Perception of French Vowels by American English Adults With and Without French Language Experience

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Abstract

This study investigated the effects of language experience and consonantal context on American English (AE) listeners' discrimination of contrasts involving Parisian French vowels /y, œ, u, i/. Vowels were produced in /rabVp/ and /radVt/ nonsense disyllables in carrier phrases by 3 speakers and presented in a categorial AXB discrimination task. Two groups were tested: AE listeners who had studied French extensively beginning after age 13 (Exp) and non-French-speaking AE listeners (Inexp). Overall, the Exp group performed better than the Inexp group on /u-œ/, /i-y/ and /y-œ/ (mean errors: Exp=5%, Inexp=24%). However, for /u-y/, the groups did not differ (Exp=30% vs Inexp=24% errors). The Inexp group confused /i-y/ more often in bilabial context, but /u-y/ more often in alveolar context, whereas the Exp group confused /u-y/ more often in both contexts. For all contrasts, the Inexp group performed better in bilabial than in alveolar context (16% vs 32% errors), whereas the Exp group revealed no context effect. Results suggest that learning a second language (L2) includes learning its coarticulatory rules. Implications for models of L2-speech perception are discussed.

Key words: cross-language speech perception; vowels; French; consonantal context; second-language learners

1. Introduction

Findings from cross-language speech perception studies point to linguistic experience as a powerful influence on listeners' perception of foreign speech sounds (e.g., Lisker & Abramson, 1964; Miyawaki, Strange, Verbrugge, Liberman, Jenkins, & Fujimura, 1975). A question with considerable pedagogical and theoretical implications is the extent to which exposure to non-native speech sounds through instruction in a second language (L2) alters listeners' perception of non-native contrasts. The present study examined the perception of French vowels by American English (AE) listeners with and without French language experience.

In particular, the perception of French rounded vowels that are not within the AE phonemic inventory were targeted, as these pose special problems for non-native listeners of French (Gottfried, 1984). Front rounded vowels, such as Parisian French (PF) /y/ (in *déjà v**u*** /vy/ "seen") and /œ/ (in *b**œ**uf* /bœf/ "beef") are produced with rounded lips, but unlike all AE rounded vowels, the tongue body is in a forward position in the oral cavity, while the lips are protruded (see Raphael, Bell-Berti, Collier & Baer, 1979, for detailed articulatory and acoustic description of front rounded vowels). Acoustically, the second and third formant frequencies are lower than for front unrounded vowels because lip rounding increases the length of the oral cavity, lowering the corresponding front cavity resonances. Although acoustically, front rounded PF /y/ is more similar to PF /i/ (Gottfried, 1984**;** see also Figure 1), most of the confusions for AE listeners confronted with French vowels are reported as occurring for /u-y/ vowel pairs rather than for /i-y/ pairs (e.g., Flege, 1987; Flege & Hillenbrand, 1984; Gottfried, 1984). The phonological categories of back rounded and front rounded vowels are contrastive in French. The contrast /u-y/, for example, is used to

distinguish French minimal pairs (e.g., *au-dessous* /odsu/ "below" from *au-dessus* /odsy/ "above").

The consonantal context in which vowels are presented has been shown to influence listeners' perception, whether these vowels are native (Nearey, 1989) or non-native (Gottfried, 1984; Trofimovich, Baker, & Mack, 2001). The AE back rounded vowels /u/ and /ʊ/ are considerably "fronted" when produced in an alveolar context (Hillenbrand, Clark, & Nearey, 2001; Strange, Bohn, Nishi & Trent, 2005). Thus, AE listeners may be more likely to categorize French high and mid front rounded vowels /y, œ/ as similar to AE /u/ or /ʊ/ (which allow for fronting) when the vowels are surrounded by alveolar consonants than when they are surrounded by non-alveolar consonants. The present study examined whether the perceptual patterns of inexperienced and experienced native AE listeners hearing French vowels varied as a function of their language experience and the consonantal context in which the vowels were presented.

1.1. Cross-language studies of vowel perception

Early cross-language studies suggested that the effect of language experience on the perception of vowels was quite different from its effect on the perception of consonants. Whereas the discrimination of consonants was "categorical" and clearly influenced by the phonetic categories of a listener's native language (e.g., Miyawaki et al., 1975), perception of vowels was more continuous, with discrimination of within and across phonetic category boundaries more nearly equal. Relative to consonant perception, vowel perception was thus described as more reliant upon acoustic differences and less subject to the influence of listeners' native phonetic categories. In an early influential perceptual study, Stevens, Liberman, Studdert-Kennedy, and Öhman (1969) asked native speakers of AE and native

Swedish speakers to listen to synthesized front rounded steady-state Swedish vowels, which are not phonemic in English. AE and Swedish listeners did not differ significantly in their accuracy of discrimination of these isolated vowels. Stevens and his colleagues concluded that, unlike discrimination of consonants, discrimination of steady-state vowels was not influenced by listeners' linguistic experience.

Stevens et al.'s (1969) conclusion, based on a study using synthetic vowels in isolation and a physical-identity (rather than name-identity) discrimination task, is inconsistent with subsequent findings using natural stimuli and new paradigms for testing listeners' labeling patterns of non-native phonemes. These more recent studies have indicated that the perception of unfamiliar vowel contrasts is indeed strongly affected by a listener's native language (e.g., Best, Faber, & Levitt, 1996; Gottfried, 1984; Gottfried & Beddor, 1988; Polka, 1995; Strange, et al., 2005). Polka's (1995) study of the perception of German vowels is most relevant here. American English-speaking adults with no German experience showed native-like discrimination performance for the northern German tense vowel pair /u/ vs /y/, but not for the lax vowel pair /ʊ/ vs /ʏ/, in /dVt/ syllables. Discrimination skills clearly depended, at least in part, on listeners' linguistic background. This is consistent with Politzer's (1961) finding of a strong positive correlation between number of years of French study and vowel discrimination abilities for AE students of French.

1.2. Task variables

Task variables became of concern to researchers as it became apparent that results from traditional discrimination studies differed from those from identification studies (Flege & Hillenbrand, 1984). Discrimination of vowels may rely partially on salient physical differences between stimuli. Consequently, results from traditional discrimination tasks do

not predict reliably whether the listener will perceive two phones as belonging to the same phonetic category (Beddor & Gottfried, 1995). Identification (labeling) tasks, however, provide evidence that listeners do tend to have difficulty categorizing non-native vowels.

In Rochet's (1995) study of labeling patterns of Canadian English, native Brazilian Portuguese, and native Standard French listeners, the participants were instructed to identify synthetic vowels on a high vowel continuum as /i/ or /u/ (or /i-y-u/ for French listeners). Vowels that were labeled as /y/ by native French listeners were most frequently labeled as /u/ by Canadian English listeners and as /i/ by Brazilian Portuguese listeners. Clearly, language background influenced not only whether identification was "native-like," but also into which native language categories non-native phones were likely to fall.

Research paradigms implemented in perception studies have undergone changes as researchers have sought direct methods of investigating listeners' identification patterns of non-native phones in natural speech (Best, 1995). The appropriateness of traditional identification tasks is questionable when subjects are unfamiliar with the orthography and phoneme inventory of a non-native language. Yet physical-identity discrimination tasks do not necessarily reveal how a listener would categorize speech sounds of a foreign language. A solution to this problem, the name-identity (categorial) discrimination paradigm (e.g., Gottfried, 1984), permits subjects to indicate whether two physically different phones are of the same category without requiring any labeling (Beddor & Gottfried, 1995). In this paradigm, the stimuli that are "the same" are actually physically different tokens of the same category (either uttered by different speakers or by the same speaker in a different utterance). In an AXB presentation format, for example, listeners are asked to indicate whether the second stimulus is the same category as the first or third stimulus. Because listeners are

required to discriminate not on the basis of physical differences among the stimuli, but rather on the basis of phonetic categories, listeners' classification of non-native phones can be examined.

1.3. American English listeners' perception of French vowels

Using a categorial ABX discrimination paradigm, Gottfried (1984) tested AE listeners' perception of French vowels produced by three native French speakers. (In each trial, the three stimuli were produced by different speakers.) Listeners consisted of two groups of AE participants and one group of native French participants. The "non-French speaking Americans" were 20 AE speakers, mostly from the Upper Midwest, with no knowledge of French. The "French-speaking Americans" were 10 native AE speakers who had studied French as adults (mean = 7.7 years of study). Some of these participants were French teachers. The 10 "Native French" participants came from several regions of France; most were graduate students in Minnesota, and all spoke English proficiently.

Eight vowel pairs that were frequently confused in an initial identification experiment were tested in Gottfried's (1984) categorial discrimination task: /e, ɛ /, /ɛ, a/, /i, e/, /ɑ, ɔ/, /u, y/, /a, ɑ /, /y, ø/, and /ø, œ/. The pairs were tested in two contexts—isolated vowels (#V#) and in /tVt/ syllables. Native French listeners performed significantly more accurately than both groups of AE listeners, revealing the powerful effect of the listeners' native language on their phonetic categorization. Furthermore, the AE listeners who spoke French discriminated vowels in /tVt/ context significantly better than those who did not speak French, but the two groups did not perform significantly differently for vowels in isolation. Gottfried (1984) found that in /tVt/ context, contrasts involving the French rounded vowels /u-y/ and /y-ø/ were more difficult for AE listeners than for native French listeners to discriminate. On these

vowel pairs, AE subjects with no knowledge of French made the most errors (mean = 32% for /u-y/ and 53% for /y-ø/). AE listeners with French experience made fewer errors than the AE listeners who did not speak French (mean = 20% for /u-y/ and 35% for /y-ø/). However, the difference between the American English groups was not statistically significant due to large within-group subject variability. Native French speakers made significantly fewer errors than either group of American speakers (6% and 19%, respectively). The results for the three pairs involving front rounded vowels in isolation were non-significant (Native French: 11%, Inexperienced: 17%, Experienced: 21% errors), although the groups showed a tendency in the same direction as for those vowels in /tVt/ context.

1.4. Consonantal context effects: Implications for models of speech perception

Gottfried's (1984) study, as well as all other studies of front rounded vowels, were performed with vowels either in isolation (Rochet, 1995; Stevens et al., 1969) or in alveolar context (Best et al., 1996; Flege, 1987; Flege & Hillenbrand, 1984; Polka, 1995; Polka & Bohn, 1996). These studies typically used citation form utterances, which differ from sentence-form speech. Stack, Strange, Jenkins, Clark III, and Trent (2006), found that English vowels produced in phrases may show "target undershoot" compared to their counterparts produced in citation form. As demonstrated by Moon and Lindblom (1994), less target undershoot occurred when speakers "overarticulated" in an effort to produce clear speech than when they simply produced vowels in citation form (but see Van Son & Pols, 1992, indicating that Dutch vowels spoken at different rates show minimal differences in formant frequency values). Perceptual consequences for AE listeners confronted with non-native vowels in various consonantal contexts in continuous speech might thus be expected, particularly in light of the findings that PF /y/ is physically more similar to PF /i/ than to PF

/u/ in all contexts, but that AE back vowels are "fronted" in alveolar context (Hillenbrand et al., 2001; Strange, Weber, Levy, Shafiro, & Nishi, 2002).

The present study readdressed Gottfried's (1984) questions regarding the discrimination of French vowels by AE listeners with and without French experience. However, this study departed from Gottfried's study and from other previous research in the following crucial ways: First, the examination focused on the effects of place of articulation of consonantal context, rather than shape of syllable, on vowel perception. A second change was that phrase-level speech was used instead of citation form utterances or isolated syllables, in an effort to render the stimuli more representative of "real world" speech. Thus, the vowels were presented in two disyllable contexts (/rabVp/, /radVt/) in phrases (raCVC à des amis). Because the memory load associated with the perception of vowels embedded in phrases was a concern, an AXB task was employed, in which the comparison stimulus was temporally equidistant from both A and B. In addition, whereas Gottfried's study examined vowel pairs such as /ø-œ/, /e-ɛ /, and /a-ɑ/, which are almost never contrastive in French, the present study focused on discrimination of the contrastive pairs /u-y/, /u-œ/, /i-y/ and /y-œ/. (Note: For the purposes of the current study, [ø] and [œ] are considered allophones in French, and the symbol /œ/ represented the mid front rounded vowel category.) Nonsense words were used in order to avoid the confound of lexical effects.

An objective of the present study was to explore the possibility of context-specific vowel perception and its implications for theories of second/foreign-language speech learning. Flege's (1995) Speech Learning Model (SLM) and Best's Perceptual Assimilation Model (PAM, 1994, 1995) emphasize L1 (native language)/L2 perceptual similarity as predictive of difficulties in discriminating non-native contrasts. Flege characterizes non-

native phones along a continuum of similarity to L1 phones from "identical," through "similar" to "new." Flege (1987) posited that French /y/ was a "new" phone for native AE speakers, based on their native-like production of French /y/ with increased French language experience. In contrast, the AE speakers did not attain native-like production of the "similar" vowel /u/. New phones, according to this theory, may be difficult to perceive by naïve listeners, but will eventually become differentiated from L1 phones (and other L2 phones) as L2-learners gain experience. Best's theory claims that naïve listeners perceptually assimilate non-native phones into L1 categories on a continuum of "category goodness." If two non-native phones are considered good exemplars of the same native category, they will be very difficult to discriminate. If the two phones are perceptually assimilated to the same native category, but differ in their perceived "category goodness," they will be easier to discriminate. Finally, if non-native phones are assimilated to different native categories, they will be very easy to discriminate. Effects of native-language coarticulatory patterns on perception or production of non-native/L2 phones are not addressed directly by these models.

Strange et al. (2005) examined the perceptual assimilation of German front rounded vowels in bilabial, velar, and alveolar contexts by naïve AE listeners, using a task in which listeners were asked to categorize the non-native vowels into native categories and rate their category goodness on a Likert scale. Results indicated that German front rounded vowels were perceptually assimilated to back rounded AE vowels more than to front unrounded AE vowels when presented in multisyllabic nonsense words in sentence context. German /y/ and /u/ were both rated very good matches to AE /u/ in both alveolar and non-alveolar contexts. The other German front rounded vowels /ʏ, ø, œ/ were also categorized as most similar to

back AE vowels /u, ʊ, o, ʌ/, although there was considerable variation in exactly which AE back vowel category they were most similar to, and category goodness ratings for /ʏ, œ/ were somewhat lower than for /y, ø/ in alveolar and velar contexts. Thus, as in the previously-discussed studies, front rounded vowels were perceived as more similar to back vowels than their acoustic properties would predict. In this perceptual assimilation study, responses did not vary as a function of consonantal context. On the other hand, in a study of native Japanese listeners' perceptual assimilation of AE vowels (Strange, Akahane-Yamada, Kubo, Trent, & Nishi, 2001), context-dependent patterns were found, with perceived similarity of /i, u, ɪ, ɛ, ʌ, ʊ/ varying with final consonant voicing. Thus, in this case, models of non-native speech perception might better predict cross-language perceptual patterns if consonantal context effects are considered.

In sum, previous research indicates that front rounded vowels are typically confused with back vowels by AE listeners, despite being acoustically more similar to front vowels (Gottfried, 1984). Furthermore, perceived similarity may (e.g., Strange et al., 2001) or may not (Strange et al., 2005) vary with consonantal context and discrimination of L2 vowels may depend on syllable shape (Gottfried, 1984). Thus, questions arise regarding AE listeners' discrimination of L2 vowels in different consonantal contexts.

1.5. The present study: Research questions and predictions

In the present experiment, perception of the PF vowel pairs /u-y/, /œ-u/, /œ-y/, /i-y/, /i-u/, and /i-œ/ by AE listeners was investigated. Examining listeners' categorial discrimination of these pairs permitted three questions to be addressed and predictions to be made:

1) Does American English listeners' discrimination of French vowels improve with French language experience?

Gottfried's (1984) study showed a non-significant tendency for AE listeners with considerable knowledge of French to discriminate French vowels better than naïve AE listeners, but less accurately than native French listeners. AE speakers with French experience in the present study were expected to perform with greater accuracy than those with no knowledge of French, although difficulty discriminating some contrasts involving front rounded vowels was expected to persist, even with French experience.

2) Are there significant differences in the discrimination of the four experimental vowel pairs involving front rounded vowels—and if so, do relative difficulties differ with experience?

The high front rounded versus high back rounded contrast /u-y/ was expected to be the most difficult to discriminate, given previous research on discrimination (Gottfried 1984) and identification (Rochet, 1995). The /u-œ/ contrast was expected to be difficult, as both might be perceived as similar to AE /u/ or /ʊ/. However, the height difference was expected to render them moderately differentiable. Likewise, /y-œ/ was expected to yield fewer errors than /y-u/ due to the height distinction. Best, Faber, and Levitt (1996) found that most AE listeners assimilated /y-œ/ into two separate categories. On the other hand, Gottfried (1984) found this contrast difficult for AE listeners. Thus, in the present study, a range of discrimination scores was predicted for this vowel pair. On the control pairs /i-u/ and /i-œ/, the expectation was that both groups of AE listeners would make few errors in discrimination.

3) Does consonantal context affect discrimination patterns, and if so, do context effects vary with vowel pair and second language experience?

It was predicted that vowel discrimination would be affected by consonantal context, as was the case in Gottfried's (1984) study. Vowels in /dVt/ context were expected to be more difficult to differentiate than vowels in /bVp/ context. Specifically, AE listeners were predicted to have more difficulty discriminating French high and mid front rounded vowels from /u/ in alveolar context than in bilabial context. These predictions were based on the acoustical finding that AE back rounded vowels are fronted in alveolar context (Hillenbrand et al., 2001), thus it might be expected that AE listeners would perceptually assimilate French front rounded vowels in alveolar context to their /u/ vowel category.

2. Method

2.1. Stimulus materials

Three female adult native speakers of PF were recorded in a sound-attenuated chamber in the Speech Acoustics and Perception Laboratory at the Graduate Center of the City University of New York (GC CUNY). The native French speakers were instructed to read the list of French sentences containing nonsense words. The list consisted of the 9 French vowels in /bVp/ or /dVt/ consonantal context within the nonsense word /rabVp/ or /radVt/ in the carrier sentence: "J'ai dit neuf raCVC à des amis." [I said nine raCVC to some friends.] Each carrier sentence was preceded by an identifying number. Although the only stimuli used for presentation were the phrases with the vowels /i/, /u/, /y/, and /œ/ in the target words, the full French vowel inventory was included in the protocol for future determination of each speaker's entire "vowel space" and so as not to cause excessive lip rounding that

might occur if the protocol included only the vowels of interest for the study, most of which were rounded. Each list ended with a repetition of the first utterance to control for differences in intonation that result when an utterance occurs at the end of a list. This last token was discarded unless the first token was deemed unacceptable. Speakers read four blocks of each list in each consonantal context. Speakers were instructed to produce the sentences as if they were in conversation with a native speaker.

The first author (a native speaker of both French and English) monitored the recording sessions. If a sentence contained inconsistent pronunciation, rate, prosody, voice quality or noise, she asked the speaker to repeat the utterance. Speakers were permitted to repeat utterances if they felt they misarticulated or heard noise. A Shure (SM48) microphone was used, and recordings were made directly onto a Dell Dimension XPS B800 computer with a Soundblaster Live Wave DF80 sound card via an Earthworks microphone preamp (Lab 101). The signal was fed through a Harman/Kardon 595 subwoofer and loudspeaker. The experimenter spoke French with the speakers through a Radio Shack 2-station wired intercom, and monitored the recording through Sennheiser HD565 Ovation headphones. During recording, the stimuli were digitized directly as computer files using Soundforge software, with a sample rate of 22,050 Hz, 16-bit resolution, and on a mono channel. Calibration was performed such that the DC offset was adjusted, and autosnap to zero was selected. The signal level was set such that levels varied from –18 dB to approximately –6 dB.

The tokens used for the experiment were those produced by the participants in the third and forth blocks, unless the first author heard noise in those recordings. If this was case, the noisy tokens were replaced by tokens from the second block. A monolingual native

speaker of French was consulted to judge whether the chosen tokens were typical instances of the target vowel. He was able to identify all vowel targets accurately and with reported ease, thus no changes were made to the selection of tokens. The digital files containing the full sentences (e.g.,"J'ai dit neuf raCVC à des amis.") were then edited so that only the phrases (e.g., "neuf raCVC à des amis") remained for presentation to listeners. From these shortened utterances, listening tests were created.

Figure 1 displays the spectral characteristics of the four PF test vowels uttered by the three native PF speakers in the current experiment, plus the low vowel /a/. Also provided for purposes of comparison are average values for AE vowels produced in nonsense trisyllables (gaCVCa) in a carrier sentence by three female native AE speakers for a production study by Strange et al. (2002). [Insert Figure 1 about here.] Vowels produced in /bVp/ context are displayed in Figure 1A; vowels produced in /dVt/ context are shown in 1B. For both vowel sets, the plots indicate the F1 and F2 values (in Bark), measured from a 25 ms window located at the temporal midpoint of the CVC syllables, using LPC algorithms (24 coefficients) with hand correction, when necessary, from FFT plots of the same interval. The average values for the two tokens of each vowel spoken by each of the three PF speakers are indicated by solid symbols. The AE vowels are values averaged over 12 tokens (4 tokens X 3 speakers) of each of the 7 long AE vowels.

As the figures show, the formant values for the high front unrounded and rounded PF vowels /i, y/ are very similar to each other, and closest to the AE front unrounded vowel /i/. F3 values (not shown in the figure) are also quite similar for these two vowels: F3 for PF /i/, PF /y/, and AE /i/ are 16 Bark, 15 Bark, and 16 Bark, respectively. PF and AE high

back /u/ are located near each other in vowel space in bilabial context, but differ markedly in alveolar context because of the greater allophonic "fronting" of this AE vowel in this context. Finally, PF /œ/ is spectrally intermediate between AE front and back mid vowels /e/ and /o/ in both contexts. Note that in alveolar context, PF /œ/ is quite similar to AE /u/ and /ʊ/ (not shown here).

Each of the six vowel pairs (/u-y/, /œ-u/, /œ-y/, /i-y/, /i-u/, and /i-œ/) was incorporated into an AXB trial. Each trial contained three tokens produced by three different speakers. For example, a trial contained A: /u/ produced by the first speaker, X: /u/ by the second speaker, and B: /y/ by the third speaker. The listener was instructed to indicate which phrase (A or B) had the target word with the same vowel as the middle phrase. In the example, a correct response was scored by indicating A. There were four possible orders for presentation of each A-B vowel pair: AAB, ABB, BBA, and BAA. The three speakers could be arranged in six possible orders. The stimulus and speaker orders within the triplets were randomly assigned without replacement, with all combinations of speakers used within each block of 24 trials. Each block contained four trials of each of the six contrasts and an equal number of A and B responses.

Three such blocks of 24 trials were presented for each consonantal context, so that each vowel pair was presented a total of 12 times within each context. For half of the subjects in each language background category, the first 3 blocks of 24 trials were presented in /bVp/ context and the next 3 blocks contained vowels in /dVt/ context. The opposite order occurred for the other half of the subjects. Thus, 6 blocks of 24 items yielded a total of 144 trials for each listener. The inter-stimulus interval was 500 ms, and trials were self-paced.

2.2. Participants

A total of 20 native speakers of AE (ages 21 to 51 years, mean of 36 years) volunteered as listeners for the tests and were paid for their participation. They were recruited primarily from Columbia University and GC CUNY. In addition, four native speakers of French who had been in the U.S. for less than a year were tested for stimulus verification purposes. All participants passed a bilateral hearing screening at 20dB at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz.

Of the AE listeners, 10 were native speakers of AE living in New York City, who had minimal experience with French (Inexp Group), i.e., they had never had French instruction nor interacted with French speakers with any regularity. Participants in this group had not had instruction in German or other languages with front rounded vowels.

The second group of AE participants, AE listeners with French experience (Exp Group), consisted of 10 native speakers of AE living in New York City, with a mean of 7 years of instruction in French that began after the age of 13 years. They were recruited primarily from Columbia University, the Alliance française (French Institute), from a weekly French conversation club at a Jewish community center, and from GC CUNY. All of these participants had spent some time (range of 12-38 months) in France as adults. Several used French daily in their professions (e.g., as French instructors, translators). Prior to their instruction, they had not had any consistent exposure to French.

2.3. Procedure

Participants listened to the stimuli presented via Sennheiser HD565 Ovation Headphones connected to a Harman/Kardon HK195 Multimedia Speaker system, receiving the signals from the computer. Stimuli were randomized and presented using customized

presentation software. Written instructions were provided in English for AE listeners and in French for native French listeners. Participants were instructed to click on "1" if the vowel in the second stimulus was the same vowel as in the first, and "3" if it was the same as the vowel in the third. Prior to testing, AE subjects were given task familiarization in which they were asked to discriminate vowel pairs involving 24 trials of AE /ɛ/, /ɑ/, /æ/, and /ɪ/ vowel pairs in the AXB paradigm. French listeners were given a similar familiarization task in French, involving French contrasts not included in the experimental trials /a/, /ɛ/, /o/, and /ɔ/). Computer feedback was provided for task familiarization. All participants performed at better than 90% accuracy on task familiarization. The AE task familiarization was followed by 24 trials of French stimulus familiarization. Stimulus familiarization was identical to the actual experimental task, except that, as participants were informed, their responses would be discarded for this block. Thus, for example, a participant would respond to one block of task familiarization trials, then 1 block of stimulus familiarization in alveolar context, 3 blocks of experimental trials in alveolar context, 1 block of stimulus familiarization in bilabial context, followed by 3 blocks of experimental trials in bilabial context.

3. Results

3.1. Data analysis

Errors were tallied over trials for each vowel pair in each context, and were converted to percentages of errors. An error was defined as responding "3" when the trial was AAB or "1" when the trial was ABB.

3.2. Stimulus and task verification

Figure 2 provides an overview of percent errors for the three subject groups for each vowel pair. [Insert Figure 2 about here.] Error bars represent standard errors of the mean for

each condition. The first four vowel pairs shown from left to right are the experimental contrasts and the last two are the control contrasts. The native French group performed at ceiling for all vowel pairs (overall mean of < 1% errors), confirming that the stimuli were appropriate. All groups performed well on both control vowel pairs (< 1 error in 12). The task was a difficult one, as the three-speaker stimulus presentation required vocal tract normalization and concentration on the stimulus in question within running speech. The excellent performance of all groups on the control vowel pairs, despite this challenging task, suggests that the task was understood by all. With the task and stimuli verified, the statistical analysis focused on the subjects and vowel pairs of interest in the investigation: the two groups of AE listeners' performance on the experimental vowel pairs /u-y/, /i-y/, /u-œ/, and /y-œ/.

3.3. Language experience

Listeners with French language experience (Exp) made fewer errors overall (11%) than inexperienced (Inexp) listeners (24%). A 2 (language) X 4 (vowel pair) X 2 (consonantal context) mixed design Analysis of Variance with repeated measures on vowel pairs and consonantal contexts within language groups confirmed a significant (between-subjects) effect of participants' language background, $F(1,18) = 15.04$; $p < 0.01$. Thus, experience with French was associated with improved differentiation of French vowels. However, this was not true for every vowel pair.

3.3.1. Experimental vowel pairs

Figure 2 further indicates that not all vowel contrasts were equally difficult to differentiate. Overall, differences were found in listeners' accuracy of discrimination of the four vowel pairs, as confirmed by a significant main effect of vowel pairs, $F(3,54) = 10.40$;

$p < 0.01$. Due to the different within-group variances, which had been pooled in the original analysis, an additional Analysis of Variance was performed within each language group (with consonantal contexts collapsed) to determine whether differences in performance for each vowel pair were significant for each group. For the Inexp group the vowel pair effect was significant, $F(3,27) = 3.02$; $p = .047$, but a post-hoc Tukey test revealed no significant differences between vowel pairs. (This finding will be explained below by an interaction between performance on /i-y/ and /u-y/ and consonantal context for the Inexp group.) For the Exp group, a within-group analysis of variance revealed a significant vowel pairs effect, $F(3,27) = 17.95$; $p < 0.01$. A post-hoc Tukey test confirmed that performance on the /u-y/ vowel pair was significantly less accurate than performance on the other contrasts.

3.3.2. Comparison of inexperienced and experienced groups on experimental vowel pairs

Figure 2 further indicates that the Inexp Group had much more difficulty distinguishing 3 of the 4 contrasts: /i-y/ (16% errors), /u-œ/ (27% errors), and /y-œ/ (29% errors) than did the Exp Group (3%, 3%, and 8% errors, respectively). However, the experienced listeners made *more* errors than the inexperienced listeners on the /u-y/ vowel pair (30% errors vs 24%, respectively). The original 2 X 4 X 2 Analysis of Variance confirmed a significant interaction between participants' language background and vowel pair, $F(3,54) = 9.29$; $p < 0.01$. Pairwise t-tests for the Inexp vs Exp groups for each vowel pair (LSD = 8.1) indicated that the two groups differed significantly for the experimental vowel pairs /i-y/, /u-œ/ and /y-œ/, but not for /u-y/. That is, for the vowel pairs /i-y/, /u-œ/ and /y-œ/, experience with French was associated with better discrimination. However, again it was evident that for the vowel pair /u-y/, several years of French instruction were not

associated with better discrimination of this contrast. These somewhat surprising results become more understandable when the consonantal context effect is considered.

3.4. Consonantal context

Figures 3A and 3B present performance of inexperienced listeners and experienced listeners, respectively, on each vowel pair in bilabial (/bVp/) versus alveolar (/dVt/) conditions. [Insert Figures 3A and 3B about here.] For each vowel pair, the left (checkered) bar represents the /bVp/ context and the right (solid) bar represents the /dVt/ context. Overall, the /dVt/ context presented more difficulties (22% errors) for listeners than did the /bVp/ context (13% errors). The original 2 X 4 X 2 Analysis of Variance confirmed the main effect of consonantal context, $F(1,18) = 17.61$; $p < 0.01$.

For the inexperienced group (Figure 3A), performance differed considerably by context, with these inexperienced listeners making more errors in alveolar context than in bilabial context for 3 out of the 4 vowel pairs (39% vs 8% for /u-y/, 35% vs 19% for /u-œ/, and 44% vs 14% for /y-œ/ in alveolar vs bilabial context, respectively). For /i-y/, however, the reverse was true: Inexp listeners made fewer errors in /dVt/ context (8%) than in /bVp/ context (24.2%). Paired t-tests for /bVp/ vs /dVt/ context for each vowel pair confirmed that the difference between errors for each experimental vowel pair as a function of context was significant ($p < 0.01$ for /u-y/, $p = 0.016$ for /i-y/, $p = 0.03$ for /u-œ/, and $p < 0.01$ for /y-œ/). That is, consonantal context influenced inexperienced listeners' performance, mostly leading to more difficulty in alveolar context, but in the case of /i-y/, leading to more difficulty in bilabial context. As predicted, listeners appeared to confuse /y/ (and /œ/) with /u/ in alveolar context. Presumably, in bilabial context, in which far less fronting of back rounded vowels

occurs in English, the /y/ tended not to be perceived as similar to AE /u/ and was more often perceived as similar to AE /i/.

Figure 3B shows the performance of experienced listeners for each vowel pair in /bVp/ vs /dVt/ context. Unlike the inexperienced listeners' performance, the experienced listeners' discrimination of vowel pairs was not clearly affected by consonantal context (e.g., 3% errors for /i-y/ in /bVp/ and in /dVt/ contexts; 24% and 35% for /u-y/ in /bVp/ and /dVt/ contexts, respectively). Although there was a consistent trend for experienced listeners to confuse phones in alveolar context (mean of 13% errors) more than in bilabial context (mean of 9% errors), t-tests indicated that the differences between performance on each vowel pair as a function of context was not significant for the Exp group ($p = 0.24$ for /u-y/, $p = 0.78$ for /i-y/, $p = 0.10$ for /u-œ/, $p = 0.71$ for /y-œ/). Evidently, as the experienced group had learned French, although they had persistent trouble with the /u-y/ distinction, they had successfully learned the coarticulatory variations that exist within categories of French vowels.

4. Discussion

4.1. Summary of the results

Results of the present study revealed that American listeners' performance on French contrasts involving front rounded vowels varied as a function of their experience with the French language, the particular vowel contrast, and the consonantal context in which the words were produced. Interactions were found among all of the variables, indicating that the /u-y/ contrast was the most difficult to learn with native-like accuracy, and that differences in consonantal context affected inexperienced listeners more than experienced listeners. For inexperienced listeners, more errors were made in alveolar context than in bilabial context on

all tested vowel pairs except /i-y/, which they differentiated with significantly less accuracy in bilabial context than in alveolar context. The three questions posed in the introduction are readdressed in light of the experimental findings:

1) Effects of L2 experience: As predicted, participants who had studied French performed better overall than participants who had not. For three of the four vowel pairs, learning French was associated with better discrimination of contrasts—discrimination that was close to native-like in accuracy. Only /u-y/ caused persistent problems in discrimination even after several years of French language experience. Table 1 lists the experienced listeners' professions, years of formal and immersion French experience, amount of use, and their performance on the /u-y/ contrast in /bVp/ and /dVt/ contexts. [Insert Table 1 about here.] Even the foreign language professionals (e.g., the professor of French, the teacher, and the translator) made 25%-75% errors in alveolar context on /u-y/ contrast, suggesting that these individuals, who presumably have metalinguistic awareness of the French vowel system, were no more skilled than the other participants in discriminating PF /u/ from /y/. Two participants, 07EF and 09EF (i.e., Participants 7 and 9 from the group of native English speakers who spoke French), made no errors in either alveolar or bilabial context, respectively, suggesting that, in Flege's (1995) terminology, they may have formed a new category for the /y/ vowel in that particular context. However, both of these participants did make errors in the other context (17% in bilabial context by 07EF and 42% errors in alveolar context by 09EF), indicating that their new vowel categories were not stable across consonantal contexts.

2) Relative difficulty of vowel contrasts: As predicted, vowel pairs were not equally difficult to discriminate. When the responses given by the two groups of Americans were combined,

error patterns were generally consistent with previous literature (e.g., Gottfried, 1984; Polka, 1995) and with the present study's prediction that listeners would have persistent difficulties discriminating /u-y/. This contrast caused the most difficulty overall; however, as will be discussed below, relative performance on vowel pairs depended upon listeners' background and the consonantal context in which vowels were presented. As expected, /i-y/ was easier to discriminate than /u-y/ overall; however, some Americans did fail to differentiate /y-i/ especially in bilabial context. The /u-œ/ and /y-œ/ contrasts caused more difficulties than had been predicted on the basis of the height distinction. However, Gottfried's (1984) study had also revealed poor discrimination for the /y-œ/ pair. For AE listeners without French experience, front rounded phones, which were not in their native language inventory, tended to be confused with each other or with back rounded phones, despite the difference in tongue height. As listeners became more familiar with French, their ability to differentiate these contrasts that involved a tongue height distinction improved.

3) Effects of consonantal context: As predicted, the results indicate that consonantal context does have a striking effect on naïve listeners' perception. Thus, studies of inexperienced Americans' perception of the /u-y/ contrast must take into account the important interaction between vowel pair and consonantal context. For the /u-y/ contrast, inexperienced listeners produced more errors than for any other contrast in /dVt/ context, and the fewest errors of all contrasts for /u-y/ in /bVp/ context. The reverse was true for the /i-y/ vowel pair: they produced fewer errors for /i-y/ than for any other contrast in alveolar context, and more errors for /i-y/ in bilabial context than for any other contrast in that context. The experienced listeners did not reveal this context effect.

Presumably, in alveolar context, in which AE back rounded vowels are fronted, AE listeners, not familiar with French vowels, will perceive phones such as /y/ as falling into their AE /u/ category, thus leading to confusion between PF /y/ and PF /u/. On the other hand, when /y/ is presented in bilabial context, in which AE back vowels remain back, /y/ may not be perceived as similar to /u/, but rather as more similar to /i/, a category to which it is spectrally closer.

The results further suggest that for all vowel pairs, including the stubborn /u-y/ contrast, experienced listeners have learned to perceive vowels in a way that is less affected by consonantal context than their inexperienced counterparts. A context effect had been predicted for both groups, with the inexperienced group predicted to have more difficulty in alveolar context than the experienced group. The findings were even stronger than the prediction: only the inexperienced group was affected by context, although there was a trend for experienced listeners for vowel contrasts to be more discriminable in bilabial context. The finding that the experienced group perceived contrasts in a way that was less affected by consonantal context suggests that they had abstracted a representation of French vowels that was closer to that of native listeners. As they learned their L2, they also learned its rules of coarticulation and allophonic variation.

4.2. Acoustic Similarity and Discrimination Difficulty

Acoustic analysis of the test materials revealed that, overall, spectral similarities among PF vowels did *not* predict AE perceptual confusions. As Figures 1A and 1B indicate, PF /i-y/ are far more similar *spectrally* than are /u-y/ in both bilabial and alveolar contexts. Yet, for both the Inexp group and the Exp group, the /u-y/ contrast was more difficult to

perceptually differentiate overall than the /i-y/ contrast. In alveolar context for both groups, and even in the bilabial context for the Exp group, discrimination of the acoustically more distinct /u-y/ contrast was more difficult than /i-y/.[1]

AE back rounded vowels are often fronted, especially in alveolar context, while AE front unrounded vowels are never "backed" (Hillenbrand et al., 2001). Thus, in this difficult discrimination task, in which the speaker varied from token to token and the target vowels were embedded in phrase-length utterances, both experienced and inexperienced listeners' discrimination performance appeared to be influenced more by the perceived similarity of French and AE vowels (based on the listeners' native phonology), than by the vowels' acoustic similarity per se. Cross-language perceptual difficulties, when tested with phrase- or sentence-length materials, appears to be based on listeners' experience with the acoustic (and underlying articulatory) variability of their native vowels, i.e., the distributional characteristics of L1 vowel categories. In terms of the PAM (Best, 1995) and the SLM (Flege, 1995), these discrimination data suggest that PF /u/ and /y/ had both been perceptually assimilated to the AE back vowel /u/, and thus were difficult to differentiate perceptually.

The mid front rounded PF vowel /œ/ was spectrally quite dissimilar from all three of the other PF vowels examined here in both bilabial and alveolar contexts and acoustically intermediate between AE front and back vowels in bilabial context (see Figures 1A and 1B). In relation to AE vowels, however, again this front rounded vowel is more similar to fronted AE /u, ʊ/ in alveolar context. Thus, whereas both inexperienced and experienced AE listeners made almost no errors in discrimination of /i-œ/ in either context, the inexperienced

listeners made many more errors on /u-œ/, especially in alveolar context. Cross-language perceptual patterns, influenced by native language phonology, again appear to predict these errors more accurately than acoustic (dis)similarity patterns.

In summary, a comparison of discrimination performance and the acoustic characteristics of the stimulus materials suggests that confusions involving French front rounded vowels cannot be predicted on the basis of acoustic similarities among the French vowels. Instead, explanations must refer to AE listeners' perceptual representations of French vowels, with inexperienced listeners relying more heavily than experienced listeners on patterns of allophonic variation within their native phonological system.

4.3. Comparison with previous studies

Results from the present experiment may be compared to Gottfried's (1984) study of AE listeners' perception of French vowels. The vowel contrasts (in alveolar context) common to both studies share the finding that Americans with knowledge of French performed at levels intermediate between native speakers and Americans without knowledge of French. Native French subjects performed better in the present study than in Gottfried's (mean of 1% vs 22% errors, respectively), and the /y-ø/ (transcribed in the present study as /y-œ/) contrast was more difficult for listeners in Gottfried's study than in the present study (36% vs 18% errors, respectively). Both studies indicated that /y-œ/ is generally more difficult than /u-y/ for inexperienced listeners (Gottfried: 53% vs 32% errors; present study: 29% vs 24% errors, respectively). Gottfried's study indicated the same was true for experienced listeners (35% errors for /y-œ/ vs 21% errors for /u-y/). However, in the present study, experienced listeners performed significantly better on /y-œ/ (8% errors) than on /u-y/

(30% errors). These differences in results are likely to be consequences of differences between the studies in subject selection, task variables, and stimulus variables. However, further studies are needed to determine French-learning Americans' discrimination abilities for /y-œ/ as they become proficient in French (see Levy, 2004, for an examination of discrimination and perceptual assimilation of French vowels by AE listeners with formal French vs formal plus immersion French experience).

Gottfried (1984) discussed his finding that French vowels in /tVt/ context were more difficult to perceive in a native-like manner than isolated vowels in terms of syllabic (/tVt/ vs /V/) shape. The present study suggests that another factor, place-of-articulation of surrounding consonants, may be added to the variables affecting performance. In the present study, vowels in alveolar (/dVt/) context were generally perceived with less accuracy than those in bilabial (/bVp/) context, presumably because of the perceived relationship between front and back French vowels and "fronted" back AE vowels in alveolar contexts. This fronting phenomenon does not occur for vowels in isolation; thus, Gottfried's reported difference in performance on /V/ vs /tVt/ syllables might have been due to this variation in coarticulatory effects, rather than to syllable structure per se.

Polka (1995), like Gottfried (1984), embedded vowels in /dVt/ syllables to examine listeners' performance on contrasts of front vs back rounded vowels, and Flege (1987) and Flege and Hillenbrand (1984) examined AE speakers' production of PF /y/ and /u/ in /tV/ context. Replications of such studies including vowels surrounded by consonants other than alveolars would help tease apart the influences of syllable shape from place of articulation of surrounding consonants. Similarly, studies such as Stevens et al. (1969) and Rochet (1995),

which involve synthesized steady-state vowels, may be reexamined with the knowledge that the vowel itself is only part of the picture.

4.4. Limitations of present study and subsequent research

A critical and distinctive finding of this experiment has been the powerful effect of consonantal context on listeners' vowel discrimination skills. Limiting the study is (as in all previous L2-vowel discrimination studies) the absence of perceptual assimilation data. Thus questions remain regarding how consonants surrounding a vowel might affect the L1 vowel category to which a non-native vowel will be perceptually assimilated. Specifically, would naïve AE listeners, for example, perceptually assimilate PF /y/ more often to AE /u/ in alveolar context and more often to AE /i/ in bilabial context, as would be predicted by the present study's finding that, overall, inexperienced listeners had greater difficulty discriminating PF /u-y/ in alveolar context and /i-y/ in bilabial context? If a consonantal context effect were revealed in perceptual assimilation, and if it diminished with increased language experience, this would provide further (and perhaps more direct) support for the notion that learning an L2 involves learning to perceive not only its vowels, but also their language-specific coarticulatory variations.

Sparked by the present study, research on the effects of consonantal context on L2 learners' perceptual assimilation and discrimination patterns will continue to be pursued by the authors. Initial indications (e.g. Levy, 2004; Strange, Levy, & Lehnhoff, Jr., 2004) do indeed point to consonantal context effects in the perceptual assimilation of PF /y/ by naïve AE listeners, but no decrease in context sensitivity with increased language experience, suggesting that L1 coarticulatory patterns may continue to exert their influence on some highly experienced L2-learners' perception of non-native vowels.

4.5. Beyond the vowel

Beyond place-of-articulation of consonants surrounding vowels, coarticulatory patterns vary across languages, resulting in potential problems for L2-speech learning. Manuel (1999) reviewed coarticulation patterns in several languages, asking whether the patterns could be predicted based on what is known about the phonemic inventory of a language. Important factors possibly impacting the relationship between coarticulation and other ways in which languages vary include prosody, as well as size and characteristics of the phonological inventory.

Coarticulation occurs not only between consonants and their neighboring vowels, but also between syllables. Beddor, Harnsberger, and Lindemann (2002) found that when listening to synthetic speech based on English and Shona disyllables, Shona listeners were more sensitive to the coarticulatory effects that occurred more often in their native language than to those that occurred less often. This was not clearly the case for English listeners, however, a finding that the authors attributed to English stress patterns.

Thus, native language expectations of coarticulation affect perception of speech sounds in foreign languages. The complexities involved in these expectations and their impact on L2 speech perception require further exploration. Such studies are in their infancy, but promise a better understanding of the phonological processes involved in L2-learning.

4.6. Implications for models of cross-language speech perception

Evidence from the present study and others indicates that differences in contextual variability of vowels across languages strongly affects non-native vowel perception. As more information becomes available about the coarticulation that occurs in continuous speech and its effects on perception and production, speech-perception and L2-learning models that

incorporate contextual variation into their analyses are expected to become more precise in their predictions of perceptual difficulties.

Using the terminology of the PAM (Best, 1994, 1995), the consonants surrounding a vowel affect how that vowel will be perceptually assimilated. The PAM, factoring in consonantal context, would predict that PF /y/ would be more difficult for naïve AE listeners to differentiate from PF /u/ in alveolar context than in bilabial (because PF /y/ is articulatorily more similar to AE /u/ in alveolar context than in bilabial context). Thus, /u-y/ may fall into a single-category assimilation pattern in alveolar context, but into a category-goodness or two-category assimilation pattern in bilabial context. This prediction was supported by the data in the present study, in that discrimination of /u-y/ was significantly more accurate in bilabial context than in alveolar.

Results of the present experiment may also be discussed in terms of the Speech Learning Model (Flege, 1995), which characterizes changes in speech perception and production as individuals gain experience with their L2. The apparent context-specific categorization patterns revealed in the present study suggest that a phonetic level of representation operates in equivalence classification, such that inexperienced listeners perceive vowels as "new" or "similar," differently, depending on the consonants surrounding the vowels. According to Flege (1987), the PF front rounded vowel /y/ is classified as a "new" vowel, although it might initially be confused with PF /u/. Flege posits that with L2 experience, individuals learn to differentiate PF /y/ from AE /u/, i.e., a new phonetic category is established, and /y/ is produced with acoustic norms close to native French values for the front rounded vowel. Results from the present experiment in alveolar context are consistent

with Flege's claim about inexperienced listeners. However, in bilabial context, the same group made fewer than 10% errors in discriminating /u-y/. Thus, in the initial stages of French learning, /y/ could be thought of as a "similar" vowel in alveolar context and as a "new" vowel in bilabial context. Learning an L2 includes learning all of the language-specific variations that occur within its phonetic categories. As listeners learn a second language, their perception is less affected by allophonic variations *within their L1*, as they become more experienced with the allophonic variations of the L2. However, the finding that very experienced listeners still had problems with the /u-y/ contrast suggests that L1/L2 perceptual similarity patterns still exert an influence on L2 perception, even with extensive formal and immersion experience in the L2.

In summary, naïve listeners perceive vowels in an unfamiliar language differently depending on the consonantal context in which they are presented. Certainly, further research into perceptual assimilation and discrimination patterns in various consonantal contexts by L2 learners of various languages is necessary to unravel the discrepancies found in the discussed studies (see also Guion, Flege, Akahane-Yamada, & Pruitt, 2000, re: perceptual assimilation and discrimination of consonants). Such investigations are expected to shed more light on the complex relationships between context-dependent and context-independent cross-language acoustic similarity, on the one hand, and cross-language perceptual similarity, on the other, in determining relative discrimination difficulty across the range of L2 experience.

Acknowledgments

This research was supported by a grant to the second author from the National Institutes of Health (NIDCD-00323). Many thanks to Gerry Docherty, Terry Gottfried, and

two anonymous reviewers for their helpful comments. The authors also wish to thank Gary Chant, Miwako Hisagi, Franzo Law II, Kanae Nishi, Valeriy Shafiro, and Bruno Tagliaferri for their technical assistance.

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Footnote

French, often described as a syllable-timed language, is characterized by approximately equal vowel length for each syllable (Tranel, 1987). In the present study, the mean durations of /i, u, y, oe/ were very similar to each other: 99, 101, 113, and 125 milliseconds, respectively, thus it is unlikely that the AE listeners relied on durational differences rather than on spectral differences to discriminate the vowels.

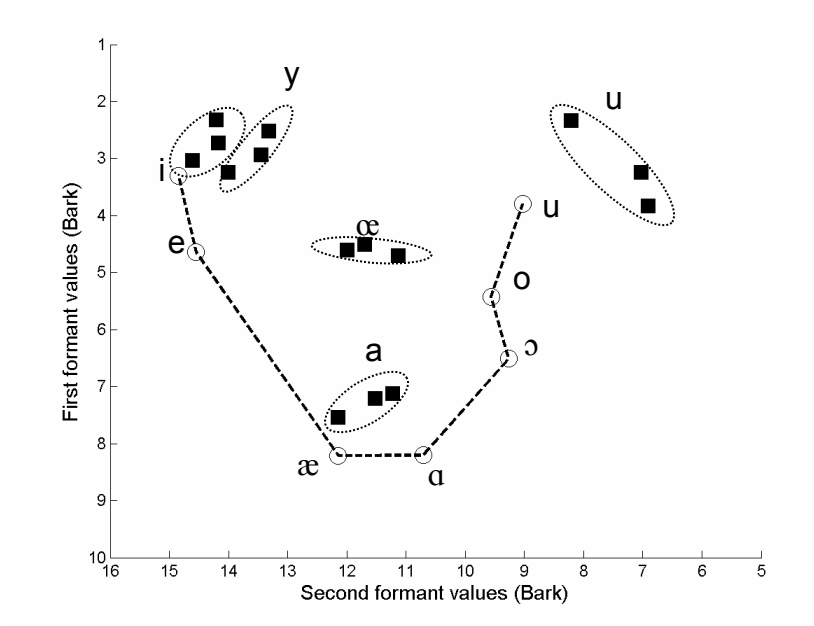
Table 1

Profession, language experience, and discrimination score on /u-y/ contrast for listeners with French experience (EF)

Partici-pant #	Profession	Years studied French	Months spent in France	Current use	Percent error u-y, bp context	Percent error u-y, dt context
01EF	Attorney	6	12	2 days/wk	75	50
02EF	Professor of French	12	26	5 days/wk	33	50
03EF	French teacher/translator	8	14	5 days/wk	8	25
04EF	Translator	8	12	5 days/wk	25	75
05EF	International business	6	13	2 days/wk	25	8
06EF	Flight attendant	7	12	3 days/wk	33	42
07EF	Student (psychology, Paris)	10	24	3 days/wk	17	0
08EF	International business	4	14	5 days/wk	17	8
09EF	Student (Rom. lang/lit)	4	38	5 days/wk	0	42
10EF	International business	5	13	3 days/wk	8	50

Figure 1

A. Parisian French stimuli (solid squares) in bilabial /rabVp/ context in current experiment and American English vowels (open circles) in bilabial /gɑbVpɑ/ context



B. Parisian French stimuli (solid diamonds) in alveolar /radVt/ context in current experiment and American English vowels (open circles) in alveolar /gɑdVtɑ/ context

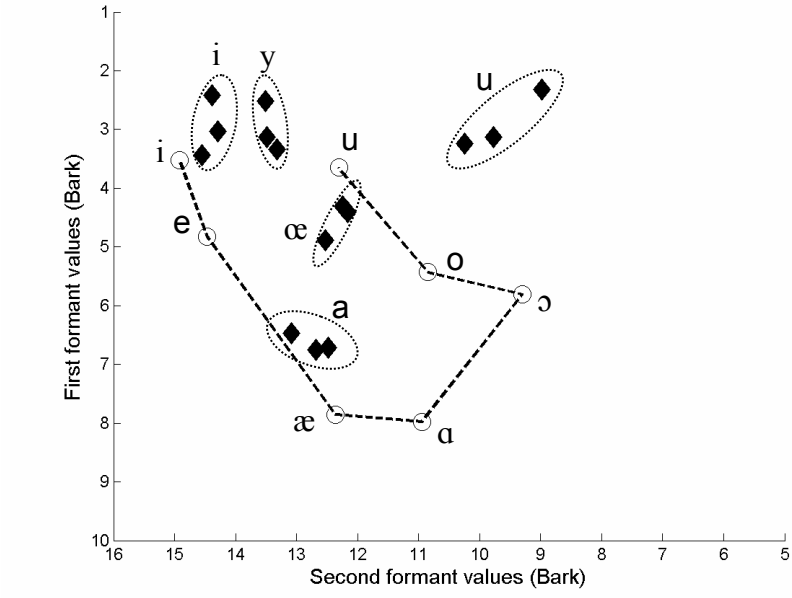


Figure 2

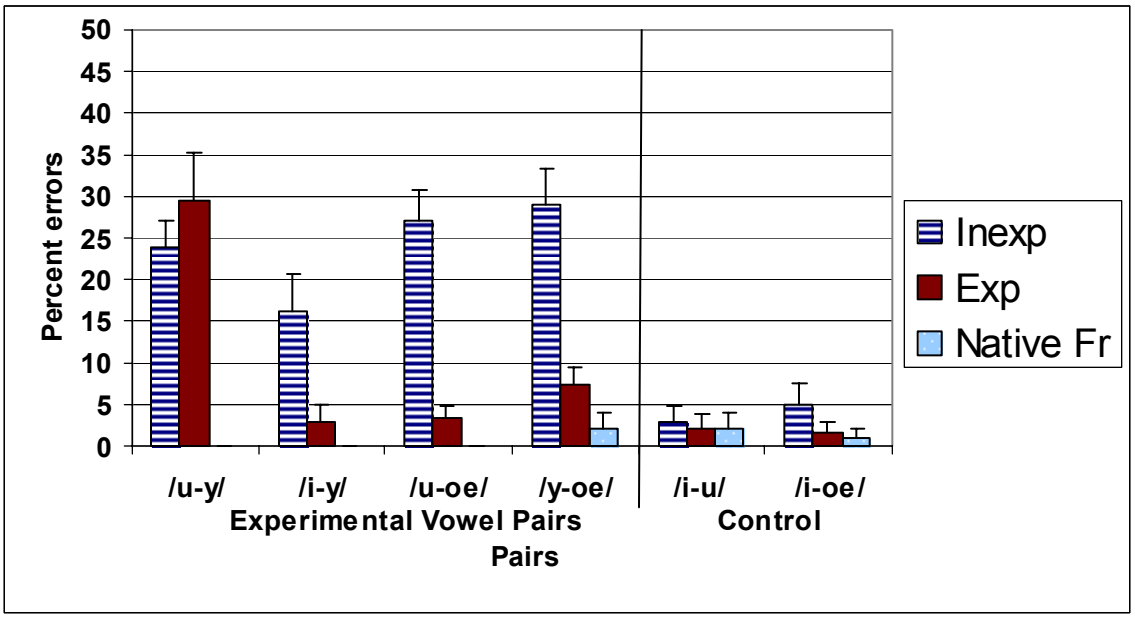
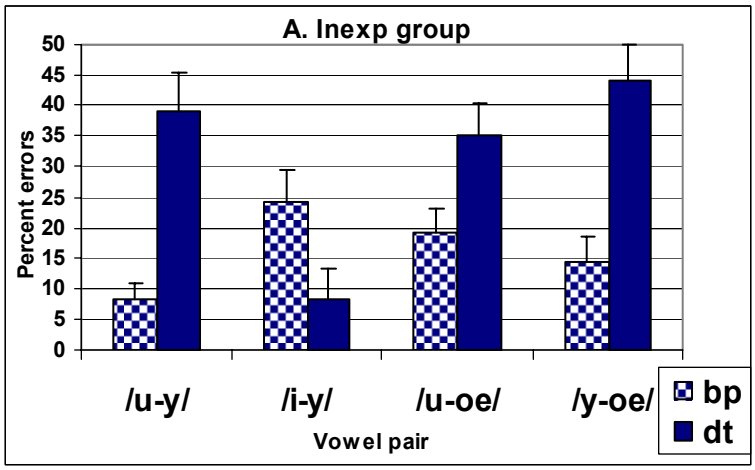

50
45
40
35
30
25
20
15
10
5
0
Percent errors
/u-y/
/i-y/
/u-oe/
/y-oe/
/i-u/
/i-oe/
Experimental Vowel Pairs
Control
Pairs
Inexp
Exp
Native Fr

Figure 3


A. Inexp group
Percent errors
50
45
40
35
30
25
20
15
10
5
0
/u-y/
/i-y/
/u-oe/
/y-oe/
Vowel pair
bp
dt

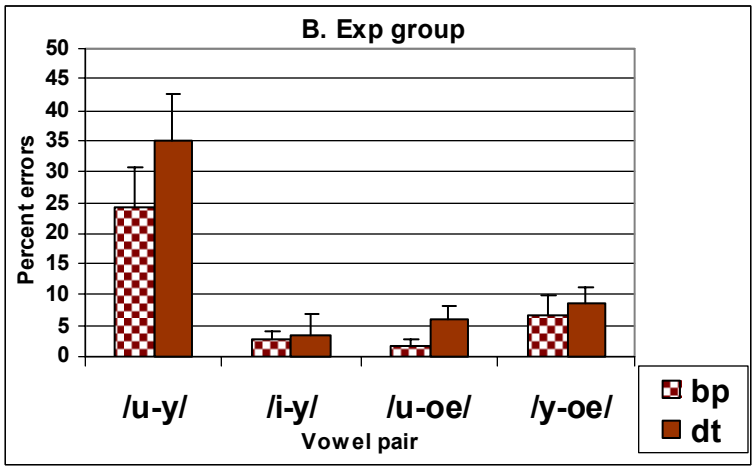

B. Exp group
Percent errors
50
45
40
35
30
25
20
15
10
5
0
/u-y/
/i-y/
/u-oe/
/y-oe/
Vowel pair
bp
dt

Figure Captions

Figure 1. Average Formant 1/Formant 2 vowel spaces (in Bark) of Parisian French (PF) vowels in bilabial /rabVp/ context (A) and alveolar /radVt/ context (B) by each female native PF speaker. For comparison purposes, averages of 4 tokens from 3 monolingual female speakers of American English in bilabial /gɑbVpɑ/ context (A) and alveolar /gɑdVtɑ/ context (B) in phrases from Strange et al.'s (2002) production study are provided.

Figure 2. Overall errors on experimental and control contrasts. Performance (percent errors) for Inexperienced (dark and light stripes) and Experienced (dark solid) and Native French (light dotted) groups for experimental and control vowel pairs (collapsed over context). Error bars represent standard errors.

Figure 3. Percent errors for Inexperienced (A) and Experienced (B) groups for experimental vowel pairs in /rabVp/ (checkered bar) vs /radVt/ (solid bar) contexts. Error bars represent standard errors.