of the vocal tract configuration during the articulation of a vowel, a single set of articulatory maneuvers involving tongue and lip position controls both simultaneously. Likewise, the amplitude of F1 (L1) may depend both on its frequency and on the frequency of higher formants (Fant, 1956); a finding of significant variation in both F1 frequency and in spectral slope (L0–L1) may reflect this dependency, rather than variation in the amplitude of f_0 (L0) resulting from variation in laryngeal configuration. If laryngeal configuration is of interest, as it is in the present study, two solutions to this non-independence problem are available. The first involves attempting an independent measure of glottal configuration, either through inverse filtering of the speech signal (Javkin, Antoñanzas-Barroso, & Maddieson, 1987; Löfqvist, 1991) or through electroglottography. These techniques are most often used to study speaker-characteristic, pervasive voice qualities, rather than time-varying phonological characteristics. In particular, inverse filtering is inappropriate for vowels in which the F1 resonance is low enough in frequency to include the fundamental, and, as a result, it is inappropriate for the study of potential laryngeal configuration differences in high vowels. Likewise, electroglottography, which measures the changing rate of electrical current transmission across the glottis as the vocal folds open and close, is very sensitive to correct electrode placement, which is easiest to achieve in adult males with very little neck fat (Colton & Conture, 1990), and it is potentially sensitive to variation among vowels in overall larynx height. The second solution to the non-independence problem is a statistical one. Rather than analyzing each parameter independently, discriminant analysis provides a global treatment. The independent contribution of each variable to the overall set of discriminant functions is assessed. If two variables are perfectly correlated, the second variable makes no independent contribution to the discriminant functions over and above that made by the first. Thus, to the extent that both F1 and spectral slope contribute to a set of discriminant functions, it can be assumed that some component of the variance in spectral slope is not correlated with F1 and *ex hypothesi* reflects underlying laryngeal configuration.

METHODS

The 8 subjects (5 from Utah and, for purposes of comparison, 3 from Connecticut), read eight randomizations of the word list in Table 1. Utah subjects were recruited from introductory linguistics classes at the University of Utah and were paid $10.00 for their participation. Connecticut subjects were recruited through acquaintance networks at Yale and Wesleyan Universities; the Wesleyan subjects were paid $6.00 for their participation, but the Yale subject, a research colleague, was not paid. For the Utah subjects (but not the Connecticut subjects), laryngeal vibration was recorded directly via a small accelerometer attached with adhesive on the external neck surface opposite the thyroid lamina. These laryngeal signals were not analyzed in the present investigation. Further demographic details about the subjects are given in Table 2. Filler words were used at the beginning and end of each column, and subjects were instructed to read slowly, with a two-beat pause after each word. All material was recorded in sound-treated rooms on a cassette tape recorder. In all, each speaker produced 440 tokens. Tokens for 4 of the Utah subjects and for all 3 Connecticut subjects were digitized at a 10 kHz sampling rate (12 bit quantization, with preemphasis) using the Haskins Laboratories PCM system. Tokens for the other Utah subject were digitized at a 8 kHz sampling rate (16 bit quantization, with preemphasis) using an

TABLE 1. *Words used in current study*

heed	*heal*	*food*	*fool*
he'd	*heel*	*poop*	*pool*
peep	*he'll*	*hood*	*full*
	peal	*cook*	*pull*
	peel	*hoed*	*hole*
hid	*hill*	*pope*	*whole*
pip	*pill*		*pole*
hayed	*hale*		*poll*
tape	*hail*	*HUD*	*hull*
	pail	*pup*	*cull*
	pale	*hawed*	*hall*
head	*hell*	*talk*	*haul*
pep	*pell*		*pall*
pap	*pal*		*Paul*
had	*Hal*	*cod*	*Col*
		pop	*pol*
			Sol

TABLE 2. *Subject characteristics*

Subject	Sex	Age	Residence
C1	female	late teens	Middletown (central Connecticut)
C2	female	late 20s	Stratford (southwest Connecticut)
C4	male	early 20s	Branford (south-central Connecticut)
U5	male	late 20s	Ephraim (central Utah)
U6	female	early 20s	Salt Lake City
U8	female	mid 30s	Davis County (north of Salt Lake City)
U9	female	late teens	Salt Lake City
U12	male	early 20s	Salt Lake City

Audiomedia A-to-D board on a Macintosh IIsi microcomputer at the University of Utah.[5] Acoustic measurements were made at three points during each vowel; an early point, the approximate midpoint, and a late point. An effort was made to avoid, as far as possible, formant transitions out of and into the adjacent consonants. With the /l/-final words, this was, of course, impossible, since the influence of the /l/ may extend through the entire vowel; all third measurements in /l/-final words were made in the vocalic portion of the word, and not in the /l/. In addition, one of the Connecticut speakers (C4) had extremely long transitions into /d/; these transitions started in some instances as early as the vowel midpoint, so that many of his late measurements reflected the influence of the following /d/. We measured four parameters: F1, F2, f_0, and VQI (spectral slope: L0–L1), for a total of 5280 data points per speaker.[6]

For each speaker, the following analyses took place. Each parameter served in turn as the dependent variable for an analysis of variance, with vowel identity and final consonant serving as independent, between-tokens factors and measurement location as a repeated, within-token factor. (In these analyses, all factors were fixed, except, of course, for token.) Given the highly significant main effects for final consonant and measurement location, and the particular interest of this study in vowel distinctions before /l/, separate ANOVAs were then performed on the subset of /l/-final words at each measurement location using vowel identity as the independent variable. Then, each parameter was standardized using z-transforms.[7] The transformed parameter values served as input for three separate discriminant analyses for each speaker (the single-speaker analyses). In the first of these analyses, target word was the grouping variable, and the 12 acoustic measures (4 parameters × 3 measurement locations) were the dependent variables. In the second analysis, VC rhyme (e.g., /id/, /ul/, /op/, etc.) was the grouping variable, and the 12 acoustic measures were, as in the first analysis, the dependent variables. The third analysis was like the second, except that discriminant functions were calculated for the /l/-final words only. Finally, additional word and VC rhyme analyses were performed in which productions by each of the Utah female subjects (U6, U8, and U9) were classified according to discriminant functions derived from productions by the other two Utah females and productions by the Connecticut female (C2) from whom we had complete data; these are the two-speaker analyses. The two-speaker analyses were restricted to the female subjects because of the suggestion (e.g., Henton, 1992; Johnson, 1989) that female speakers' vowel spaces are proportionally larger than males', even when formant frequencies are normalized to the same range of the frequency scale. All discriminant analyses were done using BMDP program 7M (Dixon, 1988), with all dependent variables forced into the discriminant function.[8]

Discriminant analysis constructs an n-dimensional coordinate space, corresponding to the input variables (see Klecka, 1980, for details).[9] This space is rotated so as to maximize the amount of variation on a minimum number of axes and to form a space of smaller dimension than the original. These derived axes are referred to as canonical variables or discriminant functions. The mean coordinates for each group within the rotated coordinate space are calculated.[10] The overall significance of the discriminant analysis reflects the extent to which the input groups occupy disparate regions of the coordinate space. The more distinct and non-overlapping the input groups actually are, the higher the significance level. The geometric distance in the coordinate space between each token and every group mean is calculated, and the token is assigned to the group to which it is closest, regardless of its original group membership. In this calculation, the token being classified is excluded from the group means to which it is being compared; thus, our classifications are made by the jackknife method. The extent to which specific tokens are classified into their original groups allows, in the present instance, assessment of homophony and even potential sound change. Second, for each pair of group means, a partial *F* value is calculated, on the basis of which the likelihood can be computed that the given pairs of groups are distinct in the derived coordinate space. This assessment complements the one arrived at through examination of the classification matrices. In cases like the present, in which the number of pairwise comparisons proliferates (1,485 in the case of the word analyses, 508 in the case of the VC rhyme analyses, and 55 in the case of the rhyme, /l/ words only analysis), extreme caution must be exercised in interpreting these partial *F* values, due to the increased likelihood of Type I error. Finally, it provides partial *F* values for each of the input variables, on the basis of which the relative strengths of their contributions to the derivation of the canonical variables can be ranked.

RESULTS

Prior to presenting the results of the main analyses, we first describe the speakers' productions in fairly conventional terms; we also present the results of our univariate analyses of variance. After outlining the sorts of results that might be expected in the single-speaker discriminant analyses, we present the results of these analyses. The results of the analyses with target word as the grouping factor show that the acoustic measures we made are in the aggregate sufficient to distinguish among words with different vowel nuclei, even though they do not distinguish between homophones. They also differentiate words with nearly merged nuclei. The analyses with VC rhyme as the grouping factor confirm that our acoustic measures distinguish among different vowels in general and between the nearly merged rhymes /il/–/ɪl/, /ul/–/ʊl/, and /el/–/ɛl/ in particular. In addition, an examination of the canonical variables derived by these discriminant analyses provides some indication of how these contrasts are implemented. Then, we discuss the two-speaker analyses, which show that, in general, the Utah speakers' productions are better classified by discriminant analyses trained on the other Utah speakers' productions than by analyses trained on the Connecticut speaker's productions.

Univariate analyses

Figure 1 shows the vowels before /d/ for C1 in F1/F2 space; Figure 2 shows the same vowels for U6. Several features of these vowel spaces are worth noting. For both of these young female speakers, /u/ and /ʊ/ have much higher F2 than would be expected on the basis of Peterson and Barney (1952) and other similar studies.[11] For both speakers, F2 decreases throughout much of /u/ and increases throughout /ʊ/. And for both speakers, /o/ decreases throughout in both F1 and F2, although there is more formant movement for the Connecticut speaker than for the Utah speaker. The single most salient

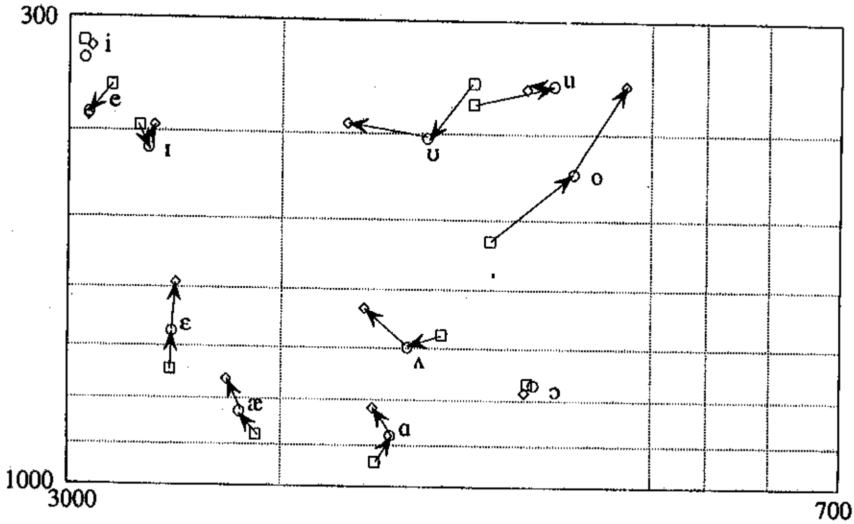

FIGURE 1. Formant tracks for C1's vowels before /d/.

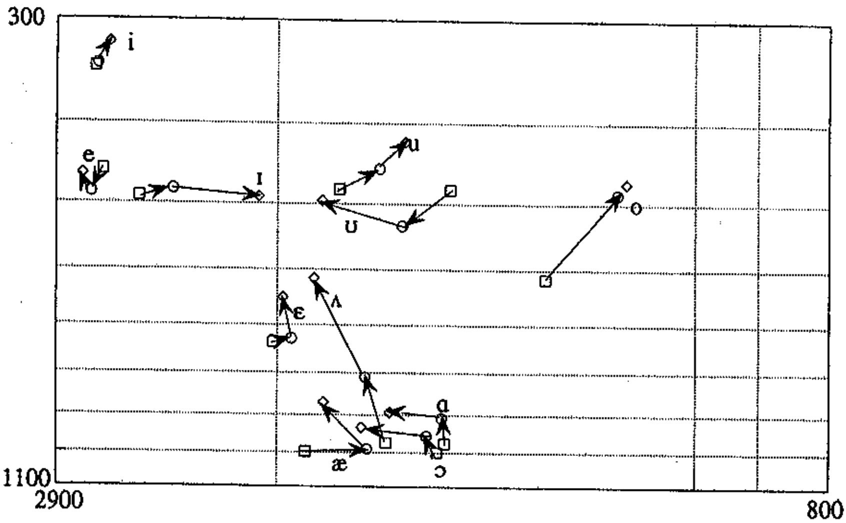

FIGURE 2. Formant tracks for U6's vowels before /d/.

difference between the two speakers lies in the low vowels. For the Connecticut speaker in Figure 1, /ɑ/, /ɔ/, and /ʌ/ are quite distinct, whereas for the Utah speaker in Figure 2, /ɑ/ and /ɔ/ have similar, but not overlapping formant tracks,[12] and /ʌ/ starts in the same region, rising to approach /ɛ/.

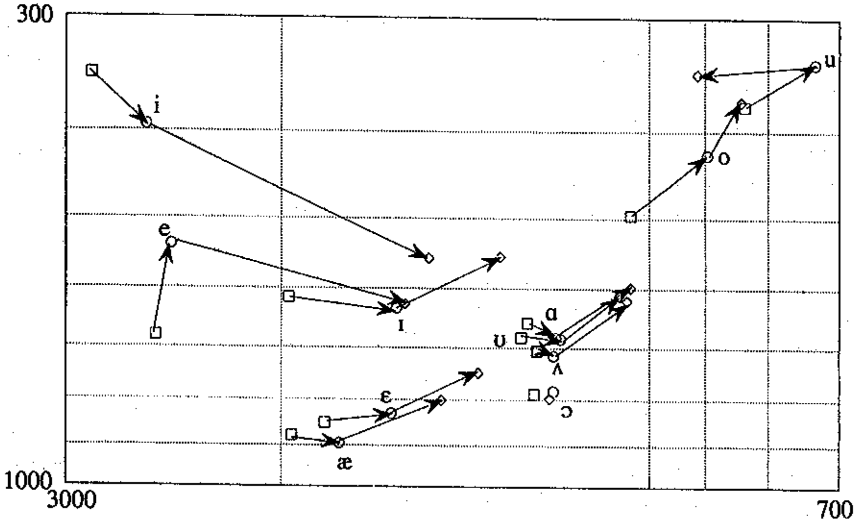

FIGURE 3. Formant tracks for C1's vowels before /l/.

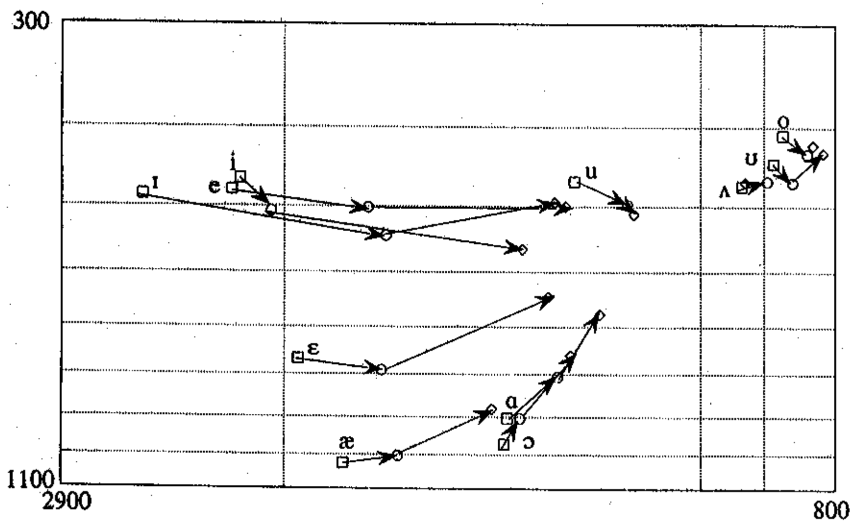

FIGURE 4. Formant tracks for U6's vowels before /l/.

Figures 3 and 4 show the vowels for the same speakers before /l/. Here again, there are several features common to the two dialect areas: namely, the tendency to lower F2 for vowels before /l/, and the fact that /u/ and /ʊ/ have much lower F2 before /l/ than in other contexts. The overlap of /ʌl/

and /ʊl/ in Figure 3 is less typical and may be a conservative feature.[13] The three-way approximation of /ol/, /ʌl/ and /ʊl/ in Figure 4 is typical of some younger speakers in the Salt Lake Valley. Similarly, the fact that /ɪl/ starts with higher F2 than /il/ is not uncommon in younger Utah speakers. Like many of the speakers described in Di Paolo and Faber (1990), this speaker has fairly parallel formant tracks for /il/ and /ɪl/. She differs from other younger speakers in maintaining a clear distinction between /ul/ and /ʊl/, perhaps because /ul/ has an unusually high F2 for this context. She is unusual also in having /el/ in the same area as /il/ and /ɪl/: some speakers have /el/ in the same area as /ɛl/; others have /el/ lower than /il/ and /ɪl/, but still distinct from /ɛl/, which in turn heavily overlaps with /æl/.

Overall, our ANOVAs for all subjects show significant differences among vowels in all of the parameters measured. In addition to the formant differences, all of the speakers clearly have vowel-related differences in f_0 regardless of the following consonant. The speakers differ, however, in the range of f_0 variation and in the relative ranking of vowels in f_0. There are also significant differences among vowels in VQI, but it is unclear how to interpret these differences, since the amplitude of F1 (L1) in a particular instance depends partly on F1 frequency; so VQI (L0–L1) will depend on F1 frequency as well as on underlying laryngeal configuration. However, when the speakers' vowels before /d/ are ranked from breathy to creaky, the order does not match the order predictable on the basis of Fant's (1956) L1 levels. Thus, our variation in VQI results from variation in L0 as well as from variation in L1.

The separate ANOVAs on the vowels in /l/-final words at each measurement point, with target vowel identity as the independent variable likewise show highly significant ($p \leq .0001$) differences among vowels on all four dimensions, but post-hoc comparisons (Bonferroni/Dunn) of the specific contrasts of interest, summarized in Table 3, reveal a rather murky picture. For the Connecticut speakers, all three contrasts are maintained. Likewise in Utah, for U5, all 3 contrasts are maintained, and for U8, the oldest speaker in our sample, /il/–/ɪl/ and /el/–/ɛl/ are only distinct in one parameter at one measurement point; /ul/–/ʊl/ are not at all distinct. For U6, U9, and U12, all three are maintained, but in some cases in only one parameter at one measurement point. So, U6's /il/–/ɪl/ are distinct only in F2 at the early measurement point, and her /ul/–/ʊl/ are only distinct in F2 at all measurement points. U12's /ul/–/ʊl/ are distinct only in F1, and only at the first measurement point. In virtually all of these cases, the contrasting vowel pairs differ only in F1 and/or F2. VQI and f_0 systematically differentiate tense–lax cognates before /l/ only for C2, U8, and U5, and the relevant pairs (with the exception of U8's /il/–/ɪl/) also differ in F1 and/or F2.

Multivariate analyses

Before we describe the results of the discriminant analyses, we must lay out the sorts of results that we would expect. First of all, unambiguous misread-

TABLE 3. *Summary of Bonferroni/Dunn test for selected contrasts from ANOVAs for /l/-final words at three measurement points*

		U5	U6	U8	U9	U12	C2	C4	C1
/i/–/ɪ/	F1	<.0001				<.0001	<.0001	<.0001	<.0001
		<.0001			<.0001	.0002	<.0001	<.0001	<.0001
		<.0001							
	F2	<.0001	<.0001		<.0001	<.0001	<.0001	<.0001	<.0001
		<.0001			<.0001	<.0001	<.0001	<.0001	<.0001
		<.0001							.0003
	f_0								—
									—
							<.0001		—
	VQI	<.0001		.0005			<.0001		—
		<.0001					<.0001		—
									—
/e/–/ɛ/	F1	<.0001	<.0001		<.0001	<.0001	<.0001	<.0001	<.0001
		<.0001	<.0001		<.0001		<.0001	<.0001	<.0001
		<.0001							.0004
	F2	<.0001			<.0001	<.0001	<.0001	<.0001	<.0001
		<.0001	<.0001	.0002	<.0001	<.0001	<.0001	<.0001	<.0001
		<.0001			<.0001			.0002	
	f_0								—
									—
							<.0001		—
	VQI								—
									—
							<.0001		—
/u/–/ʊ/	F1	<.0001			<.0001	<.0001	<.0001	<.0001	<.0001
		<.0001			<.0001		<.0001	<.0001	<.0001
									<.0001
	F2		<.0001		<.0001		<.0001	<.0001	<.0001
			<.0001				<.0001	<.0001	<.0001
			<.0001						
	f_0	<.0001					<.0001		—
							<.0001		—
									—
	VQI	<.0001					<.0001		—
		<.0001					<.0001		—
									—

Note: Items left blank indicate $p > .05$. The first row in each cell reports on the early measurement point, the second row on the middle measurement point, and the third row on the late measurement point. Because of recording problems, only formant analysis is available for C1.

ings would be classified in accord with listeners' perceptions. For example, one subject fairly consistently read *peep* as *pep*; these tokens would be classified by the discriminant analysis as *pep* or *head* rather than *peep* or *heed*. Second, we would expect homophones like *peal* and *peel* to be confused with each other as often as they are classified correctly. A priori predictions regarding non-homophones with the "same" vowel are less clear; while our measurements aimed at avoiding formant transitions out of and into adjacent consonants, we may not always have been successful. Furthermore, it is not clear that the influence of context consonants on vowels is restricted to the transitions (e.g., Sussman, 1991). As a result, it is not clear to what extent *heel* and *peel* would be confused. However, it is expected that they would be confused with each other more than with other words. In addition, words with different vowels should have different patterns of confusion. Thus, if two words have different patterns of confusion, we can infer that they have different vowel targets. And, given that there is a considerable amount of variation among speakers in the position of vowels before /l/ in formant space, we should not be surprised to find inter-speaker variation in patterns of distinctiveness.

Analyses with word as the grouping factor. All of these predictions were clearly borne out by the single-speaker analyses using word as the grouping factor. All misreadings were classified in accord with listeners' perception and were excluded from subsequent analyses. Furthermore, on the basis of the unexpected classification of one token (*Hal* as *hill*), we were able to identify and correct a measurement error. Table 4 shows the discriminant analyses' classification of /l/-final homophones.[14] Overall, tokens of *hail* and *hale*, for example, were classified as *hail* or *hale* ("self" or "homophone") more often than they were classified as *pale* or *pail* ("same rhyme"); in addition, they were classified as *pail* or *pale* more often than they were classified as *hayed*, *hill*, *pip*, or *food* ("different rhyme"). The "different rhyme" category includes classification of *heel* as *heed* or as *hill*. In spite of the fact that discriminant analysis shows cognate tense–lax vowel pairs before /l/ to be distinct in both dialect areas, there are different classification patterns for speakers in the area undergoing sound change from those for speakers in the area not undergoing change. In particular, the larger number of "different rhyme" classifications for Utah speakers than for Connecticut speakers reflects the fact that some Utah tokens of *heel* were classified as *hill*, and vice versa.

An examination of the patterns of classification for individual words reveals that there are indeed different patterns of confusion for cognate tense and lax vowels. For example, as shown in Table 5, 3 tokens each of U8's *fool* and *pool* were identified as *full* or *pull*, compared with 5 tokens each of *full* and *pull*; despite the substantial confusion, the patterns of confusion remained distinct. (The complete classification summaries are presented in Appendices 1–3.) For all three vowel locations, the Connecticut speakers' words are somewhat more accurately classified than the Utah speakers' words, and the sorts of "misclassifications" are different. For example, both the Connecticut speakers have tokens that are classified at a different general location (e.g., high front classified as mid front). However, for Connect-

TABLE 4. *Summary of single-speaker target word discriminant analyses' classifications of members of /l/-final homophone sets, expressed in percent of words in homophone sets receiving a particular classification*

Subject	*N*	Same Rhyme			Total Same	Different Rhyme
		Self	Homophone	Same Rhyme		
U5	134	21.64	19.40	44.78	85.82	14.18
U6	136	25.74	20.59	32.35	78.68	21.32
U8	135	25.19	28.89	28.15	82.23	17.79
U9	129	34.88	23.26	23.26	81.40	18.60
U12	133	24.06	26.31	34.59	84.96	15.04
C2	136	28.68	38.24	29.41	96.33	3.68
C4	120	37.50	22.50	32.50	92.50	6.67

Note: Clear speaker misreadings have been excluded.

TABLE 5. *Classification of words with high back vowels before /l/ from single-speaker target word discriminant analyses, for subject U8*

Classification/ Target	*fool*	*pool*	*full*	*pull*	Other
fool	3	1	1	2	1
pool	2	3	2	1	
full	1	1	2	3	1
pull	1	2	2	3	

Note: Figures represent the number of tokens (out of 8) for which each classification occurred. Rows represent U8's targets, and columns the classifications by the discriminant analysis.

icut speakers, tense vowels are always classified as tense and lax vowels as lax, while for the Utah speakers, there are some instances of tense vowels classified as lax, and vice versa. For the Utahns, there appears to be no difference among *heel*, *heal*, and *he'll*; all are equally likely to be confused with *hill*, *pill*, or *pip*, as shown in Table 6. However, for one of the Connecticut speakers (C4), *he'll* alone is confused with *hill* and *pill*, perhaps under the influence of *will* in the uncontracted form *he will*.[15]

Analyses with VC rhyme as the grouping factor. Only in the case of U8's /il/ and /ɪl/ do the confusion patterns from the word analyses (illustrated in Table 6) suggest a possible lack of contrast: as many cases of *heel*, *heal*, *he'll*, *peel*, and *peal* as cases of *pill* and *hill* are classified as having /ɪ/. However, the patterns of homophone classification suggest that the question of vowel contrast can be better addressed through the rhyme discriminant analyses.

TABLE 6. *Classification of words with high front vowels before /l/ from single-speaker target word discriminant analyses, for selected subjects*

Speaker	Classification/ Target	*heal*	*heel*	*he'll*	*peal*	*peel*	*hill*	*pill*	Other
C4	*heal*	3	2		2	1			
	heel	2	5			1			
	he'll		1	1			3	3	
	peal	1			6	1			
	peel	4	3			1			
	hill			1			5	2	
	pill						2	6	
U8	*heal*		2	3	1	2			
	heel		4	2	1		1		
	he'll		3	3		1	1		
	peal	1	1		1	1	2	2	
	peel				2	5		1	
	hill	1	2		4	1			
	pill					2	2	4	
U9	*heal*	2		2	1	2			1
	heel	1		3	1	2		1	
	he'll	1	3	3	1				
	peal			3	2	3			
	peel	1	1		1	5			
	hill						5	2	1
	pill						3	5	

Note: Rows represent the speaker's targets, and columns the classifications applied by the discriminant analyses.

The single-speaker analysis by VC rhymes clearly shows different patterns of confusion for U8's /il/–/ɪl/ (Table 7), as for all other contrasts before /l/ for all four subjects. (The complete analyses are summarized in Appendices 4 and 5.) The partial *F* matrices from the VC rhyme (/l/-final words) discriminant analyses paint a similar picture. For both Connecticut subjects and 4 Utah subjects, the partial *F* scores show significant contrasts between all three cognate tense–lax pairs ($p \leq .0009$).[16] For the fifth Utah subject (U8), the contrasts between /il/–/ɪl/ and /el/–/ɛl/ are also significant ($p \leq .0009$), while the contrast between /ul/–/ʊl/ is not, $F(12,200) = 8.13$, $p = .0301 > .0009$. Nonetheless, the discriminant analyses are compatible with the ANOVAs summarized in Table 3. The two analyses agree in suggesting that U8 may preserve fewer contrasts than the other subjects. We can conclude then that, for our 5 Utah subjects, contrast is generally maintained between the pairs of cognate tense and lax vowels before /l/. Near homophones, like *heel* and *hill*, have qualitatively different patterns of contrast then true homophones like *heel* and *heal*. Even though the pairs of near homophones are acoustically similar enough that they often cannot be distinguished by English speakers from other dialect areas, and even though they may not be distinct

TABLE 7. *Classification of words with front vowels before /l/ from single-speaker VC rhyme discriminant analyses for subject U8*

Classification/ Target	*N*	/il/	/ɪl/	/el/	/ɛl/	/æl/	/æp/	/ɔl/
/il/	40	**.60**	.40					
/ɪl/	16	.38	**.62**					
/el/	31			**.65**	.35			
/ɛl/	16		.06	.25	**.69**			
/æl/	16					**.81**	.06	.13

Note: Rows represent the speaker's target, columns represent the classifications applied by the discriminant analysis, and numbers represent the proportion of tokens of a given category that were classified in the way indicated.

on any single dimension, they nonetheless occupy acoustically distinct and perceptually distinguishable regions of a multidimensional vowel space. These differences preserve the phonological contrast between the cognate tense–lax pairs before /l/.

Besides indicating which potential vowel contrasts our speakers implement, discriminant analysis can also provide indirect hints about which of the acoustic parameters are used to implement these contrasts. The partial *F* scores only suggest that the tense–lax pairs for the most part occupy distinct regions of a multidimensional space defined by the measured variables. However, it is relatively straightforward to assess the contributions of the different measured variables to the overall definition of this multidimensional space. These contributions for each of the speakers are ranked in the rows labeled "vars" in Table 8.[17] For each speaker, only the 6 input variables with the highest *F*-to-remove values in the single-speaker VC rhyme /l/-final words analyses (i.e., those variables that in the aggregate make the strongest contributions to the discriminant functions) are listed.[18] The numbers that appear in Table 8 are the coefficients (standardized by group means) by which the first two canonical variables are derived from the input variables. Standardized coefficients are based on standard deviations and tend to range from −1.5 to +1.5. An input variable with a coefficient that has a relatively high absolute value makes a greater contribution to derivation of a canonical variable than an input variable whose coefficient is closer to zero (Klecka, 1980). It is clear from the coefficients that U6, U9, and U12 only differentiate among vowels before /l/ at the first and second measurement locations. In contrast, U5 and U8, both of whom are relatively conservative with regard to other features (e.g., they both have relatively low F2 for /ud/), have differences throughout the vowels. (These two speakers are also, unlike the other Utah speakers, from outside the Salt Lake Valley.) Two of the Connecticut speakers (C2 and C4) likewise have differences throughout the vowels. For these speakers, only the frequency of F1 late in the vowel (F1-l) contributes to

TABLE 8. *Variables entering into single-speaker VC rhyme discriminant functions (/l/-final words only), ranked by F-to-remove score at final step, together with coefficients (standardized by group means) for each input variable in first two canonical variables produced by discriminant analyses*

C2	var	F1-m	F2-m	F2-e	F1-e	F1-l	VQI-m
(.80593)	d1	.13	−.79	−.67	.31	.08	.25
(.94963)	d2	.69	.16	−.01	.41	.33	−.17
C4	var	F2-e	F2-m	F1-e	F1-m	VQI-m	F1-l
(.74621)	d1	−1.21	.20	.39	−.12	−.28	.20
(.94225)	d2	−.38	.52	.73	.45	.34	.16
U5	var	F1-e	F2-l	F2-e	F1-m	VQI-e	F1-l
(.82634)	d1	.18	−.55	−.73	−.05	−.10	.05
(.97757)	d2	−.69	−.19	−.06	−.35	−.22	−.29
U6	var	F2-e	F2-m	VQI-e	F1-e	VQI-m	F1-m
(.75376)	d1	−.71	−.66	.29	.86	−.32	−.01
(.90924)	d2	.11	−.23	−.02	−.59	−.21	−.42
U8	var	F2-e	F1-e	VQI-e	F2-l	F1-l	F1-m
(.86243)	d1	−1.20	.89	−.57	−.17	.26	−.26
(.98598)	d2	−.03	−.68	.24	.04	−.07	−.36
U9	var	F2-e	F1-e	F1-m	F2-m	VQI-e	VQI-m
(.81907)	d1	−1.04	.54	−.01	−.15	.29	−.04
(.97470)	d2	−.01	−.53	−.64	−.26	−.33	−.23
U12	var	F2-e	F1-e	F2-m	F1-m	f_0-e	VQI-e
(.74501)	d1	−.94	−.28	−.23	−.11	.30	−.15
(.95537)	d2	.15	−.73	−.26	−.41	.24	.08

Note: Numbers in parentheses represent, respectively, the proportion of the total dispersion of the data accounted for by the first canonical variable (d1) and the first and second canonical variables (d1 and d2) together. Letters after variables code measurement locations: early, middle, and late.

the discriminant functions, whereas for U5 and U8, both F1 and F2 late in the vowel (F1-l and F2-l) make a contribution.

However, the values of the coefficients for these variables in derivation of the first two canonical variables (i.e., the first two axes of the coordinate space derived by the discriminant analysis) in Table 8 are not straightforwardly related to the rankings, which are based on the overall analysis. As is evident from the coefficients in Table 8, interpretation of the canonical variables is

TABLE 9. *Variables entering into single-speaker VC rhyme discriminant functions for /l/-final words for speaker U9, ranked by* F-*to-remove score at final step*

	d1		d2	
U9	sign	rank	sign	rank
F2-early	neg	1		
F1-early	pos	2	neg	2
F1-middle			neg	1
F2-middle	neg	4	neg	4 (tie)
VQI-early	pos	3	neg	3
VQI-middle			neg	4 (tie)

Note: The sign of the standardized coefficient by which each of the input variables is multiplied in derivation of the first two canonical variables (d1 and d2) is given in the columns headed "sign," and the relative rankings of the magnitudes of the absolute values of the coefficients are given in the columns headed "rank."

extremely difficult. There is no direct relationship between individual canonical variables and measured acoustic parameters. Nor is a direct relationship imaginable between the canonical variables and distinctive feature specifications, either articulatory or acoustic. This difficulty arises in part because measurements of the same parameter at different points in time are treated as independent parameters. Furthermore, the articulatory gestures that produce each particular VC nucleus may have multiple acoustic consequences.

Table 9 recapitulates the panel from Table 8 concerning subject U9, with the actual coefficients replaced by an indication of their sign and of the rank of the absolute magnitude of each coefficient. Because of the nature of the standardization process, high values for each raw acoustic parameter are positive, and low values are negative. In the case of VQI, values representing relatively breathy phonation are positive, and values representing relatively creaky phonation are negative. For subject U9, the input variables that will maximize d1, the first canonical variable, are negative (that is to say, low) F2 at the early and middle measurement points, positive (that is to say, high) F1 early in the vowel, and positive (that is to say, breathy) VQI. D1 will be maximally negative for vowels with high F2, low F1, and creaky VQI. Thus, canonical variable d1 defines a vector ranging from high, front, creaky vowels at the negative end to low, back, breathy vowels at the positive end (as shown for U9 in Table 10). Similarly, d2 is maximized by low F1 at the early and middle measurement points, by negative (creaky) VQI at the early and middle measurement points, and by low F2 at the middle measurement point. It is maximally negative for vowels with high F1, breathy VQI, and high F2. So d2 defines a vector ranging from low, front, breathy vowels at the nega-

TABLE 10. *Summary of vectors defined by first two canonical variables (d1 and d2) from single-speaker VC rhyme discriminant analyses (/l/-final words only) for all speakers*

	d1		d2	
	negative	positive	negative	positive
C2	hi front creaky	lo back breathy	lo front creaky	hi back breathy
C4	hi front breathy	lo back creaky	lo front breathy	hi back creaky
U5	hi front	lo back	lo creaky	hi breathy
U6	hi front creaky > breathy	lo back breathy > creaky	lo back > front breathy	hi front > back creaky
U8	hi front breathy	lo back creaky	lo creaky	hi breathy
U9	hi front creaky	lo back breathy	lo front breathy	hi back creaky
U12	hi front breathy low f_0	lo back creaky high f_0	lo front > back low f_0	hi back > front high f_0

tive end to high, back, creaky vowels at the positive end.[19] Thus, for U9, d1 involves moving the tongue up and front or down and back from its neutral position, and d2 involves moving the tongue down and front or up and back from its neutral position. These interpretations can be verified with reference to the display of U9's vowels in the bottom lefthand panel of Figure 5. By similar reasoning, the canonical variables for the other subjects can be interpreted. These interpretations are summarized in Table 10.

The differences among the subjects can be reduced to two. First, speakers differ as to whether breathiness is associated with the high, front or the low, back range of d1. Second, U5's and U8's d2 are qualitatively different from those of the other speakers in that they do not involve the front–back dimension at all. The first difference simply means that for some speakers VQI varies in such a way that it necessarily reflects phonation differences rather than artifacts of F1 frequency variation; for other speakers, however, VQI, as measured here, may or may not reflect phonation differences.[20]

It is worth stressing also that speakers who produce two vowels contrastively may differ as to which parts of the vowels contrast. Our more conservative speakers, whether from Connecticut or Utah, distinguish tense–lax cognate vowels before /l/ at all three measurement locations, while our more innovative speakers distinguish them only at the early and middle measurement locations. Furthermore, our results suggest that the dichotomy between conservative and innovative speakers may need some refinement. According to the ANOVAs summarized in Table 3, U8 makes virtually no distinction between cognate tense and lax vowels before /l/ and, hence, would be classified as innovative with regard to the linguistic phenomenon being studied here. However, the discriminant analyses suggest that she does distinguish these pairs, and furthermore, that she distinguishes them in a conservative

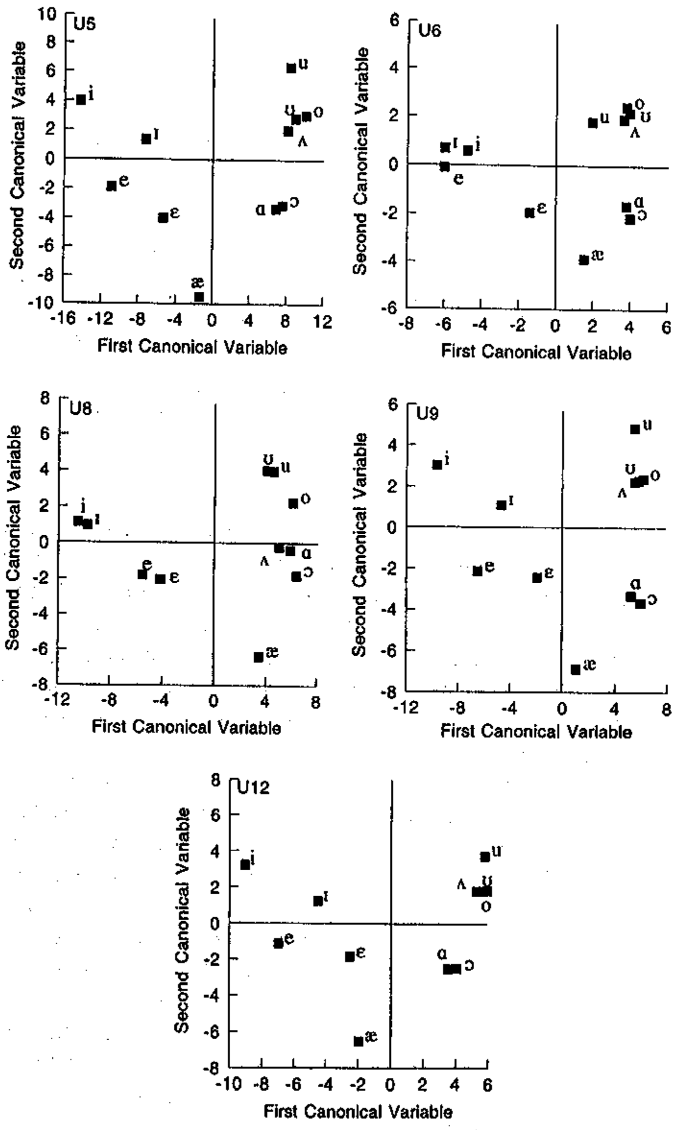

FIGURE 5. First two canonical variables from single-speaker VC rhyme discriminant analyses for /l/-final words for all Utah subjects. Each plot utilizes a different coordinate system.

fashion in that the distinctiveness is spread throughout the vowel instead of being concentrated in one portion of it.

Returning to the cognate tense–lax pairs, Figure 5 shows the locations of all vowel nuclei before /l/ for each Utah speaker in the Cartesian space de-

TABLE 11. *Implementation of tense–lax vowel contrasts before /l/ by first and second canonical variables from single-speaker VC rhyme discriminant analyses of /l/-final words*

Subject	/i-ɪ/	/e-ɛ/	/u-ʊ/
C2	d1 > d2	d1 > d2	d2 > d1
C4	d1 > d2	d1 > d2	d1 > d2
U5	d1 > d2	d1 > d2	d2
U6	d1	d1 > d2	d1
U8	d1	d1	d1
U9	d1 > d2	d1	d2
U12	d1 > d2	d1	d2

Note: d1: first canonical variable; d2: second canonical variable.

fined by the first two canonical variables, d1 and d2 in the VC rhyme /l/-final analyses; Table 11 summarizes which canonical variables differentiate which tense–lax vowel pairs. Despite these similarities, the canonical variables for each speaker are different, and so five different coordinate systems are represented, since each speaker's canonical variables are based on a separate analysis. Each speaker's d1 represents the vector through the point cloud representing that speaker's tokens along which the maximum spread is observed. It is evident from Figure 5 and Table 11 that the subjects differ as to which canonical variables differentiate which tense–lax pair. For C2 and C4, all three pairs are distinguished along both dimensions, d1 and d2, but for none of the Utah speakers is this the case. U5's /il/–/ɪl/ and /el/–/ɛl/ are distinguished by d1 and d2 together, but /ul/–/ʊl/ are distinct only in d2. U6's /el/–/ɛl/ are distinct on both dimensions, but her /il/–/ɪl/ and /ul/–/ʊl/ are distinct only in d1. For U9 and U12, /il/–/ɪl/ are distinguished by both d1 and d2, but /el/–/ɛl/ are distinguished only by d1 and /ul/–/ʊl/ only by d2. Finally, for U8 all three of the relevant pairs are distinct only in d1 and minimally so at that. In summary then, F1, F2, and VQI contribute to maintenance of the contrasts between cognate tense–lax vowels pairs before /l/ for both the Utah and the Connecticut speakers, although there are qualitative differences between the Utah and the Connecticut implementations of the contrasts.

Cross-speaker analyses. Inspection of Tables 8 and 9 reveals differences between the Connecticut and Utah speakers in the results of the discriminant analyses. Restricting ourselves to the first two canonical variables, d1 and d2, for both Connecticut speakers these variables are derived from F1 throughout the vowel, F2 early in the vowel and mid-vowel, and VQI in mid-vowel. (The two speakers differ, of course, in exactly how the canonical variables are derived from these input variables.) For both Connecticut speakers, the three cognate tense-lax vowel pairs are each distinguished by both of the canonical variables.

The Utah speakers differ from the Connecticut speakers in that for each Utah speaker at least one cognate tense–lax pair is only distinct in one of the canonical variables. Furthermore, different acoustic variables enter into the derivation of the first two canonical variables for the Utah speakers than for the Connecticut speakers. These canonical variables are derived only from variables measured early in the vowel or at mid-vowel for U6, U9, and U12. In addition, VQI at mid-vowel is supplemented in derivation of the canonical variables by early VQI for U6 and U9 and replaced altogether by early VQI for U5, U8, and U12.

These differences suggest that discriminant functions based on the Connecticut corpora should be less accurate in classifying the Utahns' words than the discriminant functions based on the Utahns' own productions. For these reasons, the two-speaker discriminant analyses were performed for the female Utah speakers (U6, U8, and U9). For each of these analyses, discriminant functions were derived based on Connecticut female C2's productions, and then the Utah speakers' productions were classified based on these discriminant functions.[21] Because a two-speaker analysis was expected to be less accurate than its corresponding single-speaker analysis, regardless of the dialect(s) of the speakers, additional two-speaker analyses were performed in which each of the female Utah speakers' productions were classified according to the vowel systems of the other two Utah females. These Utah–Utah analyses served as a control for the Connecticut–Utah analyses.

In the single-speaker analyses for these speakers, the individual words with /il ɪl el ɛl ul ʊl/ are, for the most part, classified differentially. However, as shown in Table 12, the situation is different for the Connecticut two-speaker word analyses. The Utah speakers' *heal*, *peal*, *peel*, *hill*, and *pill* are overwhelmingly classified with C2's *hill*; *heel* and *he'll* are predominantly classified as C2's *hill*, but with a substantial number of *heel* classifications (Table 12A). Utah *hail*, *hale*, *pail*, and *pale* are overwhelmingly classified with C2's *hill*; *hell* and *pell* are also generally classified with C2's *hell*, but with a substantial number of *hill* classifications (Table 12B). Finally, the Utah speakers' *pool* and *fool* are classified with C2's *hood* or *full*, while Utah *pull* and *full* are, for the most part, classified with C2's *whole* or *full* (Table 12C). In the Utah two-speaker analyses, *heal*, *heel*, and *he'll* tend to be classified as *heal*, *heel*, or *he'll*; *peal* and *peel* tend to be classified as *hill*, *pill*, or *peel*; and *hill* and *pill* tend to be classified as *hill*, *peal*, or *peel* (Table 12A). Utah *hail*, *hale*, *pail*, and *pale* tend to be classified as *pale*, *pail*, or *hail*; *hell* and *pell* tend to be classified as *pell* or *hell* (Table 12B). *Pool* tends to be classified as *cook*; *fool* as *hoed*, *hole*, or *pole*; and *pull* and *full* tend to be classified as *pole*, *hole*, or *whole* (Table 12C).

Direct comparison of the single-speaker analyses with both sets of two-speaker analyses is revealing. Such a comparison involves not only the patterns of distinctiveness, but also the specific confusions observed. *Hail*, *hale*,

TABLE 12. *Pooled classification of Utah females' (U6, U8, and U9) selected /l/-final words from two-speaker target word discriminant analyses*

A. /il/–/ɪl/		*heal*	*heel*	*he'll*	*peal*	*peel*	*hill*	*pill*	Other
< Utah subjects	*heal*	**.15**	.06	.21	.08	.13	.19	.06	.12
	heel	.13	**.21**	.31	.04	.06	.06	.10	.09
	he'll	.13	.19	**.29**	.04	.10	.04	.08	.13
	peal	.08	.08	.06	**.02**	.16	.21	.21	.18
	peel	.06	.06	.04	.10	**.16**	.27	.16	.15
	hill	.04	.02	.13	.19	.23	**.19**	.04	.16
	pill	.02	.04	.06	.06	.27	.31	**.02**	.22

		heel	*hill*	*pill*	*hail*
< C2	*heal*	.21	.71	.04	.04
	heel	**.42**	.50	.04	.04
	he'll	.35	.43	.13	.09
	peal	.08	.88		.04
	peel		1.00		
	hill	.08	**.88**	.04	
	pill		1.00		

B. /el/–/ɛl/		*hail*	*hale*	*pail*	*pale*	*hell*	*pell*	*peel*	Other
< Utah subjects	*hail*	**.35**	.08	.17	.17	.02	.02	.04	.15
	hale	.20	**.09**	.09	.35	.04	.07	.02	.14
	pail	.19	.04	**.17**	.31		.02	.13	.14
	pale	.20	.02	.30	**.39**	.02		.02	.05
	hell	.04		.10	.02	**.25**	.46	.06	.07
	pell			.06	.06	.21	**.54**	.02	.11

		hail	*pale*	*hell*	*pell*	*heel*	*hill*	*pill*	Other
< C2	*hail*	**.13**	.04	.04		.21	.54	.04	
	hale	.13	.09			.04	.61	.13	
	pail		.13			.04	.71	.08	.04
	pale	.09	**.05**	.09		.09	.64		.04
	hell			**.38**	.08		.42		.12
	pell			.50	**.17**		.21	.04	.08

C. /ul/–/ʊl/		*pool*	*full*	*hull*	*hoed*	*hole*	*whole*	*pole*	*cook*	Other
< Utah subjects	*pool*	**.10**	.10	.15	.04	.06	.04	.08	.33	.10
	fool	.10	.13	.08	.19	.17	.04	.15		.14
	pull	.08	.06	.10	.06	.15	.15	.25		.15
	full	.13	**.06**	.13		.17	.13	.21		.17

		pull	*full*	*hood*	*whole*	Other
< C2	*pool*	.04	.21	.50	.08	.17
	fool		.13	.58	.08	.21
	pull	**.13**	.17	.17	.29	.24
	full	.08	**.38**	.04	.33	.17

Note: The top part of each panel represents the average of classifications based on the other two Utah speakers and the bottom part classifications based on the Connecticut speaker.

pail, and *pale* are classified differently from *hell* and *pell* in all three sets of analyses. In the single-speaker analyses, each word tends to be classified correctly (Appendix 2). In the Utah two-speaker analyses, the words are not necessarily classified correctly, but most incorrect classifications involve the same VC rhyme. In the Connecticut two-speaker analyses, *hail*, *hale*, *pail*, and *pale* differ from *hell* and *pell* primarily in the likelihood that they will be classified as *hill*; the /el/ words are classified as *hill* more often than the /ɛl/ words are.

Likewise, the single-speaker analyses tend to classify *heal*, *heel*, *he'll*, *peal*, *peel*, *hill*, and *pill* as having the correct VC rhyme (Appendix 3). In both sets of two-speaker analyses, *peal* and *peel* are classified with *hill* and *pill*; this tendency is stronger in the Connecticut two-speaker analyses. Finally, in the single-speaker analyses *fool* and *pool* are generally classified as having the correct VC (Appendix 1), while *full* and *pull* are often classified as *hull*, *cull*, or a word containing /ol/. In the Utah two-speaker analyses, *pool* tends to be classified as *cook*, *hull*, *pool*, or *full*; *fool* as *hoed*, *hole*, *pole*, or *full*; and *full* and *pull* as *hull* or a word containing /ol/. In the Connecticut two-speaker analyses, *pool* and *fool* are classified as *hood*, and *full* and *pull* as *whole* or *full*.

The two-speaker analyses are always less accurate than the single-speaker analyses. However, direct comparison of the Utah and Connecticut two-speaker analyses is not as straightforward. For the high and mid front vowels, the Connecticut analyses are worse than the Utah analyses. However, the Connecticut analyses are somewhat better than the Utah analyses for the high back vowels.

This picture is confirmed by the two-speaker VC rhyme analyses, as compared with the corresponding single-speaker analyses for U6, U8, and U9. These comparisons are summarized in Table 13, which contains classifications received by 30% or more of the tokens with a particular rhyme in the two sets of analyses;[22] the location of selected Utah VC rhymes in C2's derived vowel space is illustrated in Figure 6. With regard to the contrasts of interest, the distinctions are always strongest in the single-speaker analyses, as would be expected. Overall, /ul/–/ʊl/ are more distinct in the Utah two-speaker analyses than in the Connecticut two-speaker analyses. For /el/–/ɛl/, the Connecticut two-speaker analyses outperform the Utah analyses for U8, but the Utah analyses better preserve the contrast for U6 and U9; for U6, both /el/ and /ɛl/ tend to be classified as C2's /ɪl/, although the tendency is stronger for /el/. Finally, Utah /il/ and /ɪl/, clearly distinct in the single-speaker analyses, are not classified differently in the two-speaker analyses, despite different mean coordinates for d1 and d2; although differences between /il/ and /ɪl/ are evident in the Utah two-speaker analyses, their classifications are substantially less accurate than those in the single-speaker analyses.

The basis for these classifications is evident in the canonical variable values plotted in Figure 6. In the three Utah panels of this figure, raw values for each speaker's vowels have been converted to values for the canonical variables based on C2's vowel space alone. Thus, in contrast with Figure 5, a sin-

TABLE 13. *Comparison of single-speaker (SS) and two-speaker VC rhyme discriminant analyses' classifications of /l/-final words*

	/ul/	/ʊl/	/ʌl/	/ol/	/ɑl/	/ɔl/	/il/	/ɪl/	/el/	/ɛl/	/æl/
A. U6 SS	ul .94	ʊl .44 ol .44	ol .56	ol .45 ʊl .35	ɑl .38	ɔl .72	il .80	ɪl .81	el .91	ɛl .81	æl .69
< U8	ʊk .50	ʊl .88	ol .69	ol .88	æl .33	æl .34	el .55	il .50	el .81	ɛl .63	æl .75
< U9	ʊk .50 od .44	ol .63	ol .44 ʌl .38	ol .63 ul .31	ɑl .46	ɔl .44	ɪl .65 il .33	il .81	el .91	ɛl .81	æl .50
< C2	ʊd .50	ol .69	ol .50	ol .75	[a]	ɑl .50	ɪl 1.00	ɪl .1.00	ɪl .63	ɪl .44 ɛl .38	æl .75
B. U8 SS	ul .62 ʊl .38	ul .31 ʊl .69	ʌl .75	ol .81	ɑl .33	ɔl .94	il .60 ɪl .40	il .38 ɪl .62	el .65 ɛl .35	ɛl .69	æl .81
< U6	ul .62 ʊl .38	ʌl .81	ɑl .38	ʌl .66 ʊl .34	ɑl .50	ɑl .59 ɔl .31	ɪl .68	ɪl .81	il .61	il .44 ɛl .56	æl .75
< U9	ul .50	ul .94	ʌl .94	ʊl .56	ɑl .52	ɑl .53	il .90	il .69 ɪl .31	el .55	ɛl .63	æl .63
< C2	ud .75	ʊl .50 ʊd .44	ʌl .63	ol .53	ʌl .48	ʌl .63	ɪl 1.00	ɪl .88	ɪl .74	ɛl .69	æl .81
C. U9 SS	ul .87	ʊl .38	ʌl .81	ol .56	ɑl .50 ɔl .50	ɑl .30 ɔl .66	il .98	ɪl 1.00	el .93	ɛl .94	æl .93
< U6	ʌl .69	ol .31	ʌl .38	ol .38	ɑl .83	ɑl .81	il .70	il .94	el .53 il .43	ɛl .75	ɛl .53
< U8	ʊl .69	ol .63	op .50	op .63	ɔl .54	ɔl .81	il .48 ɪl .43	el .56 ɛl .38	el .87	ɛl .75	æl 1.00
< C2	ʊl .38 ol .31	ʊl .56	ol .44 ʊl .31	ol .59	ʌl .63	ʌl .67	ɪl 1.00	il 1.00	ɪl .67 el .30	ɛl .69	æl .93

Note: Only classifications assigned to 30% or more of the tokens with a particular rhyme are listed. Full data for the single-speaker analyses appear in Appendices 4 and 5, and for the two-speaker analyses in Appendices 6 and 7.

[a]No one classification was assigned to at least 30% of the tokens, and six different VC classifications (with four different nuclei) were assigned to 10–24% of the tokens each.

gle coordinate space is represented in all four panels of Figure 6. For all three Utah speakers, the front vowel combinations /il/, /ɪl/, /el/, when classified according to C2's vowels, are closer to her /ɪl/ than to her /il/ or /el/ and are classified as such in the two-speaker analyses. In interpreting Figure 6, it is important to bear in mind that only the first two canonical variables are plotted. So, even though U8's /il/ appears to be closer to C2's /el/ than /ɪl/ in Figure 6, the actual distance may be much greater on axes defined by higher order canonical variables.

DISCUSSION

Univariate vs. multivariate approaches

It is important to note that the picture of how contrasts are maintained, as derived from multivariate discriminant analysis, differs from the picture

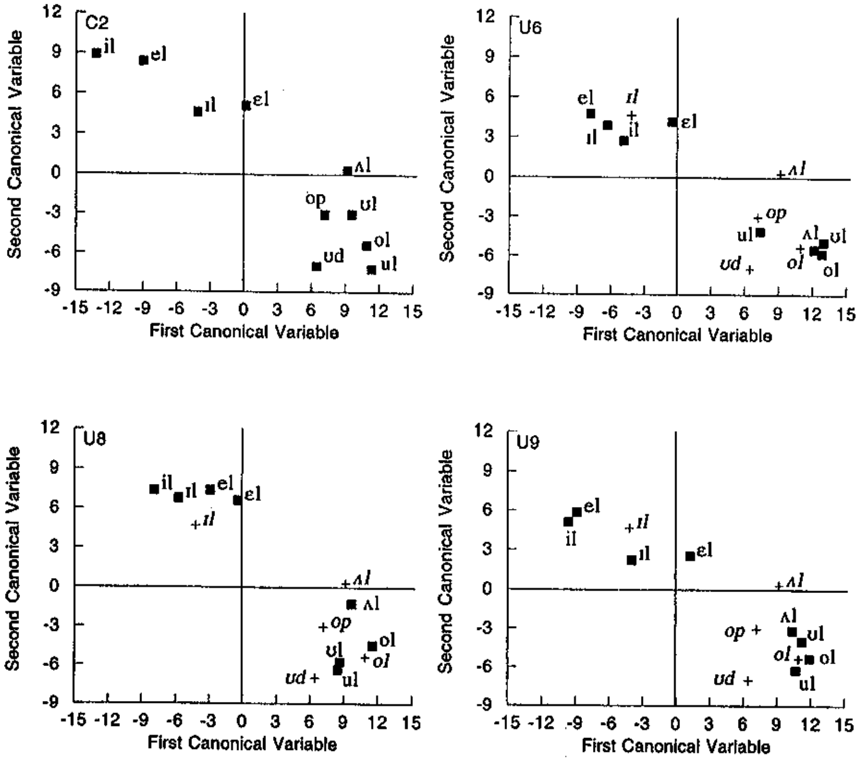

FIGURE 6. First two canonical variables from two-speaker general VC rhyme discriminant analyses for female subjects C2, U6, U8, and U9. Solid squares represent mean values for the individual speakers' VCs; to simplify inter-speaker comparison, crosses on the Utah speakers' figures represent C2's /ɪl op ol ʊd/.

derived from the consideration of the pairwise comparisons of vowel pairs along the raw acoustic dimensions in the univariate analyses (summarized in Table 3). These differences are summarized in Table 14. In particular, at the third measurement point, none of C2's tense–lax vowel pairs before /l/ differs significantly in any parameter except for f_0 and VQI. Yet it is F1 measured late in the vowel—and not f_0 or VQI measured late in the vowel—that makes the larger contribution to derivation of the canonical variables and to the distinction by the discriminant analysis between the cognate tense–lax vowel pairs. Likewise, C4's vowel pairs can be distinguished at the third measurement point only in F2 (for /el/–/ɛl/). Nonetheless, F1 at the third measurement point contributes to the overall contrasts, as reflected in the discriminant analysis. Similarly, for all of the Utah subjects except U5, there are at least two parameters that contribute to the derivation of one or both canonical variables, while themselves distinguishing at most one cognate tense–lax pair. The multivariate approach, we feel, corresponds better to

TABLE 14. *Variables used in single-speaker discriminant functions (/l/ words only) that, based on the post-hoc tests (summarized in Table 3), serve to distinguish one or no cognate tense–lax pairs before /l/*

Subject	Parameter	Location	Pairs Distinguished
C2	F1	Late	0
C4	F1	Late	0
	VQI	Middle	0
U6	VQI	Early	0
		Middle	0
	F1	Early	1
		Middle	1
U8	F2	Early	0
		Middle	1
	F1	Early	0
		Middle	0
		Late	0
	VQI	Early	1
U9	VQI	Early	0
		Middle	0
U12	F1	Middle	1
	f_0	Early	0
	VQI	Early	0

ordinary language use, in which individuals produce and perceive complex sounds that vary simultaneously along a number of dimensions rather than producing or perceiving any one dimension independently of the others.

One additional surprising result of our multivariate approach is worth noting: f_0 makes almost no contribution to any of the discriminant functions, despite the well-known intrinsic f_0 differences among vowels (e.g., Lehiste & Peterson, 1961). That is, despite the fact that vowels differ systematically in fundamental frequency, these differences do not contribute to maintaining vowel contrasts. This is true of the VC rhyme /l/-only analyses discussed here, as well as of the general VC rhyme analyses. Despite the ubiquity of intrinsic f_0 variation, in the literature as in the present corpus, there is extensive inter-speaker variation in the relative ranking of vowels in f_0. In particular, speakers tend to differ as to whether /i/, /ɪ/, /u/, or /ʊ/ has the highest f_0, and, as a result, f_0 is unlikely to provide a consistent cue to vowel identity in English.

An additional feature of the single-speaker VC rhyme analyses (both general and /l/ only) that is worth noting is the essential congruence of the canonical variables isolated. For all speakers, Utah and Connecticut, the first canonical variable defines a vector ranging from high front vowels to low back vowels. For 4 out of the 7 speakers, the second canonical variable defines a vector from low front to high back vowels; for 2 speakers, d2 is a vector from low to high vowels; and for 1 speaker, it is a vector from low fronting to high backing vowels. Where speakers differ is in which end of a canonical variable vector, if any, is associated with breathy phonation and which with creaky phonation. (They also differ as to whether f_0 contributes to derivation of the canonical variables and in the exact weight given to the input variables in derivation of the canonical variables.)

In order to understand the congruence of the VC rhyme discriminant analyses, it is necessary to review how discriminant analysis derives the canonical variables. Given the 12 input variables in these analyses, it constructs a 12-dimensional coordinate space within which all of the tokens can be situated. It then finds the single longest vector through the point cloud(s) representing the tokens. This is the first canonical variable. In effect, it is the vector through the coordinate space along which the largest spread in the data is observed. The second canonical variable is the vector along which the maximum remaining range of variation is observed, and so on.

The traditional vowel quadrilateral, illustrated in Figure 7, can be defined in terms of subjective tongue position or in terms of the first two formants. Because it is a quadrilateral and not a square, its two diagonals are not equal in length. Assuming that a speaker's vowels are distributed equally throughout the vowel space, the longest vector through the space is likely to correspond to the high front to low back dimension. Given that all of the data for each speaker were standardized, the heavy contribution of F2 to the first canonical variable is unrelated to the fact that F2 typically ranges over c. 2500 Hz, as compared with c. 700 Hz for F1; because of the larger standard deviation for F2, z scores for F1 and F2 are comparably distributed.

Assuming that phonation differences are indeed relevant in describing English vowels, we would expect breathy phonation to be associated with the high front end of d1 and with the high back end of d2. In both cases, the association of breathiness with one end of the vector or the other would maximize variation along that vector. However, since the association of breathiness with particular supralaryngeal configurations is based on other factors than the geometry of the vowel trapezoid, it is less rigid. Thus, differences among speakers can be expected. In the present sample, it appears that association of creakiness rather than breathiness with the high front end of d1 may be indicative of change in progress. U6, one of the speakers with this pattern (see Table 10), has a vowel space in which /ɪl/ has substantially higher F2 than does /il/ (see Figure 4). Thus, the different role of breathiness in derivation of her canonical variables reflects this reversal of nuclei in formant space, rather than changes in the relative breathiness of /ɪl/ and /il/.

Patterns of change

Our results to this point give rise to a question that can only be answered speculatively. How did the patterns that we have described come about? We know

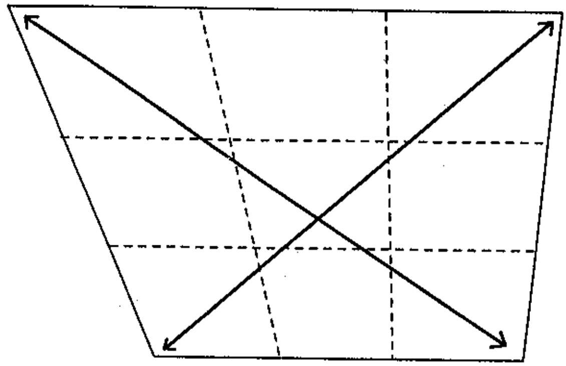

FIGURE 7. Stylized vowel trapezoid, showing the relationship between the cells defined by the traditional division into high, mid, and low vowels and front, central, and back vowels and the two diagonals.

that a series of changes began at least 25 to 30 years ago, with /ul/ and /ʊl/. Labov, Yaeger, and Steiner (1972) reported a similar phenomenon in Albuquerque, NM, and in Salt Lake City, and confusion between /ul/ and /ʊl/ in transcription exercises by University of Utah students began around 25 years ago (Wick Miller, personal communication). Our data reflect two expansions of that original approximation of /ul/ and /ʊl/. The first is the expansion to the other tense–lax vowel pairs before /l/, and the second is the development of implementations of the tense–lax contrast before /l/ that have not been reported for other dialects of English. This second expansion may be related to the approximation of /ʌl/, /ʊl/, and /ol/ for some of our speakers. The first expansion does not presuppose maintenance of the tense–lax contrast, despite the close approximation of the contrasting elements; the second expansion does. There are two possible bases for maintenance of the contrast. Either it is a reimportation from other dialects of English, or there is something in Utah speech maintaining the contrast, despite the approximation. It is worth noting that, given the original close approximation of /ul/–/ʊl/, /il/–/ɪl/, and /el/–/ɛl/, morphological support for associating /ul/, /il/, /el/ with /u/, /i/, /e/ comes from the pronominal system, in which *you'll, he'll, she'll, we'll, they'll* are derivational variants of *you, he, she, we, they*.[23] In fact, it is conceivable that vowel quality variations in *-ll* contractions, as observed, for example, in subject C4 in the present sample, provide the original basis for the approximation of tense and lax vowels before /l/, as well as for the maintenance of the contrast.

We previously argued (Di Paolo & Faber, 1990)—and continue to believe—that spectral slope differences contribute to maintenance of the contrast between tense and lax vowels before /l/ in Utah. Faber (1992) suggested a basis for reinterpretation of the contrast between tense and lax vowels as one based on phonation. In vowels with low F1 like /i/ and /u/, the fundamental is likely to fall within the F1 resonance, and thus these vowels will be characterized by spectrally prominent f_0. Breathy phonation likewise increases the spectral prominence of f_0. That is, both raising the tongue body sufficiently to produce a very low F1 and producing a vowel with breathy phonation have similar effects on spectral profile. Given such a contrast, language learners might impute it to tongue position differences, to phonation differences, or to both, covarying.[24] Indeed, some subjects in the perception study described in Di Paolo and Faber (1990) responded differentially to vowel nuclei differing only in VQI, while others did not; this suggests that to some speakers, but not others, phonation differences play a crucial role in the tense–lax contrast before /l/. U8 may be one of those speakers. In her system, tense and lax vowels before /l/ are only minimally distinguished, if at all, by a subtle combination of formant and phonation differences.

There are three possible outgrowths of such a vowel system, two of which are exhibited in the present corpus. The first possibility is that, under the influence of other dialects of English, formant differences will once again become widespread, so that Utah English will cease to differ from other dialects in this respect. This pattern is manifested by the two male subjects (U5 and U12), both of whom were, subjectively, extremely careful speakers. U5 is also the only Utah subject in the present sample with substantial exposure to other varieties of English, both as a 2-year resident of Toronto and as a teacher of English as a Second Language in Taiwan for 3 years. Second, it is possible that at some point a true merger will take place, making whatever observable differences there still might be between *heel* and *hill* qualitatively as well as quantitatively comparable to those between *heel* and *heal*. This is the pattern that U8 appears at first blush to have, although analysis in greater depth reveals, as we have shown, that she does indeed maintain the contrasts. Finally, it is possible that additional acoustic differences will be associated with the tense–lax contrast before /l/, so that the contrast ultimately will be phonetically different in the near-merger area than in other parts of the English speaking world. Two related phenomena suggest to us that the latter is the case. Both are evident in U6's data (Figure 4). The first phenomenon, which suggests an on-going reimplementation of the tense–lax contrast, is the apparent reversal of /il/ and /ɪl/ in F1, F2, or both. The second is the increase of F2 for /ul/, substantially lagging behind this change in other phonological contexts. U9 has a similar, albeit smaller magnitude, increase in F2 for /ul/. In both cases, the original lax vowel is now more peripheral in the vowel space than is the original tense vowel.

Another phenomenon regarding vowels before /l/ that we have already alluded to in our discussion is the approximation of /ʌl, /ol/, and /ʊl/. Aside from the general U.S. pattern in which all three nuclei are clearly distinct and an alternative pattern in which /ʌl/ and /ʊl/ are at best marginally distinct from each other but both are clearly distinct from /ol/ exhibited by C1 (Figure 3), we observed all logically possible combinations.[25] For 2 speakers described in Di Paolo and Faber (1990), /ʌl/ and /ol/ appear to overlap, but are clearly distinct from /ʊl/; for 4 speakers, /ʊl/ and /ol/ overlap, but are distinct from /ʌl/; and for 6 subjects, all three nuclei appear to overlap.[26] In the present sample, C2, C4, and U8 have the general pattern; C1 and U5 have the alternative pattern; U9 has /ʊl/–/ol/ distinct from /ʌl/; U6 has closely approximated /ʊl/, /ʌl/, and /ol/; and U12 apparently has three overlapping nuclei.

The speakers described in Di Paolo and Faber (1990) came from two socioeconomically and geographically distinct regions in the Salt Lake Valley, the predominantly white-collar Eastside and the predominantly blue-collar Westside. Of the 3 speakers from the Salt Lake Valley in the present sample, U6 and U9 are from the Eastside, and U12 is from the Westside. In the earlier study, we found that the tendency for formant reversals in cognate tense–lax pairs before /l/ was predominantly a Westside tendency. In terms of the current study, all of the speakers showing full overlap of /ʌl/, /ol/, and /ʊl/, 6 from the Di Paolo and Faber (1990) sample as well as U12, are from the Westside, while the other four patterns are evenly divided between the Eastside and the Westside. U5 and U8 of course are not from the Salt Lake Valley, and, like the Eastside speakers, are not participating in the Westside pattern.

The structural relationship between the phenomena under discussion is clear: /ʊl/ can, in principle, merge with /ul/, or it can merge with /ʌl/ and/or /ol/. However, on purely functional grounds, a four-way merger seems less likely and, indeed, does not occur in any of our corpora. At present, any scenario relating the two systematic changes must remain speculative, due to insufficient data regarding /ʌl/ and /ol/. It may be that the three-way approximation of /ʌl/, /ʊl/, and /ol/ represents the most recent stage in a series of diachronic developments in which /ul/–/ʊl/ approximated, their approximation was generalized to /il/–/ɪl/ and /el/–/ɛl/, and then /ul/–/ʊl/ (and possibly /il/–/ɪl/ and /el/–/ɛl/) diverged again. Alternatively, both the /ul/–/ʊl/ and /ʌl/–/ʊl/–/ol/ approximations may be competing resolutions to a perceived instability of /ʊl/. Full evaluation of these competing possibilities must await fuller investigation of vowel systems in which comparable approximations of vowels before /l/ have been reported. Only such an investigation will enable a determination of whether the precise phenomena observed in Utah are unique to Utah or whether they are characteristic responses to perceived dialect conflict in cases of urbanization in which dialects with southern admixture come into closer contact with dialects without such admixture. In any case, these approximations of vowels before /l/ are similar to, and perhaps related to, the general approximation of /u/,[27] /o/, and /ʌ/ before /r/, which also appears to be moving toward merger. The vowels /o/, /ɔ/, and /ɑ/ before /r/ have also been participating in various reported approximations and mergers in the Western United States (e.g, Labov, Yaeger, & Steiner, 1972; Norman, 1971; Stanley, 1936; Yaeger, 1974).

CONCLUSION

In summary, we have found that discriminant analysis is a worthwhile technique with which to study potential linguistic contrast. In particular, our analyses show that vowel pairs that are not distinct along any one measurable dimension – F1, F2, f_0, or spectral slope – may be distinct when all dimensions are considered simultaneously. This result underlines the importance of describing vowels in terms of as many dimensions as possible, not merely those dimensions that, like the first and second formant frequencies, are a priori assumed to distinguish among vowels. We have not addressed whether Utah listeners actively discriminate the elements of these near-merged contrasts. (See Di Paolo and Faber, 1990, and Faber, Best, and Di Paolo, 1993, 1994, for evidence that at least some Utahns do perceive the difference.) What we have shown is that, by and large, Utah speech contains sufficient information to enable Utah listeners to perceive the contrasts. Our emphasis has been on potential distinctiveness, which, after all, is logically prior to actual discrimination by listeners. This emphasis differs from that of Labov et al. (1991), who suggested that listeners may not make use of minimal distinctions in actual language use.

Our goal in this article was to describe vowel contrast in terms of a multidimensional acoustic space and, indirectly, the articulatory space therein reflected. The statistical technique that we used, discriminant analysis, distinguishes among pairs of words that are acoustically very similar (and, perhaps, indistinguishable to outsiders). These small differences in vowel location in a multi-dimensional acoustic space (reflecting small articulatory differences) suffice to preserve phonological contrasts that may not be evident to the naked introspective ear and thus provide the basis for possible future enhancement of the contrasts.

Given that there are speakers with near-mergers of /il/–/ɪl/, of /el/–/ɛl/, and of /ul/–/ʊl/, if these facts were presented in purely phonological terms, the latter developments would appear to reflect reversal of an absolute merger of the sort that has been appealed to as an account of the *meat–mate* facts in the past (Faber, Di Paolo, & Best, 1994; Labov, 1974; Milroy & Harris, 1980) and as an account of the apparent loss of a rule of final devoicing in most (if not all) dialects of Yiddish (Faber, Di Paolo, & Best, 1995; King, 1980). But this is not what is happening in Utah. By providing a detailed mechanism by which contrast can be preserved and enhanced in the case of one near-merger, we hope to have cast further suspicion on the notion of "reversal" of merger.

NOTES

1. Scattered survey work, informal observations and anecdotal evidence in the Southern and Western United States report similar phenomena of unknown geographical extent. To our knowledge, the first examination of this sound change appeared in Labov, Yaeger, and Steiner (1972).

Subsequently, there have been a number of other reports. For example, Hartman (1984) reported near-mergers before /l/ from California to Kansas. Bailey, Winkle, Tillery, and Sand (1991) observed mergers of tense and lax vowels before /l/ in younger urban Texas speakers. Tom Clark (personal communication) also reported confusions between /el/ and /ɛl/ in, for example, *bail-bell* in the Las Vegas, NV, area. Orthographic confusion between /el/–/ɛl/ is common in the Salt Lake Valley (e.g., *bake sell*), and we have also received second- and third-hand reports of similar confusions in Taos, NM (over a plate of free samples in a supermarket: *Fill free to taste*) and Florida (from an undergraduate essay: *She feels the air with joy and happiness*); we thank Nicole Kikowski and David Johns for these examples. The eye-dialect form *rilly*, widely used to characterize so-called Valley Girl speech, may also reflect a similar phenomenon. Outside the United States, the merger of /i–ɪ/ and /u–ʊ/ before /l/ is reported in London vernacular (Wells, 1982). In addition, the *Survey of English Dialects* (Orton et al., 1969–) includes scattered instances that may reflect merger or near-merger (e.g., *nail* [nɛl], *meal* [mɪl]) in the Midlands and the North Counties. We do not know how general these phenomena are or to what extent they are acoustically and perceptually comparable with the Utah phenomenon to which we have devoted our attention. There has been relatively little systematic dialect survey west of the Mississippi comparable to that done east of the Mississippi (e.g., Allen, 1973–76; Kurath & McDavid, 1961; Pederson, McDaniel, Bailey, & Bassett, 1986), so the apparent merger of cognate tense and lax vowels before /l/ might be much more widespread in the Western United States than this scattered evidence would suggest.

2. The categorization task reported in Di Paolo (1988) and Di Paolo and Faber (1990) likewise represents a relatively formal style.

3. Cf. Bond (1973) on duration differences between homophones based on morphological structure (e.g., *laps* vs. *lapse*) and Whalen (1991) on duration differences based on lexical frequency (e.g., *ewe* vs. *you*).

4. Of course, *heel* and *heal* originally were not homophones. Cf. the discussion in the text of *meet* and *meat*.

5. Our original intention had been to split the analysis so that approximately half the data would be analyzed at each site. However, it proved much less time consuming to analyze data on the Haskins VAX cluster than on the Macintosh available at the University of Utah.

6. Formant measurements for the subjects analyzed at Haskins were made via the ILS LPC-based root solving algorithm (RSO); for the subject analyzed at the University of Utah, formant measurements were made from narrow-band DFT spectra produced by Signalyze. For the Haskins subjects, f_0 was arrived at by a combination of the ILS subprogram API and hand-measuring of individual pitch periods; for the Utah subject, f_0 was determined using the Signalyze cepstral analysis routines. For all subjects, VQI was computed from narrow band DFT spectral cross-sections, produced either by Signalyze or by the Haskins Laboratories program HADES, by subtracting the amplitude of the strongest harmonic in F1 from the amplitude of the first harmonic. While it would have been desirable to include duration measurements as well, this was not possible. Vowel duration could not be measured because of the difficulty of reliably segmenting a vowel and a following /l/. Combined duration of the vowel and the following consonant could not be measured for all tokens, as some final stops for most subjects were not released, providing no release burst on the basis of which to make the measurements. For subject C1, only formant measurements are available. Background noise in the recording (the first done in a new set-up) made f_0 measurement difficult and made amplitude measurements dangerous.

7. The data were standardized with the z-transform in order to simplify interpretation of the two-speaker analyses, in which each Utah female speaker's vowels were classified in terms of C2's vowel space and in terms of those of the other two Utah females. Even though the two-speaker analyses only involved the female speakers, the male speakers' data were standardized as well. We computed separate z scores for each of the four measured parameters for each speaker. For example, we computed the mean and standard deviation for U6's F1 across all three measurement locations and all 440 tokens and, on that basis, converted each F1 value to its corresponding z score, and so forth for the other three parameters and for all speakers.

8. Even though our purpose is to determine which dependent variables make substantive contributions to each discriminant function, the stepwise procedure that program 7M defaults to, which would ostensibly select all and only the variables that make such a contribution, is inappropriate. This is because the stepwise procedure provides non-unique solutions. That is, multiple runs using the same data may arrive at different discriminant functions (discriminant functions containing different variables), depending on the order in which variables are entered

into the analysis. In the present series of analyses, the non-uniqueness problem was avoided by forcing all dependent variables into the discriminant function and then eliminating from further consideration those variables that had a partial *F* value of less than 3.00 at the final step in the analysis.

9. Discriminant analysis is one of a family of multivariate statistical techniques that can be used for assessing the reliability of an a priori division of a data set into subgroups and for concentrating the variability in a multidimensional data set onto a smaller number of (derived) dimensions. Related techniques include factor analysis, cluster analysis, and principal components analysis. Our choice of discriminant analysis rather than one of these other techniques was based on its generality in allowing simultaneous consideration of the group membership of individual tokens and of the dimension(s) along which these groups differ. While other techniques (e.g., principal components analysis; Harrington & Cassidy, 1994) may give comparable accuracy in distinguishing among groups in a data set, we are equally interested in the dimensions along which these groups differ. Johnson et al. (1993) used discriminant analysis rather than multi-dimensional scaling in a study of the independent dimensions involved in vowel articulation, because discriminant analysis is less sensitive to violations of the mathematical assumptions on which it is based, particularly concerning inter-speaker variability.

10. For example, given three input variables *length*, *width*, and *height*, the equation deriving a given canonical variable from the input variables will be of the form:

$$\mathrm{CV} = (x * \mathit{length}) + (y * \mathit{width}) + (z * \mathit{height}) + k,$$

where k is a constant. The greater the coefficient x, y, or z, the greater the contribution of the variable it is associated with to discriminant function CV.

11. This is Pattern 3 of Labov, Yaeger, and Steiner (1972), observed in British and Southern United States dialects. Labov (1991) noted an expansion of this "Southern Shift" to other United States dialects.

12. For discussion of maintenance of a minimal /ɑ/–/ɔ/ contrast despite the overt norm in which the contrast is absent, see Di Paolo (1992a, 1992b).

13. In this class, /ʌ/ and /ʊ/ reflect different developments from Middle English *u. When followed by /l/, the common Northeastern United States reflex is /ʌ/, except in a handful of words, typically described (e.g., Wells, 1982) in terms of their initial labial consonants. Thus, for most speakers, *full* and *cull* indeed have different vowel nuclei (/fʊl/ vs. /kʌl/). However, pockets of apparent lack of contrast, in which *bulge*, for example, is /bʊlǰ/ rather than /bʌlǰ/, have been observed in New England (Kurath & McDavid, 1961; LANE, map 362). Subject C1 is from Middletown, one of the areas in Connecticut where this pattern was observed in the 1930s. C1's overlap of /ɑl/ with /ʌl/–/ʊl/ may be a result of her substituting [ʌl] for /ɑl/ in the (to her) novel items *Sol*, *Col*, *pol*.

14. Because only formant measurements were available for C1, no discriminant analyses were performed on her data.

15. Some colleagues of ours from throughout the United States have reported to us that they, too, tend to group *he'll* with *hill* rather than with *heel*, but we have no evidence for how widespread this pattern might be and what it correlates with.

16. These significance levels should be interpreted as follows: given that the 11 vowels before /l/ give rise to 55 pairwise comparisons, for an overall significance level of .05, the criterion for each individual comparison is .05/55 or .0009.

17. These rankings represent independent contributions to the discriminant function. Given that F1 amplitude is dependent on F1 frequency (Fant, 1956), regardless of underlying laryngeal configuration, VQI values will tend to be correlated with F1 frequency. However, F1 frequency does not account for all of the variance in VQI. When VQI is included in derivation of a canonical variable, it is on the basis of the residual variance not resulting from variation in F1.

18. The canonical variables in the more general VC rhyme analyses serve to distinguish among VC rhymes on the basis of C as well as of V. In the present instance, our interest is in how vowels before /l/ differ, and it is easier to glean this information from the /l/-final analyses than from the general VC rhyme analyses.

19. It is essentially arbitrary which end of the vector is treated as negative and which as positive (Klecka, 1980); thus, signs have been changed on some coefficients and vectors to simplify inter-subject comparisons.

20. Vowels with low frequency F1 will also have low L1 (Fant, 1956) and may also have high L0, if F1 is low enough that the fundamental will fall within its bandwidth. Thus, high vowels will naturally tend to have spectral cross-sections that are comparable to those of vowels (of any height) produced with breathy phonation. As a result, if VQI were varying only as a function of vowel height, high breathy vowels (those with low F1 and high VQI) and low creaky vowels (those with high F1 and low VQI) would be expected to occupy extremes of the vectors defined by the canonical variables whose derivation they contribute to. In such cases, F1 and VQI should have opposite signs. Of the 18 VQI–F1 pairings observable in Table 8 (two each for C2, C4, U5, U8, and U12, and four each for U6 and U9), this natural association only occurs four times, for C2's d2, U5's d1, and U8's d1 and d2. In three additional cases, the VQI coefficient is near 0 and, hence, irrelevant: VQI-early for U6's d2, VQI-mid for U9's d1, and VQI-early for U12's d2. The F1-mid coefficient is near 0 for U6's d1, while the VQI-mid coefficient is negative. In the other nine cases, at least one for all subjects but U8, low F1 and creaky VQI comparably increase or decrease the canonical variables whose derivation they participate in. This covariation necessarily reflects active control of phonation type independently of variation in tongue position, as reflected in F1 frequency.

21. This analysis was restricted to the female speakers because of the possibility that female speakers in general have larger vowel spaces than males do, even after normalization designed to compensate for females' generally higher frequency resonances (Henton, 1992; Johnson, 1989). C2 was used as representative of Connecticut speakers, because of the restriction of C1's data to formant measurements alone.

22. The full data for the single-speaker analyses appear in Appendices 4 and 5 and for the two-speaker analyses in Appendices 6 and 7.

23. We are extremely grateful to Cathi Best for this observation.

24. This follows from the view of sound change outlined in Faber (1986, 1992).

25. The general and the alternative patterns are the only two for which we have even anecdotal evidence outside our main study area.

26. We cannot categorize our balanced word list speakers, BW and NM (described in Di Paolo & Faber, 1990), along this dimension, since the balanced word list contained no words with /ol/. Also, given that we have not studied the /ʌl/–/ol/–/ʊl/ problem in any great depth, we prefer not to talk about merger or lack of contrast; we merely note that for some speakers, some nuclei are closer together than they are for other speakers. In particular, the distinction between the /ʊl/–/ol/ overlapping and the /ʌl/–/ol/ overlapping groups may be artifactual, since there were very few data points for any one nucleus in the Di Paolo and Faber (1990) samples.

27. The vowel /ur/ in this dialect, as in others, reflects earlier /ur/ and /ʊr/, just as /or/ in the perceived standard of the area reflects earlier /or/ and /ɔr/.

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APPENDIX 1

Classification of words with high back vowels before /l/ from single-speaker target word discriminant analyses

	Class/ Target	*fool*	*pool*	*full*	*pull*	*whole*	*hull/ cull*	*poll/ pole*	Other
C2	*fool*	6	2						
	pool	3	5						
	full			6	2				
	pull			1	7				
C4	*fool*	7	1						
	pool		7					1	
	full			3	3		1		1
	pull			3	5				
U5	*fool*	6	2						
	pool	5	3						
	full			7			1		
	pull			2	3	1	1	1	
U6	*fool*	7					1		
	pool		8						
	full			3	1	2		1	1
	pull			1		2	1	2	2
U8	*fool*	3	1	2	1			1	
	pool	2	3	2	1				
	full	1	1	3	2			1	
	pull	1	2	2	3				
U9	*fool*	5	1	2					
	pool		6			1		1	
	full	1	2	3				1	1
	pull				2		4	2	
U12	*fool*	5	2		1				
	pool	4	4						
	full			2			3	2	1
	pull			1	3		1	1	2

Note: Figures represent the number of tokens (out of 8) for which each classification occurred. The panel for U8 appears also in Table 5.

APPENDIX 2

Classification of words with mid front vowels before /l/ from single-speaker target word discriminant analyses

	Class/ Target	*hail*	*hale*	*pail*	*pale*	*hell*	*pell*	*hill/ pill*	Other
C2	*hail*	5	3						
	hale	2	5	1					
	pail	1		2	5				
	pale		1	6	1				
	hell					4	4		
	pell					3	5		
C4	*hail*	2	4	1	1				
	hale	3	3	2					
	pail	2	1	4	1				
	pale	2	2	3	1				
	hell					5	2	1	
	pell						8		
U5	*hail*	1	1	4	2				
	hale	2	4	1	1				
	pail	2	2	2	2				
	pale	5	1		2				
	hell					5	3		
	pell					2	5		1
U6	*hail*	3	2	1	1			1	
	hale		3	3	2				
	pail	1	2	4	1				
	pale	3	1	1	1				2
	hell						3	3	2
	pell		1			2	5		
U8	*hail*	5			1	1	1		
	hale	1		2	2	2			
	pail	2	2	1	1	2			
	pale	2	3	2		1			
	hell	1	2	1		1	2	1	
	pell		1		1		6		
U9	*hail*	5	3						
	hale	2	4	1	1				
	pail	2	2	2	1			1	
	pale[a]			2	4				
	hell				1	6	1		
	pell					1	6		1
U12	*hail*	4	1	1	1				1
	hale	1	1	2	3				1
	pail	2	1	1	4				
	pale		3	4	1				
	hell[a]					3	3		
	pell					3	5		

[a]Fewer than 8 tokens.

APPENDIX 3

Classification of words with high front vowels before /l/ from single-speaker target word discriminant analyses

	Class/ Target	*heal*	*heel*	*he'll*	*peal*	*peel*	*hill*	*pill*	Other
C2	*heal*	1	3	3	1				
	heel	2	2	1	2				1
	he'll	1	2	2	1	2			
	peal	1	1	1	4	1			
	peel[a]	2	1	3	1				
	hill						8		
	pill							8	
C4	*heal*	3	2		2	1			
	heel	2	5			1			
	he'll		1	1			3	3	
	peal	1			6	1			
	peel	4	3			1			
	hill			1			5	2	
	pill						2	6	
U5	*heal*	4	2	1		1			
	heel[a]	1		1		4			1
	he'll	1	3	2	1				1
	peal	4	3	1					
	peel	3	1	1	1	2			
	hill						7	1	
	pill							8	
U6	*heal*		2	1	1	2		1	1
	heel	1		3		3	1		
	he'll	2	2	2	2				
	peal				5	3			
	peel	1		1	1	4	1		
	hill		1		2		4	1	
	pill	1			1			6	
U8	*heal*		2	3	1	2			
	heel		4	2	1		1		
	he'll		3	3		1	1		
	peal[a]	1	1		1	1	2	2	
	peel				2	5		1	
	hill	1	2		4	1			
	pill				2		2	4	
U9	*heal*	2	1	1	2	1			1
	heel	1		3	1	2		1	
	he'll	1	3	3	1				
	peal			3	2	3			
	peel	1	1		1	5			
	hill						4	3	1
	pill						3	5	
U12	*heal*		3	2	1	2			
	heel[a]	2		1	1	3			
	he'll	3	1	1	1	1	1		
	peal	3	1	1	1	1	1		
	peel	3	1	2	1	1			
	hill	1					4	1	2
	pill						1	6	1

Note: Data for C4, U8, and U9 are repeated from Table 6.
[a]Indicates fewer than 8 tokens.

APPENDIX 4

Classification of words with back vowels before /l/ from single-speaker VC rhyme discriminant analyses

		N	/ul/	/ʊl/	/ʌl/	/ɑl/	/ɔl/	/ol/	/ɑp/	/ɑd/	/ɔd/	/op/	/od/	Other
C2	/ul/	16	**1.00**											
	/ʊl/	16		**.94**				.06						
	/ʌl/	16			**.82**						.06	.06		.06
	/ɑl/	24				**.92**				.08				
	/ɔl/	32					**.88**				.12			
	/ol/	32						**1.00**						
C4	/ul/	16	**.88**					.12						
	/ʊl/	16		**1.00**										
	/ʌl/	16		.06	**.82**	.06						.06		
	/ɑl/	20			.04	**.71**		.04	.09					
	/ɔl/	32			.04		**.96**							
	/ol/	32		.09				**.91**						
U5	/ul/	16	**1.00**											
	/ʊl/	16		**.69**	.19			.12						
	/ʌl/	16			**.81**	.19								
	/ɑl/	23	.04		.17	**.26**	.30	.13				.09		
	/ɔl/	32			.03	.03	**.91**							.03
	/ol/	32			.06	.03		**.84**				.06		
U6	/ul/	16	**.94**	.06										
	/ʊl/	16		**.44**	.13			.44						
	/ʌl/	15		.19	**.06**		.06	.56					.06	.06
	/ɑl/	23			.08	**.38**	.29	.08		.08				.08
	/ɔl/	32		.06		.06	**.72**			.09				.06
	/ol/	32	.03	.35	.16	.03		**.45**						
U8	/ul/	16	**.62**	.37										
	/ʊl/	16	.31	**.69**										
	/ʌl/	16			**.75**	.19	.06							
	/ɑl/	24	.04		.13	**.33**	.29	.13				.08		
	/ɔl/	32		.03		.03	**.94**							.03
	/ol/	32		.03	.06	.03		**.81**				.03		
U9	/ul/	16	**.87**					.13						
	/ʊl/	16	.25	**.38**	.25			.13						
	/ʌl/	16	.06		**.81**			.13						
	/ɑl/	24				**.50**	.50							
	/ɔl/	27				.30	**.66**		.04					
	/ol/	32	.16	.13	.09	.03		**.56**				.03		
U12	/ul/	16	**1.00**											
	/ʊl/	16		**.31**	.38			.25					.06	
	/ʌl/	16		.31	**.31**			.38						
	/ɑl/	23				**.48**	.48				.04			
	/ɔl/	32				.41	**.56**							
	/ol/	30	.07	.23	.20	.03		**.47**						.03

Note: Figures represent the proportion of the total number of tokens containing a given vowel that received a particular classification.

APPENDIX 5

Classification of words with front vowels before /l/ from single-speaker VC rhyme discriminant analyses

		N	/il/	/ɪl/	/el/	/ɛl/	/æl/	/æp/	/ɛd-p/	/ud/	/ɔl/	Other
C2	/il/	40	**.98**	.02								
	/ɪl/	16		**1.00**								
	/el/	32			**1.00**							
	/ɛl/	16				**1.00**						
	/æl/	16					**.94**	.06				
C4	/il/	40	**.85**	.15								
	/ɪl/	16		**1.00**								
	/el/	32	.03		**.97**							
	/ɛl/	16		.12		**.88**						
	/æl/	16				.06	**.94**					
U5	/il/	40	**.95**									.05
	/ɪl/	16		**1.00**								
	/el/	32			**.97**							.03
	/ɛl/	16				**.88**			.12			
	/æl/	16				.19	**.63**	.12				.06
U6	/il/	40	**.80**	.15	.03					.03		
	/ɪl/	16	.19	**.81**								
	/el/	32		.03	**.91**					.06		
	/ɛl/	16			.06	**.81**	.13					
	/æl/	16				.06	**.69**	.06			.13	.06
U8	/il/	40	**.60**	.40								
	/ɪl/	16	.38	**.62**								
	/el/	31			**.65**	.35						
	/ɛl/	16		.06	.25	**.69**						
	/æl/	16					**.81**	.06			.13	
U9	/il/	40	**.98**	.02								
	/ɪl/	16		**1.00**								
	/el/	31		.07	**.93**							
	/ɛl/	16		.06		**.94**						
	/æl/	15					**.93**	.07				
U12	/il/	40	**.95**	.05								
	/ɪl/	16	.06	**.81**		.13						
	/el/	32	.03		**.97**							
	/ɛl/	14				**1.00**						
	/æl/	16					**1.00**					

Note: Information on U8 is repeated from Table 7.

APPENDIX 6

Pooled classification of words with back vowels before /l/ from two-speaker VC rhyme discriminant analyses

		/ul/	/ʊl/	/ʌl/	/ɑl/	/ɔl/	/ol/	/op/	/od/	/ud/	/ʊd/	/ʊp/	/ʌd/	/ɑd/	/æl/	Other
U6	/ul/	.09	.03					.09	.29			.50				
<U8 + U9	/ʊl/	.07	.50	.09			.32	.03								
	/ʌl/	.18	.03	.03			.65	.03	.03	.03		.03				.03
	/ɑl/	.06		.02	.23	.19	.10	.04					.02	.06	.16	.09
	/ɔl/	.03		.08	.13	.30	.02							.11	.17	.14
	/ol/	.19	.03				.75	.01								
U6	/ul/	.68	.13					.16	.06			.06				
<C2	/ʊl/	.06	.19				.69	.06								
	/ʌl/	.19	.06				.50	.06	.06		.13					
	/ɑl/			.24	.24		.14	.10	.05		.05		.10		.05	.03
	/ɔl/			.13	.50	.04	.06					.04		.16		.09
	/ol/	.03	.06				.75	.03			.13					
U8	/ul/	.56		.22			.09		.13							
<U6 + U9	/ʊl/	.50	.03	.41			.03		.03							
	/ʌl/		.06	.54	.22	.10		.06	.03							
	/ɑl/	.05	.02	.20	.51	.11	.02	.07								.02
	/ɔl/			.10	.55	.28			.02					.02		.03
	/ol/	.11	.45	.38			.06									

U8	/ul/		.06						.13	.06	.75					
<C2	/ʊl/		.50				.06				.44					
	/ʌl/		.06	.63			.06	.19					.06			
	/ɑl/			.48	.23	.04	.09				.17					
	/ɔl/			.63	.09	.25										.03
	/ol/		.53				.22	.03	.03		.19					
U9	/ul/	.13	.40	.35			.12									
<U6 + U8	/ʊl/	.06	.13	.13	.03		.46	.10	.09							
	/ʌl/	.06		.28	.22		.06	.25	.13							
	/ɑl/			.09	.48	.28			.02							.13
	/ɔl/			.03	.42	.43								.02		.10
	/ol/	.06	.03	.14	.02	.02	.26	.31	.16							
U9	/ul/	.06	.38				.31			.06	.19					
<C2	/ʊl/		.56				.13	.19	.13							
	/ʌl/		.31	.13			.13	.44								
	/ɑl/			.63	.25			.04						.08		
	/ɔl/			.67	.19			.13						.13		
	/ol/	.03	.13	.03			.59	.09	.13							

Note: The top part of each panel represents the average of separate classifications based on the other two Utah female speakers, and the bottom part classification based on the Connecticut female speaker.

APPENDIX 7

Pooled classification of words with front vowels before /l/ from two-speaker VC rhyme discriminant analyses

		/il/	/ɪl/	/el/	/ɛl/	/æl/	/æp/	Other
U6	/il/	**.25**	.38	.27	.09			.02
<U8 + U9	/ɪl/	.65	**.23**	.03	.03			.06
	/el/	.06		**.86**	.05			.03
	/ɛl/			.06	**.72**	.22		
	/æl/				.10	**.62**	.17	.11
U6	/il/		1.00					
<C2	/ɪl/		**1.00**					
	/el/	.13	.63	**.25**				
	/ɛl/		.44		**.38**	.19		
	/æl/				.06	**.75**		.19
U8	/il/	**.55**	.39	.06				
<U6 + U9	/ɪl/	.45	**.55**					
	/el/	.32	.11	**.34**	.23			
	/ɛl/	.22	.06	.13	**.60**			
	/æl/				.07	**.69**	.10	.14
U8	/il/	**.33**	.67					
<C2	/ɪl/	.12	**.88**					
	/el/		.74	**.03**	.23			
	/ɛl/		.31		**.69**			
	/æl/					**.81**		.19
U9	/il/	**.58**	.34	.05				.03
<U6 + U8	/ɪl/	.47	**.06**	.28	.19			
	/el/	.21		**.69**				.10
	/ɛl/	.03		.03	**.75**	.06		.12
	/æl/				.27	**.63**		.10
U9	/il/	**.13**	.80	.08				
<C2	/ɪl/		**1.00**					
	/el/	.03	.67	**.30**				
	/ɛl/		.19		**.69**			.12
	/æl/				.07	**.93**		

Note: The top part of each panel represents the average of separate classifications based on the other two Utah female speakers, and the bottom part classification based on the Connecticut female speaker.