EFFECTS OF LANGUAGE EXPERIENCE AND CONSONANTAL CONTEXT ON PERCEPTION OF FRENCH FRONT ROUNDED VOWELS BY ADULT AMERICAN ENGLISH LEARNERS OF FRENCH

by

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Abstract

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by

Erika S. Levy

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According to Best's (1994, 1995) Perceptual Assimilation Model (PAM), the way in which listeners perceptually assimilate unfamiliar segments into their native phonology predicts how accurately they will discriminate the speech sounds. The present study applied the PAM not just to beginning language learners, but also to more experienced second language (L2) learners. Parisian French (PF) front rounded vowels /y/ and /œ/ were investigated. Three groups of American English (AE) listeners differing in their French experience (No Experience, Formal Instruction, Immersion Experience) performed a Perceptual Assimilation (PA) task involving French vowels /y-œ-u-o-i-ɛ-a/ and a Categorial Discrimination task involving French front vs back rounded vowel pairs /y-u/, /y-o/, /œ-o/, /œ-u/, front rounded vs front unrounded pairs /y-i/, /y-ɛ/, /œ-ɛ/, /œ-i/, and a front rounded vowel pair differing in height /y-œ/. Vowels were in bilabial /rabVp/ and alveolar /radVt/ consonantal contexts produced and presented in phrases. PF front rounded vowels /y/ and /œ/ were perceptually assimilated overwhelmingly (94%) to back AE vowels by all groups, resulting in more discrimination errors for front versus back rounded PF vowel pairs (16%) than for front unrounded versus rounded PF pairs (2%). Overall, on the experimental contrasts, listeners with formal French instruction did not fare significantly better (11% errors) than listeners with no French experience (13% errors). Extensive French immersion experience, however, was associated with significantly fewer errors (4%) than formal experience alone, although discrimination of /u-y/ remained relatively poor (12% errors) for this group. A context effect was evident in PA and discrimination; more errors were made on pairs involving front versus back rounded vowels in alveolar context (20% errors) than in bilabial context (11% errors). Acoustical analyses indicated that PF /y/ and /œ/ are front vowels, but when AE /u/ is produced in alveolar context, it is "fronted," contributing to AE listeners' perceptual difficulty in alveolar context. Such findings suggest that native-language allophonic variation may explain context-specific perceptual patterns in a non-native language. A significant correlation ($\rho=.87$, $p<.01$) was found between overlap in PA responses on vowel pairs and discrimination errors for all groups, suggesting that the PAM may be extended to L2 vowel learning.

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Chapter 1. Introduction

Findings from cross-language speech perception studies point to linguistic experience as a powerful influence on listeners' perception of foreign speech segments (e.g., Lisker & Abramson, 1964; Miyawaki, Strange, Verbrugge, Liberman, Jenkins, & Fujimura, 1975). A question with tremendous pedagogical and clinical implications is the extent to which exposure to non-native segments through instruction in a second language (L2) alters listeners' perception of non-native consonants and vowels. Among the variables that have been shown to influence listeners' perception of vowels is the consonantal context in which the vowels are presented, whether these segments are native (Nearey, 1989) or non-native (Gottfried, 1984; Levy & Strange, 2002; Strange, Akahane-Yamada, Kubo, Trent, & Nishi, 2001). The present study investigated the effects of L2 experience and consonantal context on vowel perception by examining the perception of Parisian French (PF) front rounded vowels by American English (AE) L2 learners of French at three different levels of French language experience.

The class of vowels investigated in the proposed study exemplifies the difficulty individuals may encounter upon learning L2 segments (see Appendix A for description of terms and symbols). Front rounded vowels, such as PF /y/ (in déjà vu /vy/ "seen") and /œ/ (in bœuf /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. 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. 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").

These front rounded vowel categories are arguably nonexistent in AE and certainly not phonemic in the language (Gottfried, 1984). In AE phonology, front unrounded vowels contrast phonologically with back rounded vowels, i.e., rounding is redundant with tongue position. Previous studies have shown that AE listeners tend to confuse back versus front rounded vowels rather than front unrounded versus rounded vowels (e.g., Rochet, 1995). However, in other studies of front rounded vowels (e.g, Best, Faber, & Levitt, 1996; Flege, 1987; Flege & Hillenbrand, 1984; Gottfried, 1984; Levy & Strange, 2002; Polka, 1995; Stevens, Liberman, Studdert-Kennedy, & Öhman, 1969; Strange, Bohn, Trent, & Nishi, forthcoming), findings have often conflicted regarding non-native listeners' perception (and production) of these segments. A brief discussion of the relevant research follows. But first, two models of perception of non-native speech are reviewed.

1.1. Models of cross-language speech perception

Two predominant models of cross-language speech perception, the Perceptual Assimilation Model (PAM: Best, 1994, 1995) and the Speech Learning Model (SLM: Flege, 1995), have been developed to explain perception and production by adult L2 learners of non-native segments (e.g., AE L2 learners of French). Both models posit that the *perceived similarity* of non-native segments to native segments is crucial to determining the difficulties listeners will encounter in their non-native language. In their current states, the PAM is designed primarily to investigate perception by inexperienced listeners (e.g., AE listeners unfamiliar with French), whereas the SLM is designed to investigate perception and production by more experienced L2 learners (e.g., AE listeners who have learned French) and to predict changes in production patterns with L2 experience. To this author's knowledge, the two tasks traditionally used together in the PAM (perceptual assimilation and discrimination) have been implemented in one study (Guion, Flege, Akahane-Yamada, and Pruitt, 2000) to investigate consonant perception by experienced L2 learners, but have not yet been used to examine vowel perception by experienced learners.

The PAM (Best, 1994, 1995) predicts perceptual difficulty on the basis of how inexperienced listeners perceptually "assimilate" non-native segments, that is, how they perceive segments with respect to their similarity to existing native language phonological categories. The PAM posits that novel segments may be assimilated to native categories as "good" to "poor" instances along a continuum. In the single-category (SC) assimilation pattern, for example, contrastive non-native segments are both assimilated as good instances of the same category in the native language, and consequently, listeners will have great difficulty discriminating these segments. A second assimilation pattern is the category-goodness (CG) type, in which contrasting non-native segments are assimilated into the same native language category, but one is a "better instance" of the native category than the other. Discrimination in such cases should be moderate to very good. If each non-native segment is assimilated to a different native language category, this falls into the two-category (TC) assimilation pattern and discrimination will be excellent. On the other hand, a segment might be "uncategorizable", that is, within the phonological space of the native language, but outside any actual native category. When such a segment is contrasted with one that is similar to an AE phonological category (Uncategorized-Categorized [UC] pattern), discrimination is expected to be very good because listeners will perceive the uncategorized segment as clearly non-native, as opposed to the one that is within their own inventory (or at least similar to a phonological category within their inventory). If both segments are uncategorizable within the native language inventory (UU pattern), discrimination can range from very good to poor, depending upon how close the segments are to each other and to the listener's first language (L1) categories in phonological space (i.e., in the proximity of articulators and of place of constriction involved in their production).

In experiments inspired by the PAM (1994, 1995), perceptual assimilation patterns are determined empirically by listeners' transcriptions of foreign segments (e.g., Guion et al., 2000), or by directly asking listeners to classify foreign segments with respect to their similarity to stored representations of native segments (e.g., Strange et al., 2001). Listeners are then asked to rate how native-like (e.g., Strange, Levy, Weber, Lehnhoff Jr., & Law II., in progress) or how good an exemplar (e.g., Best et al., 1996) of the native segment they perceive the foreign stimulus to be, using a Likert scale. Note that exemplars of L1 stimuli are *not* presented in this task.

Unlike the PAM, Flege's (1995) SLM was designed specifically to explain the difficulties more experienced second language learners face when learning L2 contrasts, with emphasis on the problem of inaccurate *production* (i.e., accentedness) by late L2 learners and changes in production with exposure to L2. According to the SLM, listeners initially categorize L2 segments by means of a process of "equivalence classification" (Flege, 1987), assigning the segments to L1 categories, even if they might perceive phonetic differences between L1 and L2 segments. Phones in a second language, according to Flege, may be classified as "identical", "similar" or "new" when compared to native language categories. An "identical" phone has nearly the same phonetic properties as a native language phone (e.g., /i/ in AE and Northern German [Strange, Bohn, Trent, & Nishi, 2004]) and is perceived as highly similar to the native category. A "similar" L2 phone, on the other hand, has a clearly identifiable counterpart in a learner's first language, but the L2 phone is discriminably different (at least under some conditions) from its L1 counterpart and is rated as less similar to the native category. For example, American English /u/ may be the closest phone to the "similar" French /u/, but is characterized by a higher and more variable second formant frequency (Delattre, 1953; Hillenbrand, Clark. & Nearey, 2001). A "new" L2 phone, on the other hand, has no phonological counterpart in the native language. Flege (1987) refers to the French front rounded vowel /y/ as an example of a "new" L2 phone to American learners of French because the English phonological inventory contains no phonologically distinctive front rounded vowels. However, he states that in certain phonetic contexts, AE /u/ has an /y/-like phonetic quality, a topic he suggests ought to be explored. This phenomenon was indeed an important consideration in the present study.

According to the SLM (Flege, 1995), it is predicted that "new" phones, which have no L1 phonological counterpart, will come to be more accurately produced than "similar" phones, at least after some initial experience with the L2. The greater the "dissimilarity" between L2 and L1 phones, the more likely listeners will come to discern the differences and establish new categories for the L2 phones. Similarly, L2 phones continue to be assimilated to L1 categories, resulting in misperceptions and accented productions.

The SLM (Flege, 1995) posits that as individuals gain experience with a second language, they are more likely to recognize the differences between an L2 "new" phone and a native language phone. Thus, according to Flege, AE learners of French may initially classify /y/ as /u/, but with experience, they will recognize that [y] is not a realization of English /u/. In later versions of the SLM, however, Flege (1995) posited that even when new categories are established for L2 phones, the categories might be based on different acoustic characteristics from native listeners' categories. Thus even "new" L2 phones may never be perceived or produced in a native-like manner by second language learners.

"Phonetic categories" as discussed by Flege (1987) are assumed to be underlying representations based on individuals' perceptual experience. Production is thought to be a reflection of the phonetic categories created by individuals through perceptual experience. It should be noted that it is unclear how "perceptual dissimilarity" is operationally defined in this model, independent of perception and production difficulties. Empirically, studies performed in the SLM (Flege, 1995) framework have relied on both acoustical analysis of L2 productions (e.g., Flege, 1987) and on perceptual judgments by native listeners (e.g., Flege & Hillenbrand, 1984), to determine production accuracy. As shown below, results of acoustic analysis are not always consistent with those of native listeners' judgments of production accuracy. Perceived (dis)similarity of L1 and L2 phones is sometimes evaluated directly by presenting pairs of L1 and L2 productions and asking L2 learners to judge their dissimilarity on a Likert scale. Thus, this differs from the task used under the PAM (1994, 1995) in which presented L2 stimuli are judged against listeners' internal representations of native categories.

In an investigation of the *production* of the French rounded vowels /u/ and /y/ in the SLM framework, Flege (1987) reported an acoustic analysis of AE speakers' productions as a function of their L2 experience. Forty-two subjects participated, including four groups of native AE speakers with language histories ranging from minimal French experience to living in Paris for a mean of 11.7 years. The stimuli were natural tokens of /tu/ in English (e.g., "Two little boys"), /ti/ in English (e.g., "TV programs"), /tu/ in French (e.g., "Tous les prêtres") and /ty/ in French (e.g., "Tu les montres"), read by all participants in phrases and also in sentences created by the participants. Acoustical analysis of second formant frequencies was performed on all tokens for comparison within and across groups to determine "authenticity." Flege reported that preliminary analyses and a previous study (Flege and Hillenbrand, 1984) had revealed that differences between language groups in second formant frequencies were greater than in first or third formant frequencies, thus justifying his focus on acoustical analysis of only the second formant. (Vocal tract normalization was not mentioned by the author.)

As expected, French /u/ was not produced with native-like accuracy (as measured through acoustical analysis) by any group of AE speakers. AE speakers with little French experience produced a very high F2 (higher than for English) for /u/, perhaps targeting an /y/ instead of /u/. All groups of AE speakers, even those living in France, produced French /u/ with a higher F2 than did native French speakers. Increased French experience correlated with a lower F2 frequency (approaching native speakers' second formant frequencies), and thus with higher but never native-like accuracy. Unlike the back rounded vowel, the front rounded French /y/ was produced with almost native-like F2 formant values by AE speakers with French experience. Only the least experienced AE speakers produced /y/ with significantly different F2 values from native French speakers—they produced it similarly to their French /u/.

Based on this production data, Flege (1987) posited that, at the beginning of French instruction, AE listeners perceptually confuse French /u/ and /y/. Although they are able to auditorily perceive the differences between L1 and L2 phones, their representations of these phones are not established. With exposure to the language, their representations are modified, but this modification may be limited. They are only able to produce an /y/ authentically once they have established a new (non L1) phonetic category for it. According to Flege, they do eventually develop a new category for /y/, but not for French /u/.

In a study that relied on perceptual judgments of native listeners, Flege and Hillenbrand (1984) found that French /tu/ (uttered in phrases) was produced more accurately (17% errors) than /ty/ (28% errors) by a group of advanced L2 learners of French, as measured through Native French listeners' forced choice identification of the syllables. These findings run contrary to Flege's (1987) claim that "new" segments are ultimately produced more accurately than "similar" segments by experienced speakers. However, the same study by Flege and Hillenbrand also reported acoustical analyses that were inconsistent with the native listeners' judgments and consistent with Flege's predictions, with /ty/ being produced more "authentically" than French /tu/ by experienced L2 speakers. Flege and Hillenbrand's conflicting findings may be attributable, in part, to the fact that the AE "experienced" speakers had spent only 3 months in a French-speaking country and participated as judges of production accuracy for their own and other speakers' utterances. Such conflicting findings within a study (i.e., acoustical analyses of "authenticity" not in agreement with native listeners' judgments) call attention to the important role of operational definitions in reporting cross-language phonetic similarity. Moreover, Flege's (1987) notion, based on acoustical analysis, that a new category is established for /y/, is inconsistent with perceptual studies that demonstrate even advanced L2 learners' inaccurate perception of front rounded vowels. Such studies are reviewed below.

1.2. Previous perceptual research on front rounded vowels

In an early influential study, Stevens et al. (1969) asked native speakers of AE and Swedish to listen to a synthetic continuum of isolated steady-state vowels spanning the front unrounded and rounded Swedish vowels /i-y-ʉ/ with both second and third formants varying from higher to lower frequencies in approximately even steps. AE and Swedish listeners did not differ significantly in their accuracy of discrimination of these synthetic vowel tokens. The researchers concluded that, unlike discrimination of consonants, discrimination of steady-state vowels was not influenced by listeners' linguistic experience.

Since the 1960s, however, researchers using new paradigms for assessing adult listeners' labeling patterns of non-native stimuli have learned that the perception of vowels is far from immune to linguistic experience (e.g., Best et al., 1996; Gottfried, 1984; Polka, 1995; Strange et al., 1998). A study involving native Canadian French, native Canadian English, and Brazilian Portuguese listeners by Rochet (1995) demonstrates the effect of language background on the labeling of front rounded vowels. Listeners were instructed to identify steady-state synthetic vowels on a high vowel continuum, in which the F2 frequency varied between 2500 and 500 Hz, as /i/ or /u/ (or /i-y-u/ for Canadian French listeners). Results indicated that vowels that were labeled as /y/ by native Canadian French listeners were most frequently labeled (and produced) as /u/ by Canadian English listeners and as /i/ by Brazilian Portuguese listeners. Clearly, language background influenced not only whether identification and production were "native-like," but also to which native language categories the non-native segments were likely to be assimilated.

A seminal study by Gottfried (1984), using naturally-produced stimuli, examined the perception of French vowels by AE listeners with and without L2 experience. He used a (cross-speaker) categorial discrimination paradigm to investigate whether syllabic context affected the learners' perception of non-native vowels. Three different native Parisian French speakers produced French vowels in /tVt/, /Vt/, /tV/, and /V/ syllabic contexts. Speakers were instructed to utter the syllables as they would in sentences. Eight vowel pairs were tested in Gottfried's categorial discrimination task: /e-ɛ/, /ɛ-a/, /i-e/, /ɑ-ɔ/, /u-y/, /a-ɑ/, /y-ø/, and /ø-œ/. These were contrasts that were frequently confused in an initial identification experiment. In the ABX categorial discrimination task, three groups of listeners indicated whether the third stimulus was the same as the first or second stimulus. In this task, the speaker differed across A, B, and X tokens; thus, listeners had to make judgments on the basis of speaker-independent categorial representations of the vowels.

Participants consisted of 2 groups of AE listeners and 1 group of native French-speaking listeners. Of the 30 AE listeners, 20 had no knowledge of French, and 10 had studied French for many years. The experienced listeners had a mean of 7.7 years of French instruction, and some were French teachers. The 10 "Native French" listeners were graduate students in the US who had come from several regions of France.

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 inexperienced and experienced groups of AE listeners differed in their perception of French vowel contrasts in some syllabic contexts. Overall, the AE listeners who spoke French discriminated vowels in /tVt/ context significantly better than those who did not speak French; the two groups did not perform significantly differently for vowels in isolation.

Relevant to the current study, Gottfried (1984) found that contrasts involving the French rounded vowels (/u-y/, /y-ø/, and /œ-ø/) were generally more difficult for AE listeners than for native French listeners to discriminate. For these vowel pairs in /tVt/ context, AE subjects with no knowledge of French made the most errors (32% for /u-y/, 53% for /y-ø/, and 36% for /œ-ø/, 50% = chance performance). AE listeners who spoke French made fewer errors (21%, 35% and 40% for the /u-y/, /y-ø/, and /œ-ø/ contrasts, respectively). However, the difference between the American English groups was not statistically significant due to large within-group subject variability. Native French listeners made significantly fewer errors than either group of American listeners (5%, 19%, and 27% errors, respectively). Group differences for the three front rounded vowel pairs produced and presented in isolation were non-significant (Inexperienced: 21%, Experienced: 17%, Native French: 11%), although the groups showed a tendency in the same direction as in the /tVt/ condition.

The French vowels /œ/ and /ø/ are generally not thought to be contrastive in modern French, as discussed in Appendix A. Several other vowel pairs presented in /tVt/ context in Gottfried's (1984) study also contained contrasts that, in contemporary French, have questionable phonemic status (e.g., /a-ɑ/, a contrast that is being lost in contemporary French, and /e/ in the contrast /i-e/, which does not appear in closed syllable context). When these pairs were removed from the analysis, it was evident that AE listeners, regardless of their knowledge of French, had the most difficulty with the contrast involving the two front rounded vowels /y-ø/ (mean of 53% errors for the monolinguals and 35% errors for AE listeners with knowledge of French). Native French listeners, on the other hand, did not have the most trouble distinguishing this contrast (19%), but rather had the most difficulty discriminating a contrast involving back vowels (28% for the /ɑ/-/ɔ/ vowel pair).

In a more recent investigation of the perception of naturally-produced Bretagne French front rounded vowels, Best et al. (1996) had AE listeners with no French language experience perform a Perceptual Assimilation (PA) and a Categorial

Discrimination (CD) task in the PAM (1995) framework. In the Perceptual Assimilation task, participants heard the French syllable /sœ/ or /sy/ twice and chose an English keyword (from the word set "heed, hid, aid, ed, ad, food, hood, hoed, awed, odd, dud, heard, dude, owned, end, donned") with the vowel that was most similar to the French vowel. Next, they rated how similar the AE and French vowels were from 1 "not at all similar" to 5 "exactly the same." In the AXB categorial discrimination task, listeners were presented with three tokens and indicated whether the middle stimulus vowel was the "same" as the first or the third. All of the stimuli were produced by the same speaker, but different tokens of the syllables were combined in the AXB triads. Thus, indicating that X was the same as A or B did not indicate that the middle token was physically identical to A or B, but rather that it was of the same phonetic category.

The /sœ-sy/ front rounded vowel contrast was assimilated by the inexperienced AE listeners as a two-category (TC) contrast for 8 of the 13 listeners, as an uncategorizable-categorizable (UC) contrast for 3 of the listeners and category-goodness (CG) contrast for 2 of the listeners. In a categorial discrimination task, the listeners discriminated multiple tokens of the French syllables with fewer than 5% errors, consistent with the PAM's (Best, 1994, 1995) predictions of good discrimination for the perceptual assimilation patterns revealed. It should be noted that these vowels were produced in citation /sV/ syllables (i.e., beginning with an alveolar consonant /s/, produced in a list).

As part of the production study, Flege and Hillenbrand (1984) presented L2 French speakers with paired /tu/-/ty/ tokens produced by 7 native French speakers (raised in France and Belgium). The listeners were asked to identify which member in each pair was /ty/. Flege and Hillenbrand reported an average error rate of 10% for this contrast. Listeners ranged in French L2 experience, but had at least 4 years of French instruction and most had had at least 3 months of immersion experience.

Why Best et al. (1996) and Flege and Hillenbrand (1984) reported high accuracy in discrimination of the /y-œ/ and /u-y/ contrasts by naïve and experienced AE listeners, whereas Gottfried (1984) found these to be difficult contrasts for inexperienced and experienced AE listeners may be attributed to any of many variables that differed in the studies: e.g., the different consonantal contexts in which the vowels were presented (i.e., /sV/, /tV/, /tVt/), the type of task used, the number of speakers per discrimination trial or the different dialects of the native speakers. The conflicting findings across perceptual studies involving front rounded vowels, and inconsistencies between perception and production studies, motivate further research into the perception of French front rounded vowels by native AE listeners.

1.3. Effects of consonantal context on vowel perception

In all of the studies just reviewed, French front rounded vowels were produced and presented in isolation or in alveolar consonantal contexts in isolated syllables. Previous research has shown that perceptual assimilation and discrimination of vowels varies depending on consonantal context, as well as the prosodic context (sentences versus citation form syllables) (Levy & Strange, 2002; Strange et al., 2001). Thus, whether similar perceptual assimilation and discrimination patterns for French front rounded vowels might hold in other consonantal contexts in running speech for inexperienced and experienced L2 learners remained an open question—one that was addressed in the present study.

Consonant place of articulation (bilabial, alveolar, velar) has been found to affect Japanese listeners' perceptual assimilation of non-native vowels (Strange et al., 2001). AE listeners' perceptual assimilation of German front rounded vowels has also been found to be affected by both prosodic and consonantal context (Strange et al., 2004; forthcoming). For /hVp/ citation form utterances (Strange et al., 2004), German front rounded vowels /y:, ʏ, ø:, œ/ were not consistently assimilated to any particular AE vowel category by inexperienced listeners. However, when all back vowel response alternatives were pooled, front rounded vowels were categorized as more similar to AE back vowels (77%) rather than to front unrounded categories (23%). Goodness ratings indicated that the German vowels were perceived as very poor to fair instances of AE back vowels (Median ratings = 2-4 on a scale of 7 with "7" most native-like). On the other hand, when produced and presented in CVC syllables within a short carrier sentence in which the consonantal context (labial, alveolar or velar) varied randomly (Strange et al., forthcoming), German front rounded vowels were assimilated more consistently as fair exemplars of back AE vowels (97% consistency with back vowel responses collapsed, median goodness ratings = 4-5). This suggests that when consonantal context varies unpredictably, listeners tend to perceptually assimilate vowels with respect to context-independent representations of their native vowel categories. However, both studies of naïve AE listeners' perceptual assimilation of German vowels suggest that front rounded vowels are perceptually more similar to back rounded AE vowels than to front unrounded AE vowels. These perceptual assimilation results would predict the discrimination and identification patterns reported by Gottfried (1984) and Rochet (1995) for French front rounded vowels.

In an extension of Gottfried's (1984) categorial discrimination study, Levy and Strange (2002) focused on the PF vowels /y/, /œ/, /u/, and /i/ and examined consonantal context effects on listeners' categorial discrimination patterns. A motivation for investigating the effects of consonantal context was that, to the authors' knowledge, all of the previously reported studies of front rounded vowels in all languages had been performed with vowels either in isolation (Gottfried, 1984; Rochet, 1995; Stevens et al., 1969) or in alveolar context (Best et al., 1996; Flege, 1987; Flege & Hillenbrand, 1984; Polka, 1995; Polka & Bohn, 1996), thus generalization to other consonantal contexts was not evident.

In this (cross-speaker) categorial discrimination experiment, Levy and Strange (2002) presented PF vowels in /rabVp/ and /radVt/ bisyllables embedded in AXB triads of the carrier phrases "neuf /raCVC/ à des amis," similar to the context used in Strange et al. (forthcoming). However, whereas that study had randomly intermixed consonantal contexts with blocks of trials, Levy and Strange presented the French utterances blocked by consonantal context. That is, half of the listeners were presented with four blocks of vowels in /bVp/ context followed by four blocks of stimuli in /dVt/ context and the other half were presented with the /dVt/ stimuli followed by the /bVp/ stimuli. Two groups of listeners were tested: The "Inexperienced Group" were non-French-speaking AE listeners. The "Experienced

Group" were highly proficient AE speakers of French, some of whom had worked as interpreters of French.

Results showed that both French language experience and consonantal context significantly affected AE listeners' perceptual accuracy. The experienced group made fewer errors than the inexperienced group for three experimental pairs (/i-y/, /u-œ/, and /y-œ/). For the fourth pair, /u-y/, no significant difference was found in the discrimination accuracy of the two groups, despite the experienced group's many years of French instruction and immersion. An interaction was evident between listeners' language background and their performance on pairs in the different consonantal contexts. Figure 1 presents the performance of inexperienced and experienced listeners, respectively, on each vowel pair in bilabial (/rabVp/) versus alveolar (/radVt/) conditions (Levy and Strange, 2002). The inexperienced group confused /y/ with /u/ more often in alveolar context, but /y/ with /i/ more often in bilabial context, whereas the experienced group confused /y/ with /u/ in both contexts. For all contrasts except /i-y/ (where the reverse was true), the inexperienced group performed better in bilabial than in alveolar context, whereas no significant context effect was revealed for the experienced group.

It appears from this categorial discrimination study that learning an L2 involves learning to ignore the context-dependent acoustic variations within phonological categories. According to J. Flege (personal communication, January 16, 2003), the notion that L2 learning involves learning to "hear through" variations within a phonetic category is predicted by his (1995) SLM and is currently being documented in his laboratory. That is, current research indicates that, with experience in a second language, L2 learners begin to perceive segments in that language on a more abstract level, less affected by acoustic variation.

Why was a context effect found in inexperienced AE listeners' categorial discrimination of French front rounded vowels (Levy & Strange, 2002), but not in inexperienced AE listeners' perceptual assimilation of German front rounded vowels (Strange et al., forthcoming)? One possibility is that French and German vowel inventories differ acoustically, thus French /y/, for example, may not be comparable to German /y/, which has a lower second formant frequency (Strange et al., 2002). A second possibility is that presentation of stimuli blocked by consonantal context as in Levy and Strange's (2002) study is more likely to elicit context-dependent processing than stimuli presented in randomly varying consonantal contexts. A third explanation for the discrepant findings could be the different tasks that were used: Perceptual Assimilation (Strange et al., forthcoming) versus Categorial Discrimination (Levy & Strange, 2002).

In the present study of French front rounded vowels, an identification task would have been impossible to perform because participants included listeners who had had no French experience, and thus would have been unable to label the stimuli in terms of French vowel categories. Instead, this study used both a Perceptual Assimilation and a Categorial Discrimination task, blocked by consonantal context, with the same stimuli in each task. The Perceptual Assimilation task entailed mapping the French stimuli onto AE vowel categories and providing goodness ratings.

Phrases were used rather than vowels or nonsense words in isolation in order to tap into linguistic categorization processes that are employed in the perception of continuous speech. Previous perceptual assimilation studies (Strange et al., 2001; forthcoming) have shown that listeners can make relative judgments about similarity of L1 and L2 vowels when presented in sentence-length utterances. For instance, in Strange (forthcoming), Northern German /i/ was rated very similar to AE /i/ (99% consistency, Mdn. Rating=7 [out of 9]), whereas Northern German /ø/ was uncategorizable and rated a relatively poor exemplar of any AE vowel (43% consistency, Mdn. Rating=5). Thus, in the present study, the increase in memory load resulting from presenting stimuli in phrases rather than in isolation was not expected to preclude listeners' ability to perform the Perceptual Assimilation task.

By comparing results from the present study regarding Perceptual Assimilation of French vowels to Levy and Strange's (2002) Categorial Discrimination study and to Strange and her colleagues' study of German vowels, for example, the variables contributing to the conflicting findings in the literature may be better understood. Clearly, the literature would benefit from vowel studies that include both Perceptual Assimilation and Categorial Discrimination tasks and studies that track the changing effects of consonantal context as learners gain L2 experience. Such studies will not only contribute to a better understanding of the effects of experience on L2 speech learning, but they will also test the PAM's (Best, 1994, 1995) applicability to the domain of L2 speech learning. A summary of what is known and what still needs to be researched with regard to French front rounded vowels will lead to the questions that were addressed in the present perceptual assimilation and categorial discrimination study.

The results of studies of AE listeners' perception and production of front rounded vowels reviewed above do not converge on a consistent answer. Discrimination has been reported to range from poor (Gottfried, 1984; Levy & Strange, 1996) to very good (Best et al., 1996; Flege & Hillenbrand, 1984). Furthermore, it is suggested that French language experience leads to more accurate perception of some vowel pairs, but not necessarily of the /u-y/ contrast (Gottfried, 1984; Levy & Strange, 2002); and consonantal context affects performance by inexperienced listeners, but decreases with French L2 experience (J. Flege, personal communication, January 16, 2003; Levy & Strange, 2002). Important factors that may affect the outcome of perceptual assimilation and discrimination studies include whether stimuli are blocked by consonantal context (Levy and Strange, 2002), whether consonantal context varies unpredictably (Strange et al., 2004; Trofimovich et al., 2001) and whether stimuli are produced and presented in citation form (Best et al., 1996; Gottfried, 1984; Rochet, 1995) or in phrases (Levy and Strange, 2002).

Further research is needed to examine the perceptual changes that occur vis-à-vis consonantal context as AE learners of French gain experience with their L2. The present study, like Flege's (1987) production study, examined the performance of participants with different levels of French experience. However, in this study, perceptual data were collected—both in bilabial and in alveolar contexts—providing a more direct investigation of the nature of L2 learners' perceptual categories. No previous study has combined Perceptual Assimilation and Categorial Discrimination tasks to examine changes in vowel perception that occur with L2 experience and/or different consonantal contexts. The present study did just that: it replicated and extended Levy and Strange's (2002) Categorial Discrimination task, complementing it with a Perceptual Assimilation task (similarly blocked by consonantal context), in a more in-depth study of AE listeners' perception of PF front rounded vowels as a function of language experience and consonantal context.

1.4. The present study: questions and predictions

The present study examined the perceptual assimilation and categorial discrimination of front rounded PF vowels by three groups of AE listeners who differed in their French language experience: listeners with no French experience (NoExp group), listeners with formal (i.e., classroom) French training in high school and college, but little immersion experience (ModExp group), and listeners with several years of formal French training and immersion experience (HiExp group). This study thus explored the extension of the PAM's theoretical domain to L2 learning and also investigated the effect of consonantal context on vowel perception as listeners gain L2 experience.

Before discussing predicted results, it should be noted that this study performed within the PAM (Best, 1995) framework was the first investigation of both perceptual assimilation and categorial discrimination of L2 vowels by learners with different levels of language experience. This model was chosen as a framework for the present L2-learning study because it is a predominant model of speech perception (not production), which makes specific, testable predictions about perceptual performance. However, because this model was designed to test individuals at the beginning stages of learning a language (i.e., naïve listeners encountering an unfamiliar language), new methodological issues arose and predictions were necessarily based on results from experiments performed under considerably different conditions. Moreover, no previous study had looked at the consonantal context effect on categorial discrimination and perceptual assimilation by AE listeners with formal French instruction (the ModExp group); therefore, it remained to be seen whether this group of listeners would demonstrate perceptual assimilation patterns more like NoExp or HiExp listeners. Nevertheless, the following questions were asked and predictions were made:

Question 1. How do AE listeners perceptually assimilate PF front rounded vowels?

1a. Are the front rounded vowels perceptually assimilated as AE front unrounded or back rounded vowels?

1b. Do perceptual assimilation patterns vary as a function of language experience?

1c. Do perceptual assimilation patterns vary as a function of consonantal context?

1d. Are there interactions among perceptual assimilation of particular vowels, language experience, and consonantal context?

Predictions: Previous literature in discrimination and perceptual assimilation suggests that AE listeners generally perceive front rounded vowels as more similar to AE back rounded vowels than to front unrounded vowels (Gottfried, 1984; Levy & Strange, 2002; Rochet, 1995; Strange et al., 2004). In the present study, it was thus expected that, overall, front rounded vowels would be assimilated to AE back rounded vowels more often than to AE front unrounded vowels. It was predicted that perceptual assimilation patterns for most vowels would generally change with language experience (as discrimination skills typically improve), but that the PF /y/ would be perceived similarly across language groups, as even experienced AE speakers of PF have difficulty with contrasts involving the high front rounded vowel (Gottfried, 1984, Levy & Strange, 2002). Based on the assumption that learning a language involves learning to attend to the differences between native and non-native phonologies, goodness ratings were expected to decrease with language experience in that the HiExp group would perceive all French vowels as poorer instances of AE vowels than would the NoExp group.

Levy and Strange (2002) suggest that beginning L2 learners will show context-specific patterns of perceptual assimilation of L2 segments, while more experienced learners will not. Thus, it was predicted that the perceptual assimilation of the NoExp group and possibly the ModExp group would depend on the consonantal context in which the vowels were presented more than would those of the HiExp group. That is, the NoExp listeners would assimilate PF /y/ to AE /u/ in alveolar context, but to AE /i/ in bilabial context, while the HiExp listeners would assimilate /y/ to /u/ in both contexts. The context effect was expected to decrease with language experience.

Question 2. How do AE listeners categorially discriminate PF front rounded vowels?

2a. Do AE listeners have more difficulty discriminating PF front rounded vowels from PF front unrounded vowels or from PF back rounded vowels?

2b. Does perception of front rounded vowels become better with experience?

2c. Does the consonantal context in which the vowels are presented affect categorial discrimination accuracy?

2d. Are there interactions among categorial discrimination of particular vowel pairs, language experience, and consonantal context?

Predictions: Previous studies indicate that discrimination of front versus back rounded vowels would be most difficult overall (Gottfried, 1984; Levy & Strange, 2002); thus, the same was expected for the present study. It was predicted that, overall, experienced L2 learners would have more accurate perception of contrasts involving front rounded vowels than less experienced learners. The HiExp group was expected to perform more accurately on the categorial discrimination task than the ModExp group, who would perform more accurately than the NoExp group. However, based on the findings of Gottfried (1984) and Levy and Strange (2002), even the most experienced AE listeners were predicted to have difficulty with the /u-y/ contrast. Other experimental pairs expected to be difficult for the less experienced listeners were /y-œ/ and /œ-o/.

Consonantal context was expected to have a significant effect on categorial discrimination, especially for inexperienced listeners. As listeners became more experienced with their L2, the context effect was expected to decrease.

Question 3: Do listeners' perceptual assimilation patterns predict their categorial discrimination patterns (as posited by the PAM [Best, 1994, 1995] for inexperienced listeners), for all language groups and consonantal contexts?

Predictions: The predictions generated by the PAM (Best, 1995) have received support in several studies of inexperienced listeners' perception (e.g., Best, 1990; Best et al., 1996; Best, McRoberts, & Sithole, 1988; Best & Strange, 1992) and for one study of the perception of consonants by experienced listeners (Guion et al., 2000). Hence, the PAM was expected to be applicable to L2 learning in that the participants' perceptual assimilation patterns should predict their accuracy in discrimination: vowel pairs perceptually assimilated as separate categories were predicted to be discriminated better than those pairs perceptually assimilated in a category goodness or single category assimilation pattern. This was expected to be true for all three language experience groups in both consonantal contexts.

In sum, the study was expected to reveal that perception of (most) non-native French vowel contrasts would become better with L2 experience and that internal representations would become more abstract (i.e., context-independent) with experience. Taking consonantal context into consideration should render the PAM (and the SLM) even more predictive of L2 perceptual performance, at least for relatively less experienced L2 learners.

Chapter 2. Method

2. 1. Perceptual Assimilation (PA) task

2.1.1. Stimulus materials and procedures

Three female adult PF speakers 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 (for a prior experiment). These were native PF speakers who had resided in the U. S. for less than a year. They were instructed to read a list of French sentences with nonsense words (see Appendix B for protocol). The list consisted of 9 French vowels, blocked by /rabVp/ or /radVt/ context, in the carrier sentence: "J'ai dit neuf /raCVC/ à des amis." [I said nine /raCVC/ to some friends.] The target vowel received the stress according to French stress assignment rules. Similar stress assignment to a target vowel in a nonsense word would occur in an AE phrase such as "I said nine raCVCa to friends."

Each carrier sentence was preceded by an identifying number. The full French oral vowel inventory was included in the protocol for future determination of each speaker's entire "vowel space." Each list ended with a repetition of the first utterance to control for list-final intonation. This last token was discarded. The speakers read four repetitions of each list in each consonantal context and were instructed to produce the sentences as if they were in conversation with a native speaker.

The experimenter (a native speaker of both French and English) conversed in French with the speakers and monitored the recording sessions. If a sentence contained inconsistent pronunciation, rate, prosody, voice quality or noise, the experimenter asked the speaker to repeat the utterance. A Shure (SM48) microphone fed signals through an Earthworks microphone preamp to a Soundblaster Live Wave DF80 sound card of a Dell Dimension XPS B800 computer (Lab 101) (see Appendix C for flowchart of recording equipment). The stimuli were digitized using Soundforge software, with a sample rate of 22,050 Hz, 16-bit resolution, and on a mono channel. The experimenter chose the three "best" instances of each vowel in each context. A native French speaker was consulted to judge whether the chosen tokens were good instances of the target vowel. As a result, two tokens were replaced because the intonation on these stimuli did not match the others.

For the present study, the digital files containing the full sentences (e.g., "J'ai dit neuf raCVC à des amis.") were edited so that only the phrases (e.g., "neuf raCVC à des amis") remained for presentation to listeners (i.e., "neuf rabVp à des amis" and "neuf radVt à des amis") with the target vowels /i, y, u, ɛ, œ, o, a/. (See Appendix D for PF vowel quadrilateral.) The files were then transferred via zip disk to a Dell XPSR400 computer with an Aureal Vortex 8820 (WDM) Sound Card.

As shown in the flowchart in Appendix E, participants listened to the stimuli as they were presented via STAX Professional SR Lamda headphones connected to a STAX Professional SRM-1/MK-2 amplifier, receiving the signal from the computer. Sessions took place in the sound-attenuated (IAC) chamber. The Categorial Discrimination task was performed before the Perceptual Assimilation task by all listeners in order to avoid any native language categorization effects potentially introduced by the Perceptual Assimilation task involving AE key words. However, for conceptual reasons, the Perceptual Assimilation task and results are discussed here prior to the Categorial Discrimination task and results.

For the Perceptual Assimilation task, the stimuli were entered into the "Paradigm ID" program (Tagliaferri, 2002) designed to execute the Perceptual Assimilation task. During the experiment, each participant heard three tokens of seven vowels spoken by each of three speakers. Each vowel was presented twice in each of two (/rabVp/ and /radVt/) consonantal contexts, presented in phrases. Thus, each participant completed six judgments for each speaker's three vowel tokens, totaling 18 judgments per vowel in each context.

Prior to the experimental trials, key word, task, and stimulus familiarization procedures trained listeners to choose appropriate response alternatives and become familiar with the stimuli (see Appendix F for design of the Perceptual Assimilation task). In the key word familiarization task, the experimenter asked the participant to read the 13 (AE) key words ("heed, hid, hayed, head, had, hod, hawed, hud, hoed, hood, who'd, hued, herd") aloud to her. Errors were discussed and corrected. Task familiarization began with the presentation of AE phrases "five /gaCVCa/ this time" with the AE vowels (/i/, /ɪ/, /e/, /ɛ/, /æ/, /ɑ/, /ɔ/, /ʌ/, /o/, /ʊ/, /u/, /ju/, /ɝ/) in randomly presented /bVp/ and /dVt/ contexts recorded by a female native AE speaker, with key word response alternatives and feedback. The listener was instructed to select the AE key word that contained the vowel most similar to the second vowel of the nonsense word. The listener was then asked to rate the vowel from 1-9 according to how native-like (9) or foreign-sounding (1) the vowel was. In Block 1, the 13 vowels were presented in the order in which the key words appeared, with feedback provided by the experimenter. Block 2 contained two tokens of each AE vowel, thus 26 trials, in mixed /rabVp/ and /radVt/ contexts. Block 3 and 4 were identical to Block 2, but in different randomizations. On Block 4, no feedback was provided, and listeners needed to achieve a criterion of no more than 1 error in identifying a particular AE vowel token and no more than 3 errors altogether in order to proceed to the stimulus familiarization. If participants exceeded the criteria, their experimental data were discarded.

The overall structure of the remaining blocks was the following: Stimuli were blocked by context. Thus, half of the listeners were presented with all of the French stimuli in bilabial context before hearing the stimuli in alveolar context, and the other half were presented with stimuli in alveolar context before bilabial. Within each consonantal context, stimuli were blocked by speaker. Thus, in a particular context, listeners completed stimulus familiarization for a particular speaker (in order to become familiar with that speaker's vowel space), then completed two test blocks of that speaker's utterances, then proceeded to one familiarization block followed by two test blocks for each of the remaining two speakers in that context. Stimulus familiarization consisted of a block of one token each of the 7 PF vowels in the stimulus phrases, i.e., "neuf rabVp à des amis" or "neuf radVt à des amis," depending on whether the block had been designated as bilabial or alveolar. Stimulus familiarization did not include feedback, and the data collected were removed from analysis. The test blocks contained all three tokens of each of seven French vowels by a speaker, thus 21 trials. Test blocks were presented twice, with stimuli randomized within each block. The order of presentation of speakers within each context was determined by Latin square.

The perceptual assimilation experiment began with instructions (See Appendix G for instructions for Perceptual Assimilation tasks) presented to participants on the computer screen. Participants were instructed to listen to each phrase, paying attention to the second vowel (e.g., /radVOWELt/) in the target nonsense word of each phrase. They were asked to focus on the target vowel and to try to ignore other aspects of the phrases (e.g., consonants or intonation) that might be distracting or sound different from English.

The stimulus was presented once. The listeners saw the 13 AE key words and chose the one that contained the vowel that was most similar to the target vowel they heard. They heard the stimulus again and rated the French vowel on a scale from 1-9. (The 9-point scale was used for this goodness rating task based on Southwood and Flege's [1999] finding that a 9-point scale is comparable to a continuous scale for accentedness ratings.) A rating of 1indicated "most foreign-sounding", 9 indicated "most English-sounding", and participants were encouraged to rate the stimulus as any number in between, using the whole spectrum of the scale.

2.2. Categorial Discrimination (CD) task

2.2.1. Stimulus materials and procedures

The stimulus materials used for this experiment were the same as those used for the Perceptual Assimilation task. As shown in Appendix D, the five experimental "1-feature" vowel pairs presented were /y-i/, /y-u/, /œ-ɛ/, /œ-o/, /y-œ/. These are contrasts whose members differ in just one feature (e.g., rounded vs unrounded for /y-i/ or front vs back for /y-u/, high vs mid for /y-œ/). The six "2-feature" vowel pairs were /y-ɛ/, /œ-i/, /y-o/, /œ-u/, /i-u/, /a-ɛ/, whose members differ by more than one feature (e.g., front unrounded vs back rounded for /i-u/). In addition, all of these pairs included at least one vowel with a counterpart in AE (/i, u, ɛ, o/). The 2-feature pairs /i-u/ and /a-ɛ/ were considered control pairs because they had obvious counterparts in AE and did not include front rounded vowels. Two-feature vowel pairs were expected to be overall more accurately discriminated by virtue of being phonetically "more different" than the 1-feature pairs. Four orders were possible for presentation of each A-B vowel pair: AAB, ABB, BBA, and BAA. Trials contained triads of stimuli uttered by three different speakers in random order and were blocked by consonantal context, with an equal number of correct A and B responses across the experiment (see Appendix H for design of the discrimination task). Conditions were counterbalanced such that all 9 tokens of each vowel occurred in each contrasting pair an equal number of times.

The stimuli were randomized and presented using the "Paradigm Discrim" program (Tagliaferri, 2002) designed for discrimination experiments. The pairs were arranged into AXB trials. Written instructions were provided in English for AE listeners (as shown in Appendix I for bilabial context) and in French for native French listeners. Subjects 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 is the same the vowel in the third. Prior to testing, AE subjects were given task familiarization in which they were asked to discriminate 18 trials of vowel pairs involving AE /ɛ/, /ɑ/, /æ/, and /ɪ/ vowel pairs in the AXB paradigm. Computer feedback was provided for task familiarization. Participants were permitted no more than two errors (over 24 trials) on task familiarization in order to continue with the experiment.

The AE task familiarization was followed by French stimulus familiarization. Stimulus familiarization was identical to the actual experimental task, except that, as participants were informed, their responses were discarded for this block. Following the stimulus familiarization (e.g., in bilabial context), listeners heard 4 blocks of 24 experimental trials in the same context, then 1 block of stimulus familiarization trials in the other (e.g., alveolar) context, followed by 4 blocks of 24 experimental trials in that context. Each listener completed 12 judgments for each of the five 1-feature pairs in each consonantal context, resulting in 60 1-feature trials per context. Six judgments were completed for each of the six 2-feature pairs, resulting in 36 judgments on the 2-feature pairs. Thus the experiment consisted of a total of 96 triads in each context. The inter-stimulus interval was 500 ms and trials were self-paced.

2.3. Stimulus verification

2.3.1. Native French controls

For purposes of stimulus verification, three monolingual native speakers of PF who had been in the United States for less than a month identified all tokens of each vowel stimulus in an Identification task by choosing a keyword response from the word set "vie, vue, vous, cette, veut, veau, va" to indicate the vowels /i, y, u, ɛ, œ, o, a/, followed by a "goodness" rating on a 9-point Likert scale. They made 0 errors in identification and rated each stimulus a median of 9 on a 1-9 scale from foreign-sounding (1) to native French-sounding (9), indicating that the stimuli were appropriate.

The native French speakers also performed the Categorial Discrimination task without familiarization. They made no (0) errors on the experimental pairs, a total of

3 errors (= 3% errors per pair) on the non-experimental pairs /i-u/, /y-ɛ/, and /y-o/ and reported that they had no difficulty performing the task. Thus, it was concluded that the native speakers discriminated the vowel stimuli with accuracy and ease.

2.3.2. Acoustical analysis: method

Acoustical analysis of the French vowel stimuli was performed by means of customized software in Matlab. First, the onset and offset of the syllable containing the target vowel (i.e., /rabVp/ or /radVt/) were determined on the basis of the following operational definitions: Syllable onset was defined as a change in amplitude indicating release of the preceding consonantal occlusion (primarily on the waveform, but also in conjunction with the spectrogram). Offset was defined as the decrease in periodic energy indicated in the higher formants (F2, F3) on a spectrogram coinciding with decreased amplitude on the waveform, indicating the beginning of closure of the following consonant. The program then calculated the temporal midpoint (50% point) between onset and offset of the syllable and derived the first three formant frequencies for a 25 ms window centered around that point using LPC analysis (24 coefficients, 25 ms analysis window). A power spectrum was also derived using FFT analyses (bandwidth 44 Hz, 25 ms analysis window) and superimposed onto LPC analysis. Typically, the formant locations defined by FFT peaks and the LPC formant locations coincided. However, if the LPC appeared to have selected a formant where none existed or if it missed a formant indicated on the FFT, the formant frequencies were estimated manually by placing the cursor at the FFT peak and comparing this value with the formant value on the spectrographic display of the utterance. A second judge provided a second estimation of all manually adjusted values and on 10% of the remaining values. In the approximately 5% of stimuli in which disagreements persisted, a third judge resolved the conflict.

2.3.3. Acoustical analysis: results

The top scatter plot in Figure 2 represents all vowel stimuli uttered by the PF speakers in bilabial /rabVp/ context, with the second formant frequency along the X-axis and the first formant frequency along the Y-axis (in Barks). The tokens overlap considerably in vowel space, particularly the front rounded vowel /y/ with the front unrounded vowel /i/, and the back rounded vowel /o/ with the back rounded vowel /u/. Crucially, a significant separation (>2.5 Barks) is maintained between front and back vowels in bilabial context.

Contextual variation is evident in the bottom scatter plot in the figure, which represents vowel stimuli uttered by the same PF speakers in alveolar /radVt/ context. It should be noted that the vowel /i/ in French is not affected by changes in consonantal context. Front rounded /y/ remains at the "front" of the vowel space, some tokens overlapping with PF /i/, and all tokens far from back rounded /u/. This vowel space is more constricted, however. Tokens of the mid front rounded vowel /œ/ approach tokens of /ɛ/, /y/, /o/, and /u/. Back rounded /o/ and /u/ overlap.

Although, based on the acoustics, some confusion might be expected in alveolar context for pairs involving the mid front rounded vowel /œ/, all of the /y/ tokens and most of the /œ/ tokens illustrated in both plots in Figure 2 are clearly separated from back vowels. Thus, the finding that front rounded vowels are consistently confused with back vowels by AE speakers cannot be attributed solely to acoustics.

One factor that has not been discussed thus far is the third formant (F3), which is lowered with lip rounding. Could it be that PF listeners tune into F3 more than do AE listeners, and thus are more sensitive to roundedness distinctions? In order to take F3 into account, Figure 3 shows F2 minus F1 on the X-axis and F3 minus F2 on the Y-axis for the high front rounded vowels, /i/, /y/ and /u/, in bilabial (top) and in alveolar (bottom) context. Even taking F3 into consideration, front rounded /y/ is acoustically more similar (i.e., closer in vowel space) to front vowel /i/ than back rounded /u/ in Parisian French. The vowel space is decreased in alveolar context, but the distinction between front vowels and back vowels is maintained (F2-F1 Bark difference > 2).

Similarly for the vowels /ε-œ-o/ (shown in Figure 4), vowels approach each other in alveolar context, but the front rounded vowel /œ/ is clearly acoustically more similar to front vowel /ε/ than to back vowel /o/. Thus, even taking F3 into account, confusions that AE listeners have cannot be attributed to changes in PF vowel space when PF vowels are produced in alveolar context in French. Instead, attention must be paid to the listeners' native phonologies and all of their context-sensitive variations, which are clearly active as they encounter non-native or L2 phonologies.

2.4. Participants

A total of 43 native AE speakers volunteered as listeners for the tests and were paid for their participation. Data from four of these participants were discarded for the following reasons: One participant failed the hearing screening, one revealed a language history that did not meet the inclusion criteria for any language group, and two exceeded the criteria for errors in the Perceptual Assimilation familiarization task. (One NoExp participant made 4 errors in the final block, including 2 on the same vowel. A HiExp participant made 12 errors in the final block, including 2 per vowel on 4 vowels.) Thus, data from 39 AE participants (13 in each language group) were analyzed.

All of the participants were born and raised in English-speaking households in the United States (See Appendix J for participant characteristics). None had had more than a year of instruction in any language with front rounded vowels, aside from French. Of the 39 AE listeners, 13 were native AE speakers living in New York City, ages 20-40 years, who had had minimal experience with French (NoExp Group), i.e., they had had no French instruction and had not interacted with French speakers with any regularity.

The second group of AE participants, AE listeners with moderate French experience (ModExp Group), consisted of 13 native speakers of AE living in New York City, ages 22-37 years, who had had formal French training (i.e., they had attended French classes), but minimal immersion in French. They had begun learning French in school no earlier than age 12 years (Mean age of beginning learning = 16.1, SD = 2.8) and had received a mean of 3 years of instruction in French (range = 2 to 4 years, SD = .8), typically in high school and college. Most reported that French pronunciation and conversational proficiency were not emphasized in their classes—the emphasis was more on vocabulary and grammar. Their instruction occurred from .5 to 6 years before testing (Mean = 3.3 years, SD = 1.6). They were recruited primarily from the City University of New York's Graduate Center, through other universities, and on the web. These participants had spent no more than 5 months in a

French-speaking country as adults. They had not engaged in significant conversational experiences with native French speakers within the year preceding testing.

The third group of AE participants, AE listeners with extensive French experience (HiExp Group), consisted of 13 native speakers of AE living in New York City, ages 20-61 years, who had had extensive formal training and immersion experience in French and were using French regularly at the time of testing. They had had a mean of 8 years of instruction in French (range = 5 to13 years, SD = 2.4), which began no earlier than age 12 years (Mean age of beginning learning: 14 years, SD = 1.6). They were recruited from the Alliance Française (French Institute), from a weekly French conversation club at a Jewish community center, from the French program at the Graduate Center, and on the web. All of these participants had spent at least a year in a French-speaking country as adults (range = 1 year to 16 years, mdn = 1.4 years). These participants spoke or had spoken French regularly in their professions (e.g., as teachers of French, translators, foreign business consultants) and were currently using French. Three were living in France at the time of testing and just visiting NY for a fortnight. One had lived in France until 3 weeks before testing.

All participants completed a language background questionnaire in their native language during the experimental session (see Appendix K for English questionnaire) and discussed the details with the experimenter. Participants also received a bilateral hearing screening at 20dB at 500 Hz, 100 Hz, 200 Hz and 4000 Hz. One participant failed the hearing screening, thus his results were discarded.

Chapter 3. Results

3.1. Data analysis

For the perceptual assimilation data, the frequencies of selecting a particular response category in the Perceptual Assimilation task were tallied for each French vowel across all listeners within each language experience group (summing over 18 opportunities for judgment for each listener in each consonantal context). Frequencies of the modal response and the other chosen responses for each PF vowel stimulus were determined and converted to percentages of total trials. The overall median goodness ratings for each AE response category were then computed. Thus, the response percentages indicated how often each particular response was chosen by each language experience group. No statistics were performed on this analysis because the scores were nonparametric. A PRE (percent reduction in error) analysis would not have been appropriate, as that analysis is useful when modal category changes take place across groups, which was mostly not the case here.

In addition to the group data described above, each individual listener's internal consistency in perceptual assimilation was analyzed for the following reason: Multiple responses within a group (e.g., the NoExp group responded that the AE vowels most similar to PF /y/ were /u/, /ju/, and /i/) could be indicative of two possible patterns of behavior. First, multiple responses may be an indication that individuals responded with internal consistency but differed across individuals, i.e., one person responded /u/ to most /y/ stimuli, while another person responded /ju/ to most /y/ stimuli, etc. The second possibility is that individuals were not internally consistent, perhaps reflecting difficulty in categorizing, i.e., an individual responded

/ju/ some of the time, /u/ sometimes, and /i/ the rest of the time when presented with PF /y/.

In order to sort out inter- and intra-subject variability, an "internal consistency" analysis of perceptual assimilation results was performed for front rounded vowels within each consonantal context. Internal consistency was determined by examining each listener's mode, i.e., what percentage of time each listener perceptually assimilated a vowel to his or her particular modal category, regardless of what that category was. Next, the average consistency score (expressed as a percentage) for each group was calculated. A high internal consistency score, thus, indicates that individual listeners consistently gave the same response to a particular stimulus, whereas a low internal consistency score suggests that individual listeners gave several different responses to the same stimulus.

Categorial discrimination scores were derived by tallying errors over trials for each vowel pair in each consonantal context and converted to percentages of errors of total number of trials. An error was defined as responding "3" when the trial was AAB or "1" when the trial was ABB.

3.2. Organization of results section

The remaining part of this chapter is organized in the following manner: A table of overall perceptual assimilation results for all of the vowel pairs is presented, after which the perceptual assimilation of the front rounded vowels /y/ and /œ/ is discussed in terms of language experience and consonantal context. Then perceptual assimilation of back rounded vowels is discussed, followed by perceptual assimilation of the remaining PF vowels.

Next, a table of overall categorial discrimination results for all of the vowel pairs is presented. Categorial discrimination involving front rounded vowels paired with front unrounded and back rounded vowels is then discussed as a function of language experience and consonantal context. Then results for each discrimination pair in the table are discussed in the order in which the pairs are listed. These pairs are analyzed first in terms of what the expectation would be for discrimination based on the listeners' perceptual assimilation patterns (and previous literature) and then the actual results are presented.

Finally, the question of predicting categorial discrimination performance based on perceptual assimilation patterns, as in the Perceptual Assimilation Model (Best, 1994, 1995), is discussed for L2-vowel learning.

3.3. Perceptual assimilation of Parisian French vowels

An overview of perceptual assimilation results is provided in Table 1, which displays the modal AE categories chosen by the NoExp group, the ModExp group, and the HiExp group for all PF stimuli presented. Within each language group, the left-hand column lists the PF front rounded stimuli (/y/, /œ/), followed by the back rounded vowels (/u/, /o/) and the front unrounded and central vowels (/i/, /ɛ/, /a/). The second column represents the overall modal AE responses chosen (e.g., a /ju/ response indicates that the most frequently chosen keyword was "hued," an /u/ response indicates the modal response was "who'd"). The "Mode percent chosen" indicates the overall percentage of trials (summing over participants) that particular AE response was chosen by the language experience group (e.g., 73% of the NoExp responses to PF /y/ were AE /ju/). This, then, is an overall indicator of assimilation consistency. For each group, the median rating indicates the median of goodness ratings from 1 (most foreign-sounding) to 9 (most AE-sounding) summed over all of the trials on which the modal response category was selected.

Overall, the AE response choices were similar across language groups, although for mid vowels /œ/ and /o/, the modal response for Inexp vs ModExp and HiExp groups actually changed (from /u/ to /ʊ/ for PF /œ/, and from /u/ to /o/ for PF /o/). Generally, assimilation consistency percentages increased with language experience, suggesting that learning a language was associated with more stability in vowel representation. This was not true of /y/ or /u/, however, for which HiExp listeners chose their modal responses (66% for /y/ and 85% for /u/) no more often than did the NoExp group (73% for /y/ and 87% for /u/). This suggests that the representation of these vowels did not increase in stability with experience. The mid front rounded vowel /œ/ received a relatively low modal percentage score for all three groups, indicating difficulty or inconsistency in categorizing this vowel. The low vowel /a/ was also inconsistently assimilated to AE /æ/ (47%, 41%, 53%) or /ɑ/ (43%, 41%, 46%) by the NoExp, ModExp, and HiExp groups, respectively.

Median goodness ratings decreased between the NoExp group and the HiExp group for 5 out of the 7 PF vowels (/y/, /œ/, /u/, /ɛ/, /a/), suggesting that, overall, AE listeners perceived L2 vowels as less like their native vowels with increased French language experience. Ratings on the remaining pairs (/o/, /i/) did not change with experience, and no vowel response increased in its goodness rating from NoExp to HiExp. The front rounded vowel /y/ received the lowest goodness ratings (Median =

5, 3, 3 by NoExp, Mod Exp, and HiExp, respectively) of all PF vowels, suggesting that it was perceived as the PF vowel least similar to AE vowels.

3.3.1. Perceptual Assimilation of front rounded vowels /y/ and /œ/ to back, central or front AE vowels

In order to determine whether PF front rounded vowels were assimilated to AE front or back phonological categories, responses to stimuli containing the PF high front rounded vowel /y/ stimulus and the PF mid front rounded vowel /œ/ stimulus were collapsed. For this analysis, front unrounded vowel responses (/i/ and /ɪ/, the front AE vowels chosen by participants) were combined, central vowel responses (/ʌ/, /ɝ/) were combined, and back rounded vowel responses (/u/, /ju/, /ʊ/, /o/) were combined.

Responses to stimuli containing the PF front rounded vowels are shown in Figure 5. The three AE language experience groups are represented along the abscissa. Within each language group, front unrounded AE vowel responses are indicated in the checkered left-hand column, central AE vowel responses are shown in the solid light middle column, while back rounded AE vowel responses are indicated in the solid dark right-hand column. The overall percentage of trials (summing over vowel tokens and listeners) in which a front, central or back response was chosen is indicated on the vertical axis. The PF high and mid front rounded vowels /y/ and /œ/ were assimilated overwhelmingly to AE back vowels by all AE language groups. When listeners in the NoExp group were presented with PF front rounded vowel stimuli, 4% of their responses were front vowels, 1% were central vowels, whereas 95% were back vowels. Similarly, the ModExp group assimilated

1% of the front rounded vowels to front vowels, 1% to mid vowels, and 98% to back vowels. The HiExp group categorized no front rounded vowel tokens (0%) as AE front vowels and 88% as AE back vowels. Central vowel responses, primarily the rhotacized central vowel /ɝ/, accounted for 12% of the HiExp responses. Thus, despite the acoustical evidence that /y/ and /œ/ are front vowels characterized by a high second formant frequency, AE listeners perceived these vowels as most similar to AE back vowels. This finding is consistent with studies in the categorial discrimination literature (e.g., Gottfried, 1984; Levy & Strange, 2002) documenting AE listeners' difficulty in discriminating PF front rounded vowels from back vowels, as well as findings of North German front rounded vowels being perceptually assimilated primarily to back rounded vowels (Strange et al., 2004; forthcoming).

Although both front rounded vowels were perceptually assimilated to back vowels, the particular back vowels to which the listeners assimilated the PF vowels differed. Moreover, no language experience effect was evident in the perceptual assimilation of high front rounded vowel /y/, whereas language experience did affect perceptual assimilation of the mid front rounded vowel /œ/. Thus, perceptual assimilation of /y/ and of /œ/ are examined separately below.

3.3.2. Perceptual assimilation of high front rounded /y/: language experience effects

Perceptual assimilation patterns for stimuli containing the PF high front rounded vowel /y/ are shown in Figure 6 (top). Again, the three AE language groups are represented along the abscissa, while the percentage of trials for which a particular response was selected is shown on the vertical axis. When listeners in the

NoExp group were presented with a PF /y/ stimulus, 73% of their responses were /ju/. That is, /y/ was heard as most similar to the AE vowel in "hued" on 73% of the trials by the NoExp group. The modal choice of /ju/ rather than /u/ would suggest that overall, PF /y/ is not perceived as identical to the AE back rounded /u/ vowel; thus, discrimination of PF /y/ from PF /u/ (which will be shown to perceptually assimilate to AE /u/), should be better than chance. The median rating for each response is indicated on each response bar: The NoExp group gave /y/ a median goodness rating of 5 for the /ju/ response.

The second most frequently selected response by the NoExp group was /u/, which was chosen on 19% of the trials and which also received an overall median goodness rating of 5. The /i/ response was chosen on 6% of the trials by the NoExp group, (primarily by one participant, to be discussed below) and received a median goodness rating of 7. The remaining 2% of responses (represented by the striped section at the top of the bar) were miscellaneous perceptual assimilation responses chosen less than 10% of the time. For all three groups, the overwhelming majority of responses to stimuli with PF /y/ were back vowels (NoExp: /ju/ 73%, /u/: 19%; ModExp: /ju/ 78%, /u/: 18%, HiExp: /ju/ 66%, /u/: 31%). This had been predicted, based on previous studies (e.g., Gottfried, 1984; Levy & Strange, 2002; Strange et al., 2004).

The NoExp and ModExp language groups performed very similarly in their top two most frequent response choices /ju/ (73%, 78%, and 66% for the NoExp, ModExp, and HiExp groups, respectively) and /u/ (19%, 18%, and 31%), while the HiExp group tended to assimilate /y/ to /u/ somewhat more often. However, the modal response /ju/ was the same for all three groups. Thus, despite the participants' vastly different language histories, their perceptual assimilation patterns for /y/ were similar. This pattern of perceptual assimilation of /y/ across groups was predicted based on discrimination studies (Gottfried, 1984; Levy & Strange, 2002) indicating that listeners with extensive French experience perform similarly for the /u-y/ contrast to listeners with no French experience. A difference among the groups in the present study, however, was revealed in the goodness ratings of the front rounded vowel: the median rating decreased from 5 to 3 for both /ju/ and /u/ responses with extensive language experience, suggesting that listeners became more attuned to the differences between PF and AE phonologies with French experience.

3.3.3. Perceptual assimilation of mid front rounded /œ/: language experience effects

Perceptual assimilation patterns for stimuli containing the PF front rounded vowel /œ/ are shown in the bottom graph of Figure 6. As for /y/, the mid front vowel /œ/ was perceived overwhelmingly as most similar to back AE vowels. However, /œ/ perceptually assimilated to more AE categories than did /y/. In fact, in response to the /œ/ stimulus, no AE category was selected more than 50% of the time by the NoExp group (/u/: 46%, /ʊ/: 27%, /o/: 12%). For this vowel, a language effect was evident in perceptual assimilation. The modal response for the NoExp group was /u/ (46%) and the second most frequently chosen response was /ʊ/ (27%). With moderate experience, the modal responses were reversed, with /ʊ/ becoming the most frequently chosen (52%) and /u/ becoming the second most frequently chosen response (17%). The AE /ʊ/ response was chosen even more often by the HiExp group (60%) than by the ModExp group, and this group only rarely assimilated /œ/ to /u/ (6%). Rather, a new response category became the second most frequent response: the rhotacized vowel /ɝ/ as in "herd" (24%).

The overall median goodness rating of responses to PF /œ/ was relatively high (6) for the NoExp group, dropped to 4 for the ModExp group, then rose to 5 for the most frequently chosen responses by the HiExp. The HiExp group's relatively high median goodness ratings suggest that these listeners had come to accept PF /œ/ as a fairly good instance of the AE category /ʊ/ or /ɝ/. Such a perceptual assimilation pattern may be useful for discrimination purposes in that neither of the AE vowels is in the PF vowel inventory. Thus, /œ/ heard as /ʊ/ or /ɝ/is not likely to be confused with a PF vowel that is heard as an exemplar of AE /u/ or /ju/. In terms of production, however, these listeners' "perceptual acceptance" of /œ/ as relatively American-sounding may also be associated with accented pronunciation of this vowel.

3.3.4. Perceptual assimilation of high front rounded /y/: consonantal context effects

Responses to the high front rounded /y/ are broken down in Figure 7 according to consonantal context, revealing a context effect on listeners' perceptual assimilation patterns. The graph reads similarly to the above figures, but now for each language experience group (on the abscissa), responses for stimuli in bilabial /rabVp/ context are displayed in each left-hand column and responses for stimuli in alveolar

/radVt/ context are displayed in each right-hand column. The AE vowel /ju/ was more often chosen as a response to PF /y/ stimuli in bilabial context (80%, 85%, 72%) than in alveolar context (65%, 71%, 61%) by the NoExp, ModExp, HiExp groups, respectively. Conversely, the /u/ response was chosen less often in bilabial context for all language experience groups.

This effect of consonantal context had been predicted based on the context effect found in Levy and Strange's (2002) discrimination experiment. In the present study, the context effect decreased with experience (difference between alveolar and bilabial contexts for PF /y/ being assimilated to AE /u/: 24%, 9%, 6% for NoExp, ModExp, Hi Exp, respectively, and 15%, 14%, 11% for /y/ being assimilated as /ju/.) Such results are consistent with Levy and Strange's finding of decreased consonantal context effects with increased L2 experience.

The mean individual internal consistency (expressed as a percent of trials/listener) is indicated under the bar graph in Figure 7 for each consonantal context within each language experience group. Individual listeners were relatively consistent in their responses to /y/ stimuli (range = 73%-95%). With increased language experience, listeners became more internally consistent in their responses for stimuli in bilabial context (88%, 91%, 95% for NoExp, ModExp, and HiExp groups, respectively), but not for stimuli in alveolar context (76%, 73%, 78% for NoExp, ModExp, and HiExp, respectively). A 3 (language experience group) by 2 (consonantal context) mixed design analysis of variance indicated that the language experience effect was not statistically significant, $F(2, 36) = .56$, $p = .574$ (see Appendix L for ANOVA). Internal consistency was significantly higher in bilabial context than in alveolar context for all groups, $F(1, 36) = 28.30$, $p < .001$, suggesting a more stable internal representation of /y/ in bilabial context than in alveolar context. Most experienced listeners heard /y/ as a palatalized back vowel, selecting /ju/ as their modal response, while the remaining experienced listeners heard /y/ as a nonpalatalized back vowel, selecting /u/ most often. There was no significant interaction between experience and context, $F(2, 36) = .488$, $p = .618$.

A brief discussion of the interpretation of /ju/ responses is merited. In the present experiment, the word "hued" (i.e., the /ju/ response) was included as an AE keyword response option, based on the observation that AE learners of French frequently produce /ju/ in French conversation when targeting production of the French front rounded vowel /y/. However, difficulties arise in interpreting the choice of /ju/ as a response. If a listener perceptually assimilated the PF vowel /y/ as AE /ju/, for example, and the same listener perceptually assimilated the PF vowel /u/ as AE /u/, it is not evident whether the perceptual assimilation pattern for the /u-y/ pair should be considered single-category assimilation (because both AE responses include the /u/ vowel) or category-goodness (because /ju/ is a palatalized version of /u/) or two-category assimilation (because the minimal pair /who'd-hued/ would suggest these fall into different phonological categories).

What can be expected, however, is that pairs characterized by this assimilation pattern would be less easily distinguished than a clear 2-category pair such as /i-u/ (for which perceptual assimilation responses rarely overlap) and more easily distinguished than pairs that assimilate more frequently to the identical AE category (as in 46% of /œ/ stimuli and 32% of /o/ stimuli being assimilated to AE /o/ in the present experiment, as will be shown). Thus, although it is unclear how this assimilation pattern should be characterized, the prediction is that it will result in fewer discrimination errors than unambiguous single-category pairs and more errors than unambiguous two-category pairs.

An interaction had been predicted based on the Levy and Strange (2002) study indicating that listeners with no experience (but not listeners with extensive experience) had more difficulty discriminating /y/ from /u/ in alveolar context and /y/ from /i/ in bilabial context. The results displayed in Figure 7 are consistent with that interaction, albeit for a smaller group of individuals: In bilabial context, the NoExp group perceptually assimilated /y/ to /i/ for 12% of the trials and to /u/ for 7% of the trials. In alveolar context, this pattern was reversed, with 1% of the stimuli perceptually assimilating to /i/ and 30% to /u/.

Individual data suggest that this pattern was primarily due to one NoExp participant's perceptual assimilation performance. One participant perceptually assimilated /y/ to /i/ 100% in bilabial context and 0% in alveolar context. All other NoExp participants' modal responses to /y/ were back vowels. However, their non-modal responses revealed that /y/ was perceptually assimilated to /i/ in bilabial context on 17% of trials by two participants and on 6% of trials by two other participants. In alveolar context, two participants perceptually assimilated /y/ to /i/ in 6% of the trials. The interaction will be further discussed below.

3.3.5. Perceptual assimilation of mid front rounded /œ/: consonantal context effects

Responses to the mid front rounded vowel /œ/ stimuli also varied as a function of consonantal context, as demonstrated in Figure 8. The /u/ response was less frequently chosen in the bilabial condition (the left-hand column in each language experience group: 34%, 11%, 3%) than in alveolar context (right-hand column in each group: 59%, 23%, 9%) by the NoExp, ModExp, and HiExp groups, respectively. Conversely, more /ʊ/ responses were selected by the NoExp and ModExp groups in bilabial context than in alveolar. The modal response for the HiExp group /ʊ/, was approximately the same (60% for bilabial, 61% for alveolar context), regardless of consonantal context, consistent with the notion that with extensive L2 experience, perception of vowels in the second language becomes more abstract, that is, less affected by consonantal context. On the other hand, the /ɝ/ and the /u/ responses did differ slightly as a function of consonantal context for the HiExp group.

Individual listeners' internal consistency in categorizing PF /œ/ was generally lower (range = 57%-90%) than for /y/. That is, individual listeners varied more in assigning PF /œ/ to a particular AE vowel than they did in assigning PF /y/. For the mid PF vowel /œ/, increased language experience was associated with greater internal consistency for stimuli in bilabial context (59%, 75%, 90%) but not for stimuli in alveolar context (77%, 57%, 83%). Furthermore, internal consistency was lower in bilabial context than in alveolar context for the NoExp group, but higher in the bilabial context for the ModExp, and HiExp groups, respectively. A 3 (language experience) by 2 (consonantal context) analysis indicated that the main effect of consonantal context was not statistically significant, $F(1, 36) = .63$, $p = .43$ (See

Appendix M for ANOVA). However, it confirmed the main effect of language experience, $F(2, 36) = 8.01$, $p < .01$, and the language experience/context interaction, $F(2, 36) = 11.88$, $p < .001$. Planned comparisons indicated no significant difference between consistency of the NoExp group and the ModExp group, $p = .823$, but significantly greater consistency in the HiExp group relative to the ModExp group, $p < .01$. Thus, French immersion experience was associated with a more stable internal representation of /œ/, whereas formal instruction only was not.

3.3.6. Perceptual assimilation of back rounded vowel /u/

Figure 9 shows AE the perceptual assimilation of French /y/, /u/, /œ/, /o/ by AE listeners. Perceptual assimilation patterns for all four vowels are displayed on one page to facilitate predictions of discrimination performance based on how the vowels were perceptually assimilated. The top figure shows the (previously discussed) graph representing the perceptual assimilation of /y/ (on the left) and /u/ (on the right). As before, language experience groups are displayed on the X-axis and percent of responses chosen are shown on the Y-axis. PF /u/ was perceptually assimilated by all three language groups primarily as AE /u/ (87%, 80%, and 85% by the NoExp, ModExp, and HiExp groups, respectively), and otherwise as AE /ju/ (8%, 9%, and 2%, respectively). The median ratings for PF /u/ as an exemplar of the AE response /u/ were 7 for NoExp, decreasing to 4 for ModExp, and increasing to 6 for HiExp.

3.3.7. Perceptual assimilation of back rounded vowel /o/

The bottom left graph in Figure 9 shows perceptual assimilation of PF /œ/ (previously discussed) and PF /o/ for comparison purposes. Although it was expected that PF /o/ would be perceived as most similar to AE /o/, the NoExp group assimilated /o/ primarily to AE /u/ (53%) and less often to AE /o/ (32%). The modal category and the second most frequently chosen response reversed themselves with moderate experience (/o/ = 70%, /u/ = 19%). With immersion experience (i.e., the HiExp group), virtually all listeners perceived PF /o/ as most similar to AE /o/ (/o/ = 98%, /u/ = 0%). Thus, there was an unexpected language experience effect on AE listeners' perceptual assimilation of PF /o/.

Perceptual assimilation of /o/ to the AE /u/ category by NoExp listeners may have two explanations. First, PF /o/ is produced higher in the oral cavity (thus with a lower F1) than AE /o/, rendering it articulatorily and acoustically more similar to an AE /u/ and sometimes overlapping in acoustic space with PF /u/. The acoustic overlap of the PF back vowels /u/ and /o/ was shown in the scatter plot of the stimuli (Figure 2). Secondly, PF /o/ is a monophthong; thus, listeners may have been more likely to choose the AE monophthong /u/, rather than the AE diphthongized /oʊ/ as the most similar AE vowel to the PF vowel /o/.

3.3.8. Perceptual assimilation of high front unrounded /i/

Perceptual assimilation of the PF front unrounded vowel /i/ is shown in the top graph in Figure 10. Listeners overwhelmingly perceived AE /i/ as the closest AE vowel to the PF high front unrounded vowel (mean of 99%). The high percentage of /i/ assimilation responses to its native language counterpart is typical of other perceptual assimilation results (e.g., Strange et al., 2004). This may be a consequence of the acoustic similarity of /i/ vowels across languages due to the extreme height and frontness of this vowel, which is limited by the dimensions of the human oral cavity. Thus, perceptual assimilation patterns for this vowel also serve as a "control" condition to confirm participants' adherence to the Perceptual Assimilation task. Furthermore, the relatively high median rating of 7 across language groups for this vowel suggests that a 7 signified the highest relative goodness rating for the participants in the present study.

3.3.9. Perceptual assimilation of /a/ and /ɛ/

Perceptual assimilation patterns for two PF vowels /a/ and /ɛ/ remain to be discussed briefly. It was assumed that PF low central unrounded /a/ and mid front unrounded /ɛ/ would perceptually assimilate to AE /ɑ/ and /ɛ/, respectively. As shown in the bottom left graph of Figure 10, however, /a/ was perceptually assimilated about equally often to AE /æ/ (mean of 47%, 41%, 53% by the NoExp, ModExp, and HiExp groups, respectively) and AE /ɑ/ (43%, 41%, 46% by the three groups, respectively). When produced in bilabial or alveolar context, PF /a/ is a higher, more front vowel than AE /ɑ/, explaining why /æ/ may have been perceived as the AE vowel most similar to PF /a/. Median goodness ratings for the /æ/ response were relatively high (7, 6, 6, by the NoExp, ModExp, and HiExp groups, respectively) and slightly lower for the /ɑ/ response (6, 5, 6 for the three language experience groups, respectively), suggesting that PF /a/ was perceived as somewhat more similar to AE vowel /æ/ than to /ɑ/.

PF /ɛ/ (bottom right graph in Figure 10) was perceptually assimilated primarily to AE /ɛ/, although 11% of the NoExp responses were that /æ/ was the closest AE vowel to /ɛ/. It would follow that some difficulty might be expected in the

NoExp discrimination of PF /a-ɛ/. Median goodness ratings for the AE /ɛ/ response to PF /ɛ/ were relatively high (Median = 7, 6, 6, by the NoExp, ModExp, and HiExp groups, respectively).

3.3.10. Perceptual assimilation: summary

In sum, PF front rounded vowels were perceptually assimilated overwhelmingly to AE back rounded vowels. Language experience was not associated with differences in response choices for perceptual assimilation of the PF vowel /y/ (primarily AE /ju/ and /u/). In contrast, responses to /œ/ did change as a function of language experience (e.g., the AE /u/ response decreased in representation, /ʊ/ increased, and /ɝ/ emerged as a response). A consonantal context effect was evident for both front rounded vowels, with perceptual assimilation to /u/ more frequent in alveolar context than in bilabial context. Overall, median goodness ratings decreased for front rounded vowels as a function of language experience.

Back rounded PF /u/ was perceived as closest to its AE counterpart /u/. The back rounded PF vowel /o/ was also perceptually assimilated to AE /u/ on more than half of the trials by the NoExp group. However, with experience, /o/ was perceived as more similar to its AE counterpart /o/. Front unrounded PF vowels /i/ and /ɛ/ were consistently assimilated as excellent exemplars of their AE counterparts /i/ and /ɛ/, and the PF unrounded low vowel /a/ was perceived as similar to either AE /æ/ or /ɑ/. Overall, median goodness ratings decreased with increased language experience.

Perceptual assimilation patterns for PF front rounded vowels were not predictable from their acoustic structure relative to other PF vowels. French front rounded vowels, which are acoustically more similar to French front unrounded vowels than to back rounded vowels, were perceived overwhelmingly as most similar to back AE vowels. Based on these perceptual assimilation results, predictions may be made regarding difficulties in categorial discrimination by AE listeners of PF vowel pairs and in how discrimination will be affected by language experience and consonantal context. In Section 3.4 below, predictions for discrimination are made on the basis of the perceptual assimilation data (and previous studies), and these predictions are followed by presentation of the actual categorial discrimination results.

3.4. Categorial discrimination of Parisian French vowels

For an overview of categorial discrimination findings, Table 2 presents the percent errors and standard errors of the mean (in percent) by each language experience group (NoExp, ModExp, HiExp across the top row) for each contrasting vowel pair. The vowel pairs are listed in the left-hand column beginning with the front rounded vowels paired with back vowels (/y-u/, /y-o/, /œ-o/, /œ-u/), followed by the front rounded vowels paired with the front unrounded vowels (/y-i/, /y-ɛ/, /œ-ɛ/, /œ-i/), the front rounded vowels paired with each other (/y-œ/), and the control pairs (/a-ɛ/, /u-i/).

Asterisks by pairs /œ -i/, /y-ɛ/, /y-o/, /œ -u/, /a-ɛ/, /u-i/ indicate that they differed by 2 phonological features (i.e., roundedness, height, front vs back). PF /a-ɛ/ and /u-i/ were control pairs because they had obvious counterparts in AE. At the outset of the experiment, it was expected that the 2-feature pairs would be more easily discriminated than the 1-feature experimental pairs. Therefore, half as many trials (12 judgments instead of 24) were presented to listeners for each of these pairs. As it turned out, however, errors occurred despite height differences for the /œ-u/ and the /a-ɛ/ pairs. Thus, results from these "non-experimental" pairs were included in the analysis.

As this table shows, overall, discrimination errors decreased with language experience (13%, 10%, and 3% for NoExp, ModExp, and HiExp, respectively). This was due to increased discrimination accuracy on front vs back rounded vowel contrasts, on contrasts between front rounded vowels and between /a-ɛ/. More errors occurred when front rounded vowels were paired with back rounded vowels (first four contrasts) than when they were paired with front unrounded vowels (next four contrasts). Vowel pairs were not equally difficult to discriminate, with the NoExp group making 0% to 33% errors, depending on which contrast was presented. The consonantal context effect will be discussed below. It should be noted that although statistical analyses for each vowel pair were performed using "number correct scores" in discrimination, scores were converted into percent errors of opportunities for presentation in graphs and for comparison of pairs involving different numbers of trials (i.e., 1-feature vs 2-feature pairs).

3.4.1. Categorial discrimination of front rounded vowels paired with back or front vowels

Because front rounded vowels were perceptually assimilated primarily to back vowels in the present study and in previous studies (e.g., Strange et al., 2004) and because even advanced listeners have demonstrated difficulty differentiating front rounded vowels from back rounded vowels (Gottfried, 1984; Levy & Strange, 2002), more errors in discrimination were expected to be found in the present experiment when front rounded vowels were paired with back vowels than when they were paired with front vowels.

For this analysis, the discrimination data were divided into two scores: total percent of errors made on pairs containing a front rounded vowel and a front unrounded vowel (/i-y/, /y-ɛ/), /œ-ɛ/, /œ-i/) and total percent errors made on pairs containing a front rounded vowel and a back rounded vowel (/y-u/, /y-o/, /œ-o/, /œ-u/). As predicted, based on the perceptual assimilation data, difficulties with categorial discrimination occurred significantly more often when front rounded vowels were paired with back vowels than when they were paired with front unrounded vowels. Figure 11 summarizes these patterns produced by the three AE language experience groups and the Native French listeners (along the abscissa). The front rounded vowels paired with front unrounded vowels are represented by the left-hand checkered column in each language experience group and the front rounded vowels paired with back vowels are represented by the right-hand solid column in each language group. The vertical axis indicates percent of errors and the error bars represent standard error of the means (in percent). When front rounded vowels were contrasted with front unrounded vowels, listeners in all groups made few errors (3%, 2%, 1% for the NoExp, ModExp, and HiExp groups, respectively). When front rounded vowels were contrasted with back rounded vowels, on the other hand, listeners made far more errors (22%, 19%, 6% for the NoExp, ModExp, and HiExp groups, respectively), as predicted.

As expected, discrimination accuracy increased with language experience. The NoExp group made the most errors (13%) overall on all pairs involving front rounded vowels, followed by the ModExp group (11%), followed by the HiExp group (3%). (The native French listeners performed at ceiling, as discussed in Stimulus Verification.)

Since listeners in all three groups made almost no errors on front rounded vs unrounded pairs, no further statistical analysis of these results were conducted, and the analysis focused on discrimination of front rounded vowels paired with back rounded vowels. Figure 12 shows the mean percent errors and standard errors on each of the four front rounded vs back rounded pairs (/y-u/, /y-o/, /œ-o/, /œ-u/) for the three language groups. On these pairs, the NoExp group made the most errors (22%), followed by the Mod Exp group (19%), followed by the HiExp group (6%). A 3 (language experience) X 4 (front vs back rounded vowel pairs) mixed design analysis of variance with repeated measures on vowel pairs within language groups confirmed a significant main effect of participants' language experience, $F(2, 36) = 222.55$, $p < .001$ (see Appendix N for ANOVA). Planned comparisons indicated that the overall difference in performance between the NoExp group and the ModExp was not significant ($p =.145$), whereas the HiExp group did make significantly fewer errors overall in discrimination than did the other two groups ($p < .001$). This finding reveals an association between extensive instruction and immersion experience and increased discrimination accuracy on front vs back rounded vowels, but no association between formal instruction (without immersion) and overall better performance on these contrasts. A significant main effect of vowel pair was also revealed, $F(3, 108) = 28.85$, $p < .001$, as well as a significant interaction between vowel pair and language experience $F(6,108) = 8.72$, $<.001$; thus, vowel pairs and language effects are discussed individually below.

Due to significant heterogeneity of variance, further analyses were performed on each of the four pairs individually to examine the effects of language experience and consonantal context on discrimination accuracy. If variance across language experience groups was heterogeneous for a vowel pair (typically, there was less variance in the HiExp group), a further analysis of variance was performed without the HiExp group, i.e., a 2 (language experience: NoExp vs ModExp) X2 (context) mixed design. Such was the case for the pairs /œ-o/ and /œ-u/. The results of the 2X2 analyses confirmed the original analysis of variance results.

3.4.2. Categorial discrimination of /y-u/ and /y-o/: experience and context effects

Because the PF high front rounded vowel /y/ was perceptually assimilated to /ju/ or /u/, as was PF /u/, the /y-u/ contrast was predicted to result in discrimination difficulty for all groups, although performance was predicted to be better than chance (i.e., 50%). Figure 13 presents mean errors for discrimination of pairs involving the front rounded vowel /y/ and the two back rounded vowels /u/ and /o/. The top graph shows percent errors (Y-axis) in discrimination of the /u-y/ pair by the NoExp, ModExp, and HiExp Groups (along the X axis). Scores for each language group are divided into bilabial (left checkered bar) and alveolar (right solid bar) context. For the high vowel pair /u-y/, listeners performed above chance, but not significantly differently across groups: NoExp: 16%, ModExp: 19%, HiExp: 12%. A 3 (language experience group) by 2 (context) analysis of variance confirmed that the language effect was not significant, $F(2, 36) = 1.55$, $p = .23$ (see Appendix O for ANOVA). This is consistent with Levy and Strange's (2002) finding that advanced listeners of French fared no better than listeners with no French experience for this vowel pair—a contrast that is particularly resistant to improvement. The consonantal context main effect, on the other hand, was significant, $F(1, 36) = 49.26$, $p < .001$, as predicted from the perceptual assimilation findings, with more difficulty revealed in alveolar context than in bilabial context. The language by context interaction was not significant, $F(1, 36) = 1.11$, $p = .340$.

The bottom graph in Figure 13 presents the data for the /y-o/ contrast, which was expected to be more easily discriminated than /y-u/ for two reasons: First, the high front rounded vowel /y/ was perceptually assimilated primarily to /ju/, whereas /o/ was perceptually assimilated primarily to /o/, a different category, except for the least experienced group. Since the NoExp listeners assimilated /o/ to AE /u/ on more than half of the trials, some discrimination difficulty could be expected for this language group. Secondly, this pair differed not only in front-back place of articulation, but also in height. As the figure shows, few errors were made by any group in discriminating this pair (NoExp = 8%, ModExp = 5%, HiExp = 3%). With so few errors, no significant experience effect, $F(2, 36) = 1.66$, $p = .20$, nor consonantal context effect, $F(1, 36) = .2.15$, $p = .15$, was present, as indicated in the ANOVA in Appendix P.

3.4.3. Categorial discrimination of /œ-o/ and /œ-u/: experience and context effects

The mid-front rounded vowel paired with the mid back rounded vowel, /œ-o/, was expected to show increased discrimination accuracy with language experience. The NoExp group assimilated both vowels primarily to AE /u/, but also to /ʊ/ and /o/. This overlap in assimilation patterns would predict poor discrimination for the /œ-o/ pair. Less overlap was present in the ModExp group's assimilation patterns, in that both vowels assimilated less frequently to AE /u/. Finally, in the HiExp group, the two vowels virtually never assimilated to the same AE vowel: /o/ assimilated overwhelmingly to AE /o/ (98% of responses), whereas /œ/ assimilated primarily to /ɝ/ and /ʊ/ and only rarely to /o/ (2% of responses). Moreover, with extensive language experience, listeners perceived /œ/ as most similar to AE vowels (such as /ɝ/) that do not have direct counterparts in French, and were therefore less likely to cause confusion with other French vowels. Thus, by the time listeners had extensive immersion, few difficulties were expected in discriminating these vowels.

Figure 14 presents discrimination of pairs involving the mid front rounded vowel /œ/ and back rounded vowels. The top graph shows percent errors (Y-axis) in discrimination of the /œ-o/ pair by the NoExp, ModExp, and HiExp groups. Again, results within each group are divided into bilabial /rabVp/ (left checkered bar) and alveolar /radVt/ (right solid bar) context. For the /œ-o/ contrast, the NoExp group made the most errors (26% in bilabial and 39% in alveolar context), followed by the ModExp group (15% in bilabial, 29% in alveolar context), followed by very few errors by the HiExp (1% in bilabial and 6% in alveolar context). A 3 (language experience group) by 2 (context) analysis of variance (in Appendix Q), revealed a main effect of language experience, $F(2, 36) = 33.36$, $p < .001$, with increased experience being associated with fewer errors in discrimination for this vowel pair. Planned comparisons indicated that the ModExp group made significantly fewer errors than did the NoExp group ($p < .01$), thus formal instruction was associated with better discrimination for this vowel pair. The HiExp group performed significantly better than did the ModExp group ($p < .001$); thus, extensive language instruction and immersion was associated with even fewer errors than was formal instruction without immersion. The prediction of a significant context effect, based on perceptual assimilation differences as a function of context for /œ/, was also borne out, $F(1, 36) = 18.88$, $p < .001$, with more errors in alveolar context than in bilabial context for all groups. Due to significant heterogeneity of variance, a 2 (language experience group) by 2 (context) analysis of variance (in Appendix Q) was performed on the NoExp group versus the ModExp group. The results confirmed the significant language experience effect, $F(1, 24) = 6.10$, $p < .05$, and the significant context effect, $F(1, 24) = 14.78$, $p < .01$. No significant interaction was present between language experience and context, $F(2, 36) = 1.54$, $p = .228$.

The /œ-u/ contrast was expected to show similar patterns to /œ-o/, with a language experience and consonantal context effect. However, this pair was predicted to be more easily discriminated than /œ-o/ due to its height difference along with the front-back difference. The bottom graph in Figure 14 displays discrimination results for this contrast, with consonantal context within language group on the X-axis and percent errors on the Y-axis. A (3 language X 2 context) ANOVA confirmed a significant effect of language experience, $F(2, 36) = 18.75$, $p < .001$ (see Appendix R), but one that was different from that found for the /œ-o/ pair. The NoExp group made the most errors (31% in bilabial and 35% in alveolar context), followed by the ModExp group (31% in bilabial, 26% in alveolar context), followed by very few errors by the HiExp (1% in bilabial and 10% in alveolar context). Thus, as predicted, a language effect was present, with increased experience being associated with fewer errors in discrimination of this vowel pair. However, for this pair only the immersion group performed better than the other groups ($p < .001$). The formal experience group (ModExp) did not perform significantly better than the NoExp group ($p= .347$). Again, due to significant heterogeneity of variance, a (2 group X 2 context) ANOVA (see Appendix R) was performed on the NoExp versus the ModExp group. The results confirmed that there was no significant difference on discrimination performance between the two non-immersion groups (NoExp versus ModExp), $F(1, 24) = .78$, $p = .386$.

That listeners actually made more errors with the /œ-u/ pair than with the /œ-o/ pair was unexpected due to the height difference of the pair's members (along with the front-back difference). However, in light of the finding that less experienced listeners often perceptually assimilated PF /o/ to AE /u/, it follows that the height difference did not help these listeners distinguish the front rounded vs the back rounded segments.

Another unexpected finding for this pair was the lack of a significant context effect $F(1, 36) = .49$, $p = .49$, despite differences in perceptual assimilation of /œ/ as a function of context. The 2 (language experience group) by 2 (context) analysis of variance confirmed the lack of a significant context effect for the NoExp versus ModExp group, $F(1, 24) = .02$, $p = .90$. The NoExp group and HiExp group appeared to have more difficulty in alveolar context than in bilabial, but this was not true for the ModExp group. Because of these unexpected results and because half as many pairs (12 judgments per participant) were presented for this contrast compared to the 24 judgments per participant for the contrasts that were expected to be difficult, further research is needed to explain the absence of a consonantal context effect on discrimination of this pair.

3.4.4. Interaction of vowel pair, language group, and consonantal context for /u-y/, /i-y/ in perceptual assimilation and categorial discrimination

When consonantal context was taken into consideration, the only score to reach above 6% errors in pairs involving front rounded versus unrounded vowels was the score of 10% errors for the /i-y/ pair in bilabial context by the NoExp group. Despite the low error rate, this contrast merits examination in light of the interaction of vowel pair, language experience, and consonantal context.

The top graph in Figure 15 shows the (previously discussed) pattern of perceptual assimilation for the NoExp group. (The other language experience groups rarely assimilated /y/ to /i/ in either context.) As mentioned in the report of the context effect on perceptual assimilation of /y/, an interaction was found in the present study, primarily for one individual with no French experience, in which /y/ was perceptually assimilated to /i/ more often in bilabial context than in alveolar context.

The interaction noted in the perceptual assimilation results is consistent with the interaction in discrimination shown in the graph at the bottom of Figure 15 (discrimination of /i-y/ and /u-y/ by the NoExp group). In bilabial context, the NoExp group made more errors for the /i-y/ pair (10%) than for the /u-y/ pair (5%), whereas in alveolar context, they made more errors for the /u-y/ pair (27%) than for the /i-y/ pair (4%). As in the Perceptual Assimilation task, this pattern was primarily due to one participant, who made 33.3% errors on /i-y/ in bilabial context and no (0%) errors in alveolar context. Of the other NoExp participants, four made errors on /i-y/ in bilabial context (mean of 18.8% errors) and three made errors on this contrast in alveolar context (mean of 13.9% errors).

A closer examination of the discussed individual listener's perceptual assimilation and discrimination patterns demonstrates this interaction and provides an example of the Perceptual Assimilation Model (Best, 1994, 1995) being predictive on an individual level: One NoExp listener (Participant #111) perceptually assimilated all /y/ vowel stimuli to /i/ (100% of responses—more than all other listeners) when /y/ was presented in bilabial context. As predicted by the Perceptual Assimilation Model, he had discrimination difficulty (33% errors) with the /i-y/ contrast in bilabial context—the highest percent of errors of any participant on this pair. In alveolar context, on the other hand, he perceptually assimilated /y/ exclusively to back vowels (39% to /u/, 50% to /ʊ/ and 6% to /ju/--never to /i/). As predicted, in alveolar context, he discriminated the /i-y/ pair far better (0% errors) than the /u-y/ contrast (25% errors). Thus, for this individual listener, the Perceptual Assimilation Model predicted his discrimination performance from his perceptual assimilation patterns, and most effectively when consonantal context was taken into account.

Although the present discrimination results are consistent with the predictions based on Levy and Strange's (2002) similar finding and on the perceptual assimilation data reported, only a small percentage of responses in the present study revealed this difficulty with the /i-y/ pair in bilabial context (10% in the present study compared to the 24% in Levy and Strange's study). In the present discrimination experiment, only 5 out of the 13 NoExp participants (= 38%) made more errors in bilabial context than in alveolar context on the /i-y/ pair (see Appendix S). In Levy and Strange's study (see Appendix T), 8 out of the 10 participants with no French experience (= 80%) made more errors in bilabial context than in alveolar context for the /i-y/ pair. Thus, results from the present study provide valuable data on individual perceptual patterns, but may not be generalized to naïve AE listeners as a group.

3.4.5. Categorial discrimination of front rounded vowels /y-œ/

Both the high front rounded vowel /y/ and the mid-front rounded vowel /œ/ were perceptually assimilated to back vowels, sometimes to the same vowel /u/. This observation, as well as previous literature documenting AE difficulty discriminating the front rounded vowels /y-œ/ led to the prediction that this pair would be difficult for all groups of listeners. Errors were expected to decrease with language experience, as /œ/ was less frequently perceptually assimilated to AE /u/ with increased experience, while /y/ was perceived as most similar to /u/ or /ju/ for all language experience groups. In addition, a context effect was expected based on the perceptual assimilation results.

The above predictions were for the most part confirmed by the discrimination data. As shown in Figure 16, NoExp listeners made the most errors in differentiating the /y-œ/ pair (12% errors in bilabial and 22% in alveolar context), followed by the

ModExp Group (10% errors in bilabial and 21% in alveolar context), followed by the HiExp Group (3% errors in bilabial and 4% in alveolar context). A 3 (language experience) by 2 (context) analysis of variance (see Appendix U) confirmed the significance of the language main effect, $F(2, 36) = 9.0$, $p < .01$, and the consonantal context main effect, $F(1, 36) = 8.39$, $p < .01$. Planned pairwise comparisons indicated no significant difference between performance of the NoExp group and the ModExp group, $p = .70$, but a significant difference between ModExp and HiExp performance, $p < .01$. That is, listeners with no French language experience and listeners with formal French instruction experience performed similarly. Listeners with extensive French instruction and immersion experience outperformed listeners in the other two groups. No significant interaction between language experience and context was obtained, $F (2, 36) = 1.18$, $p = .32$. Due to significant heterogeneity of variance, a 2 (language experience group) by 2 (context) analysis of variance was performed on the NoExp vs ModExp groups, confirming the context effect, $F(1, 24) = 7.50$, $p < .05$, the lack of a language effect between the non-immersion groups, $F(1, 24) = .737$, and the lack of a language/context interaction, $F (1, 24) = .030$, $p = .86$.

3.4.6. Categorial discrimination of /a-ɛ/ and /u-i/

The control pairs /a-ɛ/ and /u-i/ were, by definition, expected to result in few discrimination errors, based on the assumption that these vowels would fall into the "two-category" assimilation pattern. Figure 17 shows the mean discrimination errors for these two pairs for each language group. For the /a-ɛ/ pair, the groups made more errors than expected (NoExp = 19%, ModExp = 10%, HiExp = 2%). However, recall that the NoExp group perceived both PF /a/ and /ɛ/ as most similar to /æ/ some of the time. Furthermore, the acoustic data (e.g., scatter plots in Figure 2) also indicate that PF /a/ is relatively high and front (compared to AE /ɑ/), sometimes overlapping with PF /ɛ/ in acoustic F1 space, contributing to the /a-ɛ/ confusion. As predicted from the perceptual assimilation patterns, discrimination difficulty decreased with language experience. A 3 (language experience) by 2 (context) analysis of variance (see Appendix V) confirmed the significance of the language main effect, $F(2, 36) = 20.460$, $p < .001$. Planned pairwise comparisons indicated that the ModExp group performed significantly more accurately than the NoExp group, $p < .01$, and that the HiExp group outperformed the ModExp group, $p < .01$. Thus, formal instruction was associated with better discrimination accuracy on /a-ɛ/, and extensive instruction and immersion were associated with even better discrimination performance. Due to significant heterogeneity of variance, a further 2 (language experience) by 2 (context) analysis of variance was performed on the NoExp group versus the ModExp group. This analysis confirmed the significant language experience effect between the NoExp and the ModExp groups, $F(1, 24) = 9.2$, $p < .01$. A context effect was also significant, $F(1, 36) = 11.30$, $p < .01$), with more errors in alveolar context than in bilabial context.

The control contrast /u-i/ was indeed discriminated without difficulty by all language groups (NoExp = 1%, ModExp = 1%, HiExp = 0% errors), indicating that listeners were on task.

3.4.7. Categorial discrimination: summary

In sum, AE listeners had more difficulty discriminating PF front rounded vowels from PF back rounded vowels than from PF front unrounded vowels. Overall, listeners who had immersion experience with French performed significantly better than those without any L2 French experience and those with only formal French instruction experience. Only the /u-y/ vowel pair remained difficult for highly experienced listeners. Front rounded vowels were more easily discriminated from other PF vowels in bilabial context than in alveolar context, except for the /i-y/ contrast, which was more easily discriminated in alveolar context than in bilabial by one NoExp listener.

The pattern of discrimination performance described above was generally predicted at the outset of the experiment. A few discrimination patterns, however, were not predicted when the experiment was designed: that difficulty would exist for the "control pair" /a-ɛ/ and that the /œ-u/ contrast would be difficult and not show a consonantal context effect. However, in light of the PA data found in the present study, demonstrating confusions in PF vowel height by AE listeners, initial difficulty with the /a-ɛ/ and /œ-u/ pairs are explainable. Further research is still needed to understand the unusual lack of context effect for /œ-u/.

Similarly, an interaction between language experience group and consonantal context had been expected, based on Levy and Strange's (2002) finding of decreased consonantal context effect with increased L2 experience. None of the pairs in the present experiment showed this decreased context effect in discrimination, except that with extensive experience, fewer errors were made and therefore there were fewer errors within which a context effect could be revealed.

3.5. Testing the Perceptual Assimilation Model on L2-vowel learning

In the above sections, discrimination errors for each language pair were compared with the general predictions made on the basis of perceptual assimilation patterns for the contrasting vowels. What remains to be explored is a systematic way in which to predict whether errors in discrimination increase as perceptual assimilation patterns change from two-category to category-goodness to single-category assimilation, i.e., as members of the PF vowel pairs become increasingly perceptually assimilated to the same AE vowel category. Such a relationship is predicted by the Perceptual Assimilation Model (Best, 1994, 1995) for naïve listeners. The goal of this section is to determine whether such a method can account for vowel discrimination performance by the naïve listeners (i.e., the NoExp group) in the present study and might be extended to account for discrimination performance by the L2 learners (i.e., the ModExp and HiExp groups).

3.5.1. Percent overlap scores

A quantitative measure of perceived similarity was created for the present study instead of relying on the more typically-used method of categorizing patterns according to type of perceptual assimilation (e.g., two-category, category goodness, etc.) and then comparing expected performance based on perceptual assimilation type with actual performance (similar to the technique used by Best et al., 1996). The present method was used for two reasons: First, it was not evident how to characterize the assimilation of AE /u/ and /ju/ response categories. As discussed above, it is not clear whether this was two-category (palatalized /u/ vs nonpalatalized /u/), category goodness (allophonic variation) or single-category (phonological /u/) perceptual assimilation. Secondly, by quantifying how much perceptual assimilation for one vowel in a pair overlaps with the perceptual assimilation of the other vowel in a pair (e.g., for the /u-y/ pair, how often both PF /u/ and P F /y/ assimilated to the same AE vowel category /u/), it is possible to make finer-grained predictions about discrimination performance for vowel pairs; that is, it is possible to place contrasting pairs along a continuum from most similar to least similar on the basis of overlap in perceptual assimilation responses.

The following technique was used in predicting discrimination errors from perceptual assimilation patterns (see Appendix W for calculation of overlap score): Vowel pairs were the sampling variable. A "percentage of overlap" score was obtained for each vowel pair within each language group. The percentage of overlap was operationally defined as the smaller percentage of responses when two members of a PF pair were perceptually assimilated to a particular AE vowel category. For the /u-y/ experimental vowel pair in bilabial context, for example, when PF /u/ was presented to NoExp listeners in the Perceptual Assimilation task, the modal response (90.2%) was /u/. When /y/ was presented, 6.8% of stimuli were categorized as /u/, thus for 6.8% of the stimuli (the portion that overlaps between 90.2% and 6.8%, i.e., the smaller percentage), perception of /y/ and /u/ overlapped. In addition, the NoExp group categorized PF /u/ as /ju/ for 6.4% of the stimuli, which overlapped with the modal choice of /ju/ (79.9%) when PF /y/ was presented. Both /y/ and /u/ also were perceived as closest to /i/ for an overlap of .4%, and both were perceived as /ʊ/ for an overlap of 1.7%. Thus, when 6.8%, 6.4%, .4%, and 1.7% (the overlap percentages when both stimuli were perceptually assimilated to the same AE vowel) were summed, the result was a total overlap score of 15.3% for the perception of /u-y/ by the NoExp group in bilabial context.

Overlap scores were tallied for the remaining experimental vowel pairs in each consonantal context within each language group and then ranked from lowest to highest. Finally, the discrimination error scores associated with each vowel pair were correlated with total overlap score for each pair. (In the above example, the NoExp group made 5% discrimination errors for /u-y/ in bilabial context, which was compared with the percentage overlap score of 15.3% for that pair). Nonparametric correlations (Spearman Rank Order) were performed because the perceptual assimilation results could not be considered interval measures. The higher the perceptual assimilation overlap score, the higher the percent errors were expected in discrimination. Thus, when overlap scores for each pair were ranked from lowest to highest, discrimination error results were also predicted to be ordered from lowest to highest.

3.5.2. Results: bilabial context

Figure 18 graphs the correlation between perceptual assimilation overlap and discrimination performance for vowel pairs in bilabial /rabVp/ context. Along the x-axis are the perceptual assimilation overlap scores, while the y-axis represents the percent errors in discrimination (up to chance of 50%). Each point on the graph represents a particular vowel pair (/y-u/, /œ-o/, /y-o/, /œ-u/, /y-i/,/y-ɛ/, /œ-ɛ/, /œ-i/, /a-ɛ/, /u-i/, /y-œ/). Data for the NoExp Group are represented as stars, whereas data for the ModExp group are represented by squares, and for the HiExp group, by triangles.

For the NoExp group, as perceptual assimilation overlap increased, so did discrimination errors. A Spearman rank order correlation for these data confirmed a strong correlation between overlap scores and discrimination errors, $\rho = .91$, $p < .001$ (as shown in Appendix Y). Thus, for this naïve group of listeners, perceptual assimilation patterns were highly predictive of discrimination performance on French vowel contrasts in bilabial context, as posited by the Perceptual Assimilation Model (Best, 1994, 1995).

Was L2-learners' discrimination performance also predictable from their perceptual assimilation patterns? Indeed, the correlation for bilabial context data was also significant, $\rho = .85$, $p < .01$, for the ModExp group. Thus, for these L2-learners with formal French instruction, the Perceptual Assimilation Model (Best, 1994, 1995) successfully predicted relative vowel discrimination difficulty. Predictions were also significant for the HiExp group, $\rho = .79$, $p < .01$. However, this correlation is not particularly informative, as there were so few errors to interpret for that group. As the figure shows, most of the triangles representing the HiExp group cluster and overlap below 5.5% in perceptual assimilation and below 3.5% errors in discrimination, with only one outlying vowel pair, /u-y/, revealing higher overlap (28.2%) and discrimination error (6%) scores.

3.5.3. Results: alveolar context

Turning to alveolar context, Figure 19 reveals more variability in discrimination errors and perceptual assimilation overlap (i.e., larger spread) for all groups than did bilabial context, reflecting the perceptual difficulties encountered by AE listeners in this context. With more errors to work with, the correlation coefficients are even higher than for the bilabial context comparison for the three language experience groups, NoExp $\rho = .93$, $p < .001$, ModExp, $\rho = .88$, $p < .001$., HiExp $\rho = .86$, $p < .01$ (as shown in Appendix Y). Once again, this confirms that the Perceptual Assimilation Model (Best, 1994, 1995) may be used to predict relative accuracy in vowel discrimination from perceptual assimilation patterns, not only for naïve learners of a language, but also for intermediate and advanced adult learners of a second language.

Chapter 4. Discussion

4.1. Summary of results

In this section, first, perceptual assimilation and categorial discrimination results are summarized, as well as the Perceptual Assimilation Model's (Best, 1994, 1995) accuracy in predicting perceptual performance in L2 learners. Following this, possible explanations for the phenomena revealed in the current experiment and prospects for further studies and future directions in the field of L2 speech perception are discussed.

4.1.1. Perceptual assimilation results: language experience and context effects

AE listeners perceptually assimilated Parisian French front rounded vowels almost exclusively to AE back rounded vowels, consistent with expectations from Gottfried's (1984) and Levy and Strange's (2002) discrimination studies of PF vowels, as well as Strange et al.'s (2004) perceptual assimilation study of North German vowels by naïve AE listeners. To which particular AE vowel the PF front rounded vowel was perceptually assimilated varied as a function of language experience for /œ/, but not for /y/. All of the above findings were predicted at the outset of the experiment.

As predicted, consonantal context affected perceptual assimilation patterns for both front rounded vowels, with more tokens perceptually assimilating to /u/ in alveolar context than in bilabial context. That listeners perceptually assimilated PF /y/ to AE /ju/ more often in bilabial context and less often in alveolar context may be attributed to the phonotactic acceptability of palatalized /ju/ following bilabials in AE (e.g., "beautiful"), whereas /u/ cannot be palatalized following an alveolar consonant in AE (e.g., "news" with a palatalized /ju/ is acceptable in British English, but not in most dialects of AE.) The consonantal context effect decreased with immersion experience, but even the HiExp group showed context-dependent perceptual patterns (i.e., more /u/ responses in alveolar context than in bilabial). This conflicts somewhat with expectations from Levy and Strange's (2002) study, in which highly experienced listeners demonstrated no significant context effect in discrimination performance. For naïve listeners, a small interaction was evident, in that the NoExp group assimilated front rounded /y/ more often to /i/ in bilabial context and to /u/ in alveolar context, consistent with Levy and Strange's findings of a similar discrimination pattern. However, in the present study, it was displayed by fewer individuals. The small number of listeners to demonstrate this pattern here may be attributed to listeners opting for /ju/ as a response when they would have chosen /i/ if forced to choose between /i/ and /u/. On the other hand, in a perceptual assimilation study by Strange et al. (in progress), which does not offer /ju/ as a key word response, only one out of 10 listeners thus far has perceptually assimilated PF /y/ to AE /i/ (and for only 3 out of 9 trials in bilabial /rabVp/ context and 1 out of 9 trials in alveolar /radVt/ context), suggesting that the option of a palatalized /ju/ response in the present study was not responsible for the reduction in listeners' likelihood of perceptually assimilating /y/ to /i/.

4.1.2. Categorial discrimination results: language experience and context effects

Categorial discrimination was far more difficult for AE listeners when front rounded vowels were paired with back rounded vowels than when they were paired with front rounded vowels, consistent with the perceptual assimilation results in the present study. Discrimination of contrasts involving the high front rounded vowel /y/ (paired with back rounded vowels) did not show increased accuracy with formal French instruction nor with extensive French immersion experience. This finding supports studies indicating that the PF /u-y/ pair is a particularly difficult contrast for AE listeners to learn to differentiate (Gottfried, 1984; Levy & Strange, 2002). Discrimination of pairs involving the mid front rounded vowel /œ/ with back rounded vowels did increase in accuracy with increased L2 experience, especially with immersion.

Overall, discrimination of front versus back rounded vowels was significantly more difficult in alveolar context than in bilabial context. The context effect was evident in both pairs involving the vowels of the same height (/y-u/, /œ-o/). All of the above findings had been predicted based on previous literature and on the perceptual assimilation findings for this study. However, contrary to expectations, no significant context effect was found for front rounded vowels paired with vowels of a different height. For the /y-o/ pair, this can be attributed to too few errors to show a significant interaction, i.e., to ceiling effects. The lack of a context effect in the /œ-u/ pair remains to be understood.

Stimuli in previous studies of the perception of front rounded vowels by American English listeners have been vowels preceded and/or followed by alveolar consonants (e.g., Best et al., 1996; Flege, 1987; Flege & Hillenbrand, 1984; Gottfried, 1984; Polka, 1995; Polka & Bohn, 1996) or produced in isolation (e.g., Gottfried, 1984; Rochet, 1995; Stevens et al., 1969). Results from the present experiment suggest that replications of such studies using stimuli in which the vowels are produced and presented in other consonantal contexts would reveal different results. In bilabial context, for example, AE listeners are likely to make fewer discrimination errors for pairs involving front rounded vowels, although some naïve individuals may have difficulty discriminating the /i-y/ contrast.

No significant interaction was found between language experience and consonantal context in the present study. Thus, the significant decrease in context-dependent perception with increased language experience found in Levy and Strange's (2002) discrimination study was not replicated here. However, with extensive immersion, listeners tended to make very few errors in both context conditions for all pairs except /y-u/. Thus, an overall interaction may have been difficult to detect.

For the /y-u/ vs /y-i/ pairs, one participant with no French experience (and a small number of responses from other participants) showed a tendency similar to that revealed in Levy and Strange (2002). The /y-i/ pair was more difficult for Participant # 111 to discriminate in bilabial context, whereas the /y-u/ contrast was more difficult in alveolar context, a pattern that paralleled the participant's perceptual assimilation (discussed above) of /y/ to /i/ in bilabial context and /y/ to /u/ in alveolar context. In the present study, fewer than half of the NoExp participants made more discrimination errors on the /i-y/ pair in bilabial context than alveolar context. In Levy and Strange's study, on the other hand, most participants with no French experience made more errors in bilabial context than alveolar context for the /i-y/ pair, as previously mentioned. This demonstrates a stronger context effect on discrimination for the previous group of naïve listeners. For the /u-y/ pair in both studies, naïve listeners, as well as experienced listeners, made more discrimination errors in alveolar context than in bilabial context. Further studies are needed to determine how prevalent such context-specific interactions are among AE listeners with no French experience.

The overall effect of better discrimination in the HiExp group, but not in the ModExp was not true for every vowel pair. Both formal and immersion experience in late L2 learners was associated with some increased accuracy in perception of non-native contrasts. Table 3 shows four vowel pairs that were initially difficult for listeners to discriminate and demonstrates the patterns of change with experience. The left-hand column lists the type of language experience the groups received. "Formal training" was represented by the ModExp group and "Extensive formal training plus immersion" was represented by the HiExp group in the present study. The rows show the vowel pairs that were initially difficult for listeners to discriminate: /y-u/, /œ-o/, /œ-u/, /y-œ/. A "+" sign by the "formal training" group indicates a statistically significant increase in discrimination accuracy between the NoExp group and the ModExp group, while a "-" sign indicates no significant increase in accuracy. Similarly, a "+" sign by the "extensive formal training and immersion" group denotes a statistically significant increase in accuracy between the ModExp group's discrimination accuracy and HiExp group's performance, whereas a "-" sign indicates no significant increase in discrimination accuracy. For the /u-y/ vowel pair, formal experience alone was not associated with greater accuracy. Even with extensive instruction and immersion experience, performance remained essentially the same as for the NoExp group. Thus, this contrast is particularly resistant to improvement with language experience. The mid-vowel pair /œ-o/ was more accurately discriminated by listeners with formal training alone, and even better discriminated by listeners with extensive formal training and immersion. No increase in discrimination accuracy for the vowel pairs /œ-u/ and /y-œ/ was associated with merely formal training, but extensive training and immersion were associated with significantly better discrimination. The overall lack of increased discrimination accuracy with only formal instruction supports the notion that, to be most effective, language instruction programs must include more than the typically-administered foreign language requirements in United States high schools and colleges and had best include immersion experience.

It must be noted that, in this study, formal instruction and immersion experience are confounded to some extent. Because the HiExp listeners had not only immersion experience, but also had more formal language instruction than the ModExp listeners, one cannot conclude whether it was the extensive instruction or the immersion experience (or current use or other variables such as greater motivation in the HiExp group) that was associated with better discrimination performance. The ModExp group in the present experiment was intended to represent individuals "en route" to extensive experience, such that perceptual changes that occur at a stage between having no experience with a language and having immersion in it could be observed.

Future studies might compare perceptual performance by listeners who have had several years of formal training with no immersion with performance by listeners who have had several years of immersion with no formal training (e.g. AE listeners living in France, who have never studied French in school). Such studies, if they are able to control for the numerous complex language history variables found in bilinguals, might provide valuable information on the effectiveness of immersion-based versus formal-instruction-based pedagogical techniques. The details of the formal instruction would need to be assessed because classes that include immersion-like learning (e.g., Berlitz) might confound the study.

4.1.3. Unpredicted findings in perceptual assimilation and discrimination: height confusions

Serendipitous findings that emerged during this study are worth noting: Height differences in PF vowels caused some confusion for AE listeners with less L2 experience. The PF vowel /o/ was assimilated to AE /u/, which probably contributed to the difficulty these listeners had in differentiating mid front rounded /œ/ from high back rounded /u/. Listeners may have perceived /o/ as more similar to /u/ than to /o/ because French /o/ is indeed a higher vowel than AE /o/ in articulation, and, unlike AE /o/, it is a monophthong.

Difficulty in discriminating French front rounded /y/ and /œ/, which differ in height, was evident in the present study, as well as in Gottfried (1984) and Levy and Strange (2002). Perceptual assimilation data for /y/ and /ø/ in North German (Strange et al., 2004) also suggest that these so-called "high" and "mid" German vowels might be difficult to discriminate for American listeners. On the other hand, Best et al.'s (1996) study of front rounded vowels did find that naïve AE listeners discriminated the Bretagne French open syllables /sy-sœ/ with 95% accuracy. Better performance on the /y-œ/ contrast in Best et al.'s (1996) study than in the other studies may be a result of open syllables being more easily discriminated than French closed syllables by AE listeners (Gottfried, 1984).

The /a-ɛ/ pair caused some difficulty for listeners with no French experience. In perceptual assimilation, /a/ was assimilated to AE /ɑ/ on fewer than 50% of trials. The remaining responses to /a/ were primarily AE /æ/, but also the mid front AE vowel /ɛ/. Such perceptual patterns may be attributed to the higher, more front characteristics of PF /a/ compared to AE /ɑ/.

Other difficulties by American English listeners in differentiating height contrasts have been found for the PF /e-i/ pair in the discrimination study by Gottfried (1984) and North German /e-i/ and /o-u/ in the perceptual assimilation study by Strange et al. (2004). The observation in the present study that discrimination was better with increased language experience for pairs differing in height suggests that learning an L2 includes becoming attuned to height differences in L2 phonological categories. The difficulties along the front-back dimensions appear to be more difficult to master.

4.1.4. Predicting discrimination performance from perceptual assimilation patterns

American English listeners' perceptual assimilation of PF vowels predicted their discrimination performance, as posited by the Perceptual Assimilation Model (Best, 1994, 1995). This was true not only for listeners who had never had significant exposure to French, but also for listeners with formal French instruction and for listeners with extensive formal instruction and immersion experience in French.

Accurate prediction of relative discrimination difficulty for all language experience groups was expected at the outset of the experiment, although this was the first study to apply the model to vowel perception in L2 learners. It may be concluded that the Perceptual Assimilation Model is predictive of non-native vowel perception not only in naïve listeners of a language, but can also be extended to the domain of listeners in the more advanced stages of L2 learning.

The "percent overlap" method for comparing perceptual assimilation patterns to discrimination performance assessed the accuracy of predictions made by the Perceptual Assimilation Model. This method relied on quantifying perceptual assimilation responses rather than on the sometimes ambiguous task of categorizing perceptual assimilation patterns as "single category," "category goodness" or "two-category" types.

This method is especially effective when the relationship between two responses is not evident, as was the case for the AE /u/ and AE /ju/ responses in the present study. In this study, /ju/ and /u/ responses were not characteristic of two-category responses because discrimination of the /y-u/ contrast was poorer than a 2-category pattern would predict. On the other hand, discrimination was better than chance, suggesting that these vowels were perceptually assimilated in a category goodness pattern, rather than in a single category pattern. If palatalized /ju/ and nonpalatalized /u/ are allophonic variations of the phonological category /u/, this raises the question of the level of representation of categories appropriate for the Perceptual Assimilation Model (Best, 1994, 1995). For example, one might ask whether non-native vowels are perceptually assimilated on an allophonic level, and whether more common allophones of a particular phonological category are perceived as "better instances" of that category than are less common allophones.

4.2. Explaining why PF /y/ and /œ/ are perceived as most similar to AE back vowels

As was shown in the acoustic analysis of stimuli used for this experiment (Figure 2), PF front rounded vowels /y/ and /œ/, which are produced with the tongue body forward in the oral cavity, are also characterized by the salient acoustic properties of front vowels, namely, high second (and third) formant values, relative to back vowels. PF/œ/ in alveolar context may be considered an exception. In the bottom scatter plot in Figure 2, /œ/ is approximately equidistant from front and back vowels. Unlike other front PF vowels, however, /y/ and /œ/ are produced with rounded lips, corresponding to a lower F3 frequency (and a slightly lower F2 frequency) than front unrounded vowels. Nonetheless, even when these lower frequencies are taken into consideration, as in Figures 3 and 4, front rounded vowels remain acoustically far more similar to front vowels than to back vowel "targets" in formant structure. Thus, AE confusions involving French vowels cannot be predicted on the basis of the acoustic similarities of French vowels. Instead, explanations must rely on AE listeners' perceptual categorization of French vowels based on their AE phonological systems. What then accounts for AE listeners' perception of PF front rounded vowels as most similar to back vowels? A developmental/linguistic explanation and an explanation involving L1 allophonic rules are offered.

4.2.1. Developmental explanation: linguistic redundancy of AE "back" and "rounded" features

A developmental/linguistic explanation might be the redundancy of the "roundedness" feature in AE. From infancy, AE monolinguals learn to equate "roundedness" with "backness," as every AE rounded vowel is a "back" vowel (at least at an abstract level of representation) and mid to high back vowels are always rounded. Although AE infants as young as 6-8 months are able to discriminate German /u/ and /y/, this skill begins to diminish even by 10 months of age (Polka & Werker, 1994). Part of becoming efficient in their native language requires individuals learning American English to expect that any rounded vowel will (redundantly) be a back vowel. For countless phenomena documented in L2 learning, efficiency in L1 interferes with facility in learning an L2 after the L1 phonological system is in place (Flege, 1995). In this example, when native AE listeners are exposed to front rounded vowels in French after age 12, they perceive these vowels as most similar to native language back rounded vowels and thus have difficulty differentiating front vs back rounded vowels, which are contrastive in French. Such discrimination skills are not always successfully learned with L2 experience, accounting for the persistent difficulties listeners continue to have with the /y-u/ contrast.

This explanation, however, does not account for three phenomena discussed in the present study: One is why, even when roundedness is taken into consideration, front rounded vowels are acoustically more similar to front vowels, yet are perceived as back vowels by AE learners. Secondly, it is not clear from this explanation why the "redundancy" effect would be stronger in alveolar context than in bilabial. Thirdly, this explanation does not account for why AE discrimination performance for the high PF vowel /y/ differs from discrimination performance for the mid PF vowel /œ/. As was shown, initially, /œ/ is more difficult than /y/ for AE listeners to discriminate from back vowels. With language experience, perceptual differentiation of /œ/ from back vowels becomes better, whereas perception of /y/ does not.

4.2.2. Allophonic variation explanation: coarticulation of back AE vowels

A second explanation involves the allophonic variation of back vowels in AE. Figure 20 displays the average spectral patterns for American English (top) and Parisian French (bottom) vowels uttered by three monolingual female native speakers in bilabial /gabVpa/ context and alveolar /gadVta/ context in sentences, as well as in citation /hVba/ syllables (from Strange, Weber, Levy, Shafiro, and Nishi, 2002). Second formant (F2) Bark space is represented on the X-Axis and first formant (F1) Bark space is represented on the Y-axis, such that the resulting pattern appears similar to a traditional vowel quadrilateral. Bilabial context is represented in squares and alveolar in triangles.

For front vowel categories within each language, tokens vary little as a function of consonantal context. However, high back AE vowels in the context of alveolar consonants display an unusual property in AE: /u/ (and /ʊ/) are considerably "fronted" (i.e., produced with the tongue further forward in the oral cavity than for bilabial context) (Hillenbrand et al., 2001). This "fronting" phenomenon is evident in the top graph in Figure 20. In alveolar context, /u/ is produced approximately 2.5 Barks more "front" than in bilabial context. This results in a change in the relative locations of high and mid vowels in vowel space because other back vowels (/o/, /ɔ/, /ɑ/) do not change significantly in alveolar context.

Comparing now the French data Strange et al. (2002) collected in bilabial /rabVp/ and alveolar /radVt/ context, the bottom graph in Figure 20 shows that "fronting" also occurs in alveolar context in French, including for the vowels /ɔ/ and /a/. However, the relative locations of back vowels remain similar, i.e., /u/, /o/ are further back (i.e., characterized by a lower F2) than are /ɔ/ and /a/. Crucially, front rounded vowels remain clearly separated from French back rounded vowels by their higher F2 values. (Note that /œ/ values shift upward in alveolar context. Thus, while French vowels become spectrally more similar in alveolar context, due to coarticulatory influences, their relative locations in "vowel space" are similar.)

The implications are as follows: In English, the phonological category /u/ is produced as back rounded [u] in most consonantal contexts (e.g. boom [bum]), but when the tongue is "fronted", as occurs in alveolar context in dude [dyd], for example, the phonetic realization of AE /u/ is actually a front rounded vowel. Thus, in French (and other languages such as German or Swedish), the phonetic segments [y] and [u] represent two different phonological categories (/y/ and /u/), whereas in English, the phonetic segments [y] and [u] are allophones of the same phonological category /u/. AE listeners, then, may be more likely to categorize high and mid front rounded vowels as an AE /u/ or /ʊ/ (which allows for fronting) when the vowels are surrounded by alveolar consonants than when they are surrounded by non-alveolar consonants.

In the present study, all PF /i/ tokens, regardless of consonantal context, remained within one Bark of each other in acoustic space. Moreover, PF /i/ was readily perceived as closest to AE /i/ on virtually all trials, and received the highest median goodness rating of all the PF vowels. Across languages, in fact, the vowel /i/ remains a stable vowel, contained by its extreme front, high position in the oral cavity and in acoustic space, as demonstrated in acoustic studies, such as Strange et al. (2002) and Strange et al. (2004). Thus, any vowel that is detected to be at all different from /i/ is likely to be categorized as a vowel other than /i/ (Strange, personal communication, Feb. 13, 2004). This would be particularly true for AE listeners, whose back rounded phonetic category /u/ has diverse phonetic realizations, with F2 varying more than 2 Barks across consonantal contexts. Thus, high vowels in a non-native language that do not sound quite like front vowels may be perceived as similar to exemplars of the highly variable back vowel categories of AE /u/, /ʊ/.

Also contributing to the particular perceptual difficulties AE listeners encounter with PF /y/ is that acoustically, AE /u/ generally has a higher second formant frequency than PF /u/, such that AE /u/ may be closer to /y/ than /u/ in PF vowel space. This explanation would account for the increased number of AE /u/ responses to /y/ and confusions in alveolar context—the context in which fronting of AE /u/ is most extreme.

Better discrimination of contrasts involving /œ/ (but not /y/) with language experience may be understood by examining the AE vowels to which /œ/ was perceptually assimilated. As discussed, naïve listeners have difficulty differentiating height and frontness of L2 rounded vowels, thus /œ/ is initially perceived as most similar to AE /u/. With experience, listeners perceive /œ/ as lower than /u/ and thus perceptually assimilate /œ/ to AE vowels lower than /u/ (e.g., /ʊ, ʌ, ɝ, o/) none of which have direct PF counterparts (except /o/, which is a diphthong in AE and was selected in only 2% of the responses by the HiExp group). Thus, single category assimilation of this vowel and other PF vowels is unlikely to occur for the HiExp group, resulting in few discrimination errors for pairs involving /œ/.

4.3. Implications for models of speech perception and L2 learning

Regardless of which account is more likely, the evidence from this study and other studies (e.g., Gottfried, 1984; Levy & Strange, 2002; Strange et al., 2001; Strange et al., 2004) indicates that contextual variation in the phonetic realization of vowels across languages strongly affects non-native vowel perception. As more information becomes available about the contextual variation 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 even more precise in their predictions of perceptual difficulties.

In the terminology of the Perceptual Assimilation Model (Best, 1994, 1995), the consonants surrounding the vowels affect to which native vowel a non-native vowel will be perceptually assimilated. When surrounded by bilabial consonants, for example, a PF /œ/ will be perceived as more similar to /ʊ/, whereas in alveolar context, it will be perceived as most similar to /u/, as shown in the present study. The Perceptual Assimilation Model, factoring in consonantal context, would thus predict that /œ/ would be more difficult to differentiate from /u/ in alveolar context than in bilabial, a prediction that is supported by the data in the present study. As listeners assimilate /œ/ less to /u/ and more to other AE vowels (e.g., /ʊ/ and /ɝ/), contrasts involving this vowel come to represent a two-category pattern of assimilation, and discrimination accuracy is predicted to increase. However, discrimination may still be less accurate in alveolar context than in bilabial, even for highly experienced L2 learners. These predictions, too, were supported by the data in the present study.

Results for the present experiment can also be discussed in terms of the Speech Learning Model (Flege, 1995). The SLM posits that when L2 vowels are encountered, they are classified as "identical," "similar," or "new," relative to the listener's native phonological inventory. According to Flege (1987), the PF vowel /u/ is classified as a "similar" vowel by AE speakers, resulting in inaccurate pronunciation, i.e., production of PF /u/ with higher (i.e., more AE-like) F2 values than PF /u/, even by individuals with French immersion experience. The relatively high median goodness rating of 6 for /u/ by the HiExp group in the present experiment supports Flege's claim that /u/ is perceived as a good instance of AE /u/ and thus might be produced in a similar, i.e., accented manner.

According to Flege, the PF front rounded vowel /y/, which has no counterpart in AE, 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 are consistent with Flege's (1987) claim in bilabial context, but not in alveolar context. Based on the perceptual data in the present study, it can be concluded that the consonantal context in which the vowel appeared, not the listener's language experience, determined whether /y/ was confused with /u/. Moreover, whatever confusions existed in the initial stages of learning French remained with increased language experience. All three language experience groups made fewer than 10% errors in discriminating /y-u/ in bilabial context, thus /y/ could be said to have been perceived as a new vowel in bilabial context from the beginning. In alveolar context, on the other hand, all three language experience groups made significantly more discrimination errors on this pair than in bilabial context. The apparent context-specific categorization patterns revealed in the present study suggests that an allophonic level of representation operates in equivalence classification, such that listeners perceive vowels as "new" or "similar," depending on the consonants surrounding the vowels. Thus, /y/ could be thought of as a "similar" vowel to AE /u/ in alveolar context and as a "new" vowel in bilabial context. However, the decrease in goodness ratings for /y/ in both contexts with increased language experience suggests that, as listeners became more familiar with French, they begin to discern differences between PF /y/ and AE vowels, but not enough for a new category to be created if one has not already been established.

In order to explore context-dependent similarity patterns, a study could be performed that would extend Flege's (1987) investigation of the production of /y/ and /u/ by listeners with several levels of French proficiency. Flege's investigation involved production of vowels in alveolar context only. This study would test production in both bilabial and alveolar contexts and evaluate whether the learner has categorized the vowel as "similar" in alveolar context and as "new" in bilabial context. Such a pattern would be indicated if individuals produced /y/ more accurately in bilabial context than in alveolar, as judged by native PF speakers. (Production data were collected for the present investigation, thus these could serve as at least as pilot data for the suggested study.) Implications for the level of analysis involved in equivalence classification would be addressed.

4.4. Implications for L2 perceptual training

Perceptual training protocols that take consonantal context into consideration might better assess listeners' perceptual difficulties with vowels and gain effectiveness by targeting those consonantal contexts in which listeners have the most difficulty. These measures might help determine whether stubborn contrasts, such as /u-y/ may ever be mastered. Furthermore, such training studies might ask whether perceptual training alone might result not only in improved perceptual skills, but in more intelligible production, as has been shown in a handful of studies of Japanese listeners' perceptual training on AE consonants (Bradlow, Pisoni, Akahane-Yamada & Tohkura, 1997, 1999) and AE vowels (Strange & Akahane-Yamada, R., 1997).

4.5. Interaction of variables in speech perception research

Reflecting on the state of research in cross-language speech perception, Jenkins and Yeni-Komshian (1995) ask why so many problems in the field remain unsolved. They answer that research of this sort is complicated because of the interactive nature of variables relevant to the issues under investigation. In the present experiment, only a few of those variables were tested systematically: the particular vowels, the listeners' language background, and the consonantal context in which the vowels appeared. However, in the perception (or production) of the French /u-y/ contrast alone, it is evident that an explanation of a listener's accuracy in discriminating an L2 contrast depends upon the following variables discussed in the introduction: the relationship between L1 and L2 phonological categories (Best, 1995; Best et al., 1996; Flege, 1987; Flege, 1995; Flege and Hillenbrand, 1984; Levy & Strange, 2002; Rochet, 1995), the allophonic variations occurring in various syllabic and consonantal contexts (Gottfried, 1984; Levy & Strange, 2002; Strange et al., 1998, Strange et al., 2001) the listener's experience with the second language (Flege, 1987; Gottfried, 1984; Guion et al., 2000; Levy & Strange, 2002; Trofimovich, Baker, & Mack, 2001), experimental variables such as synthetic versus natural stimuli (Gottfried, 1984; Levy & Strange, 2002; Rochet, 1995; Stevens et al., 1969), discrimination versus identification tasks (Stevens et al., 1969), whether consonantal context is presented in blocks or varied unpredictably (Strange et al., 2004), and many more known and as yet undiscovered variables that affect listeners' perceptual performance on L2 contrasts.

4.6. Conclusion and future directions

For cross-language speech researchers, a crucial task that lies ahead is to explore the many variables described above, which interact in complex ways. As such carefully controlled studies are performed, clarity will emerge regarding what it is that listeners perceive when they hear non-native segments and what level of analysis is needed to predict the perceptual patterns they might demonstrate for any given language they might learn.

No evidence has been presented suggesting that listeners encode contrasts in terms of context-independent phonemic units (Pisoni, Lively, & Logan, 1994)—no such account could explain the context effects found in the present study or in numerous other studies (e.g., Gottfried, 1984; Levy & Strange, 2002; Strange et al., 2001; Strange et al., 2004; Trofimovich et al., 2001). Clearly, neither an abstract, phonemic analysis nor an acoustic description of an L2 segment will adequately predict the way it might be learned by a non-native speaker. For now, it may be concluded that segments from a second language are initially perceived on an intermediate, context-sensitive allophonic level. Learning a second language ideally involves the formation of new phonological categories, including knowledge about the systematic variations that exist within each L2 category (Flege, 1987; Levy and Strange, 2002). Although perception and production of L2 segments might improve with experience (Flege, 1987, Gottfried, 1984; Levy & Strange, 2002), and with laboratory training (Bradlow et al., 1997), late learners' native phonological knowledge (including language-specific allophonic rules) may always be present and thus may continue to influence L2 perception and production (Flege et al., 1997; Gottfried, 1984; Levy & Strange, 2002). Thus, we can expect inaccurate perception and accented production in individuals who learned their second language in adulthood, as have been well documented in the L2 learning literature.

Despite such discouraging prospects for L2 speech perception and production, it must be emphasized that the study of contextual variation and its effects on L2 perception is in its infancy. As more is understood about these phenomena, such findings may be incorporated into programs of L2 learning and speech remediation. Bradlow and her colleagues' (1999) finding of Japanese listeners' long-term retention of identification and production skills for AE /r-l/ after perceptual training, despite trainees' lack of contact with English, led the authors to conclude that high variability training (involving introduction of stimuli in several syllabic and consonantal contexts) holds promise for long-term improvement of perception and production of even the most difficult contrasts. These procedures may even be extended to several types of "phonologically disabled" populations. Indeed, consonant training studies by Rvachew's and Jamieson (1995), and Rvachew (1994) demonstrated the benefits of perceptual training on production therapy with phonologically delayed children. Improvement in production performance as a result of perceptual training (Bradlow et al., 1997, Rochet, 1995) and retention of trained skills 3-6 months after the completion of training (Bradlow et al., 1999) provide hope that future work involving training of both perception and production, taking into account the complex contextual variability that exists in all languages, might yield even greater, long-lasting success.

5. Tables

Table 1

Perceptual Assimilation of Parisian French (PF) Vowels Summed Over /rabVp/ and /radVt/ Contexts by American English (AE) Listeners with no French Experience (NoExp), Moderate French Experience (ModExp) and Extensive French Experience (HiExp): Percent chosen for each modal response (most frequent category chosen) and median goodness ratings are presented for each vowel.

NoExp				ModExp				HiExp			
PF stim-ulus	**AE modal choice**	**Mode percent chosen**	**Mdn. rating**	**PF stim-ulus**	**AE modal choice**	**Mode percent chosen**	**Mdn. rating**	**PF stim-ulus**	**AE modal choice**	**Mode percent chosen**	**Mdn. rating**
y	ju	73	5	y	ju	78	3	y	ju	66	3
œ	u	46	6	œ	ʊ	52	4	œ	ʊ	60	5
u	u	87	7	u	u	80	4	u	u	85	6
o	u	53	6	o	o	70	6	o	o	98	6
i	i	98	7	i	i	99	7	i	i	99	7
ɛ	ɛ	78	7	ɛ	ɛ	88	6	ɛ	ɛ	92	6
a	æ	47	7	a	æ, ɑ	41, 41	6, 5	a	æ	53	6

Table 2

Categorial Discrimination of Parisian French (PF) Vowels Summed Over /rabVp/ and /radVt/ Contexts by American English Listeners with no French Experience (NoExp), Moderate French Experience (ModExp) and Extensive French Experience (HiExp): Percent errors and standard error of the mean (in percent) are given.

PF pair		No Exp % Error	No Exp (SE of mean)	Mod Exp % Error	Mod Exp (SE of mean)	Hi Exp % Error	Hi Exp (SE of mean)
High front rounded	y-u	16	(3)	19	(3)	12	(3)
vs back rounded	*y-o	8	(3)	5	(2)	3	(2)
Mid front rounded	œ-o	33	(3)	22	(3)	4	(1)
vs back rounded	*œ-u	33	(4)	29	(3)	6	(3)
High front rounded	y-i	7	(2)	1	(1)	0	(0)
vs front unrounded	*y-ɛ	1	(1)	1	(1)	1	(1)
Mid front rounded	œ-ɛ	3	(1)	2	(1)	1	(1)
vs front unrounded	*œ-i	0	(0)	3	(1)	1	(1)
High front rounded vs mid front rounded	y-œ	17	(3)	16	(3)	4	(2)
Experimental Pairs (Overall)		13	(2)	11	(2)	4	(2)
Control pair	*a-ɛ	19	(2)	10	(3)	2	(1)
Control pair	*u-i	1	(1)	1	(1)	0	(0)

*Note. Vowel pairs with asterisks were 2-feature vowel pairs and were presented for 12 judgments per participant. (The remaining pairs were 1-feature vowel pairs and were presented for 24 judgments.)

Table 3

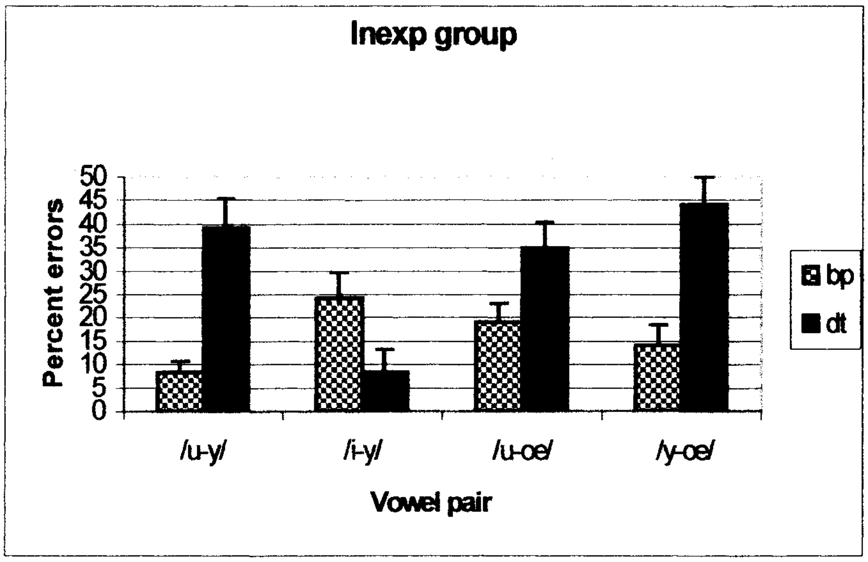
Language experience effects on discrimination for four vowel pairs: Formal training vs. extensive formal training and immersion. A "+" sign by the "formal training" group indicates a statistically significant increase in discrimination accuracy between the NoExp group and the ModExp group, while a "-" sign indicates no significant increase in accuracy. Similarly, a "+" sign by the "extensive formal training and immersion" group denotes a statistically significant increase accuracy between the ModExp group's discrimination accuracy and HiExp group's performance, whereas a "-" sign indicates no significant increase in discrimination accuracy.

PF Experience	**/y-u/**	**/œ-o/**	**/œ-u/**	**/y- œ/**
Formal training	-	+	-	-
Extensive formal training + immersion	-	+	+	+

6. Figures

Figure 1. Effects of consonantal context on vowel discrimination (Levy & Strange, 2002)

Percent errors for inexperienced (top) and experienced (bottom) groups for experimental vowel pairs in /rabVp/ (checkered bar) vs /radVt/ (solid bar) contexts. Error bars represent standard errors of the mean.



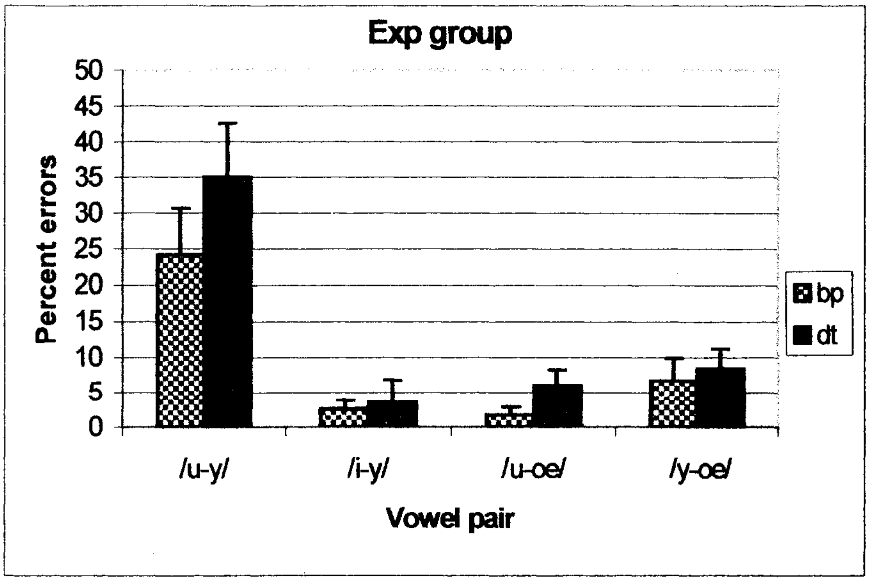


Figure 2. Formant 1/Formant 2 vowel spaces for bilabial /rabVp/ stimuli (top) and alveolar /radVt/ stimuli (bottom) uttered in carrier phrases by three native speakers of French.

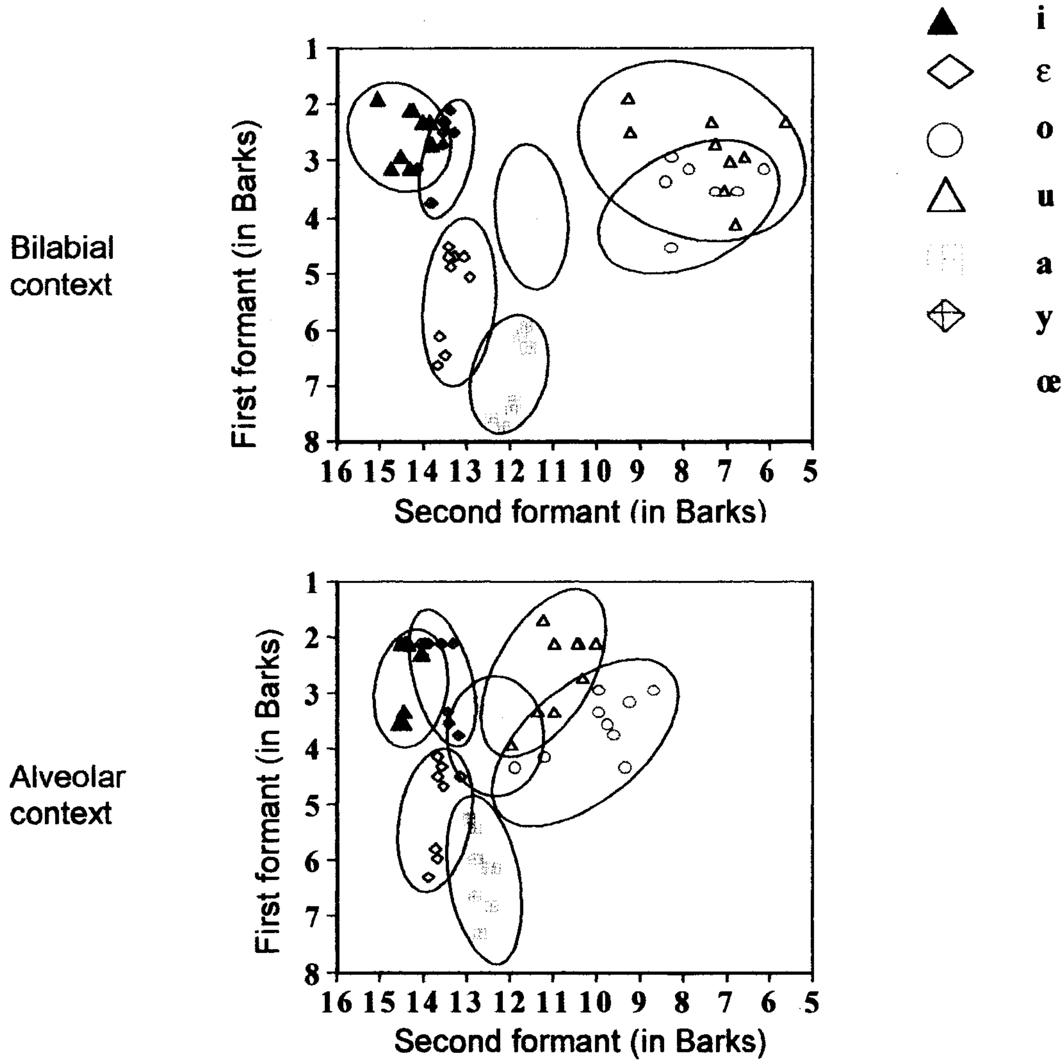
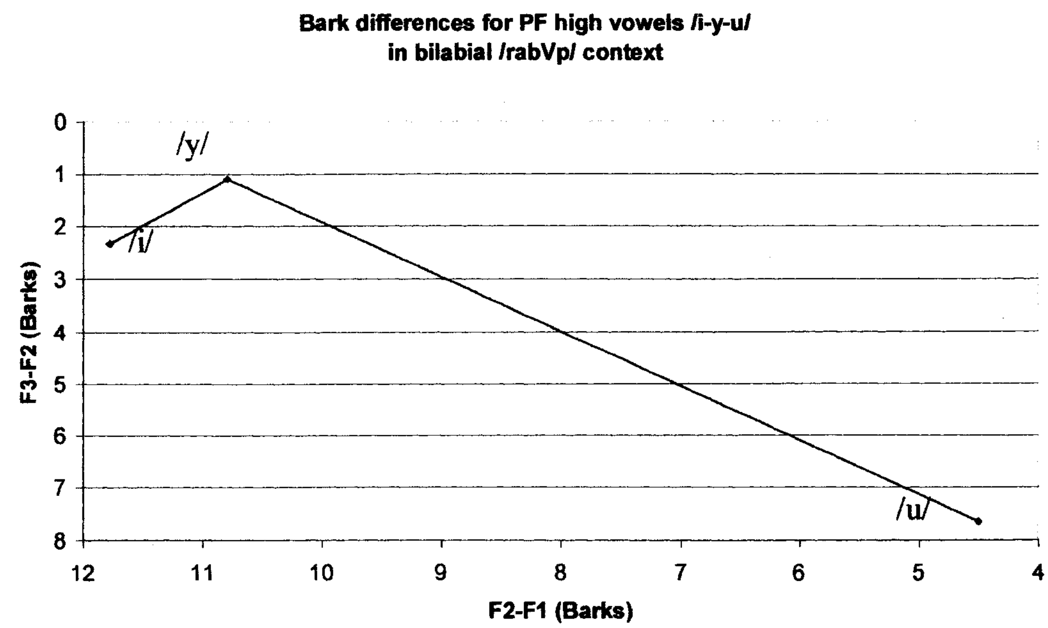


Figure 3. F2-F1 and F3-F2 Bark difference plots for Parisian French high vowel stimuli /i-y-u/ in two consonantal contexts.



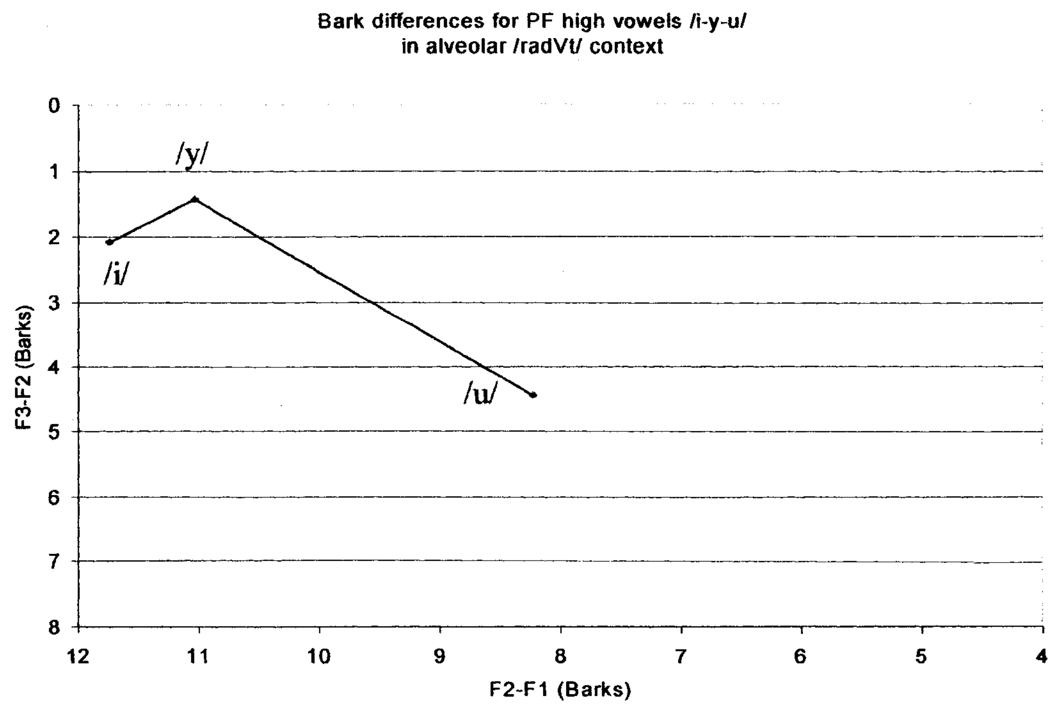
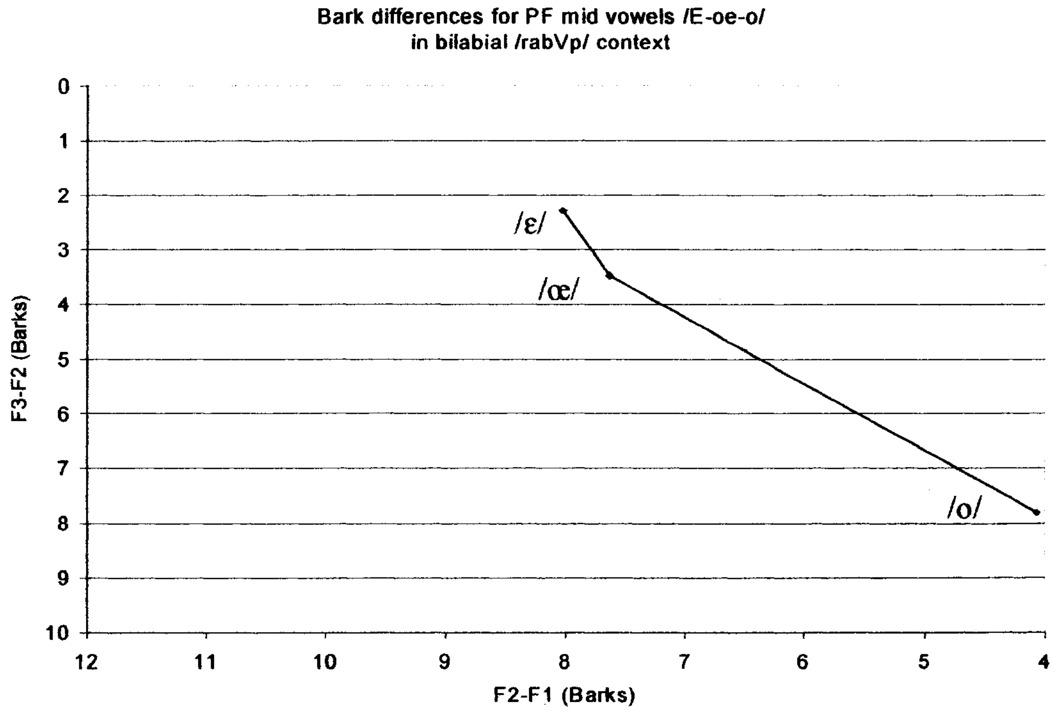


Figure 4. F2-F1 and F3-F2 Bark difference plots for Parisian French mid vowel stimuli /ɛ-œ-o/ in two consonantal contexts.



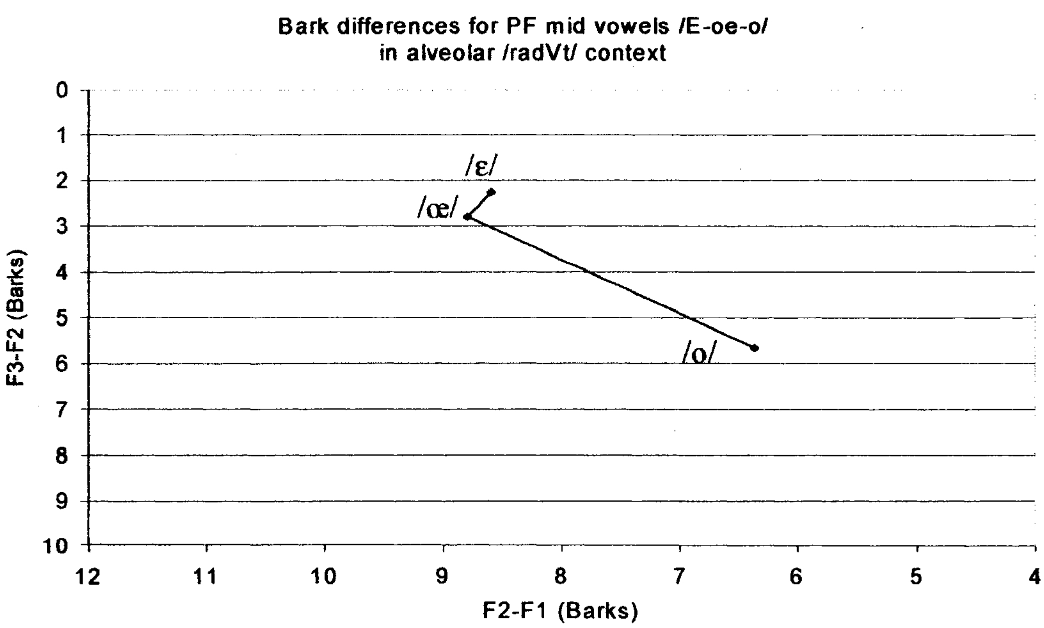


Figure 5. Perceptual assimilation of Parisian French front rounded vowels (/y/ and /œ/ collapsed) to front (/i/, /ɪ/), central (/ʌ/, /ɝ/) or back (/u/, /ju/, /ʊ/, /o/, /ʊ/) AE vowels by American English listeners with no French experience (NoExp), moderate French experience (ModExp), and extensive French experience (HiExp).

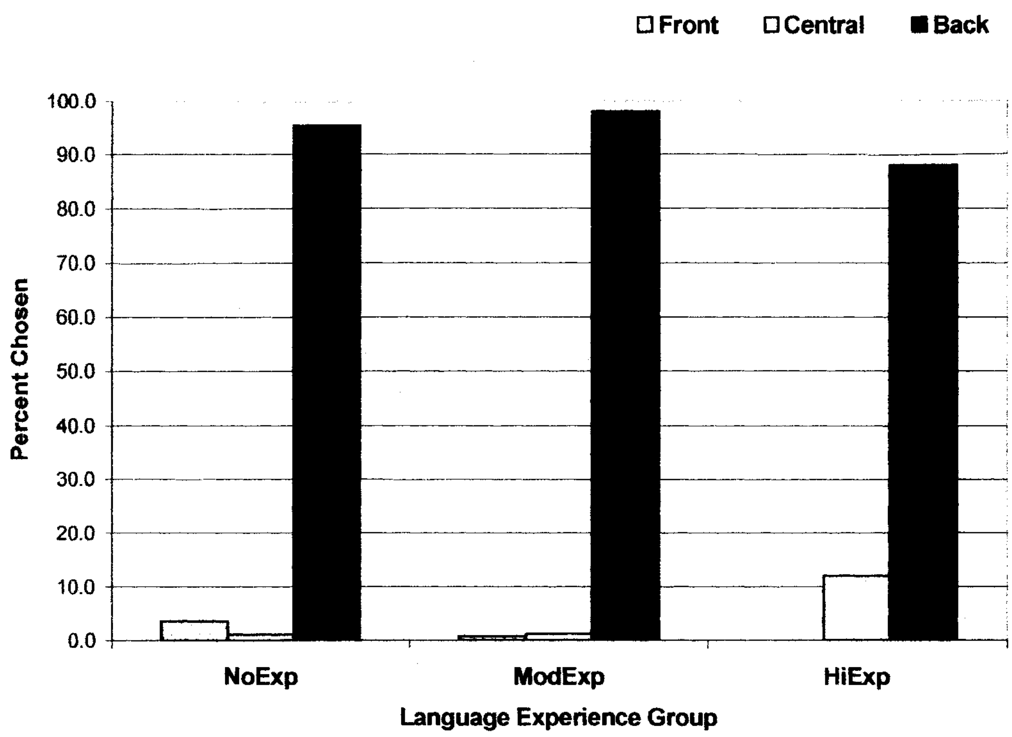
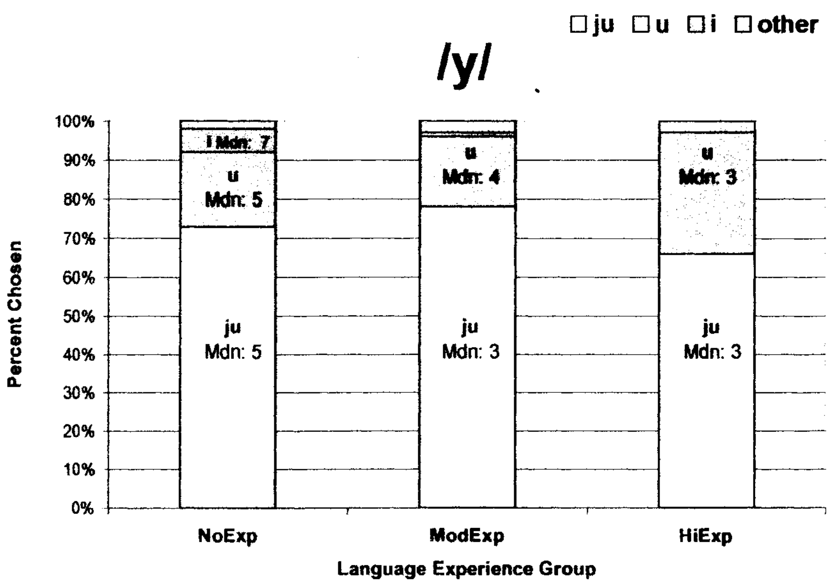


Figure 6. Perceptual assimilation of Parisian French (PF) /y/ (top) and PF /œ/ (bottom) by American English listeners with no French experience (NoExp), moderate French experience (ModExp), and extensive French experience (HiExp): Response category distributions and median goodness ratings (within bars).



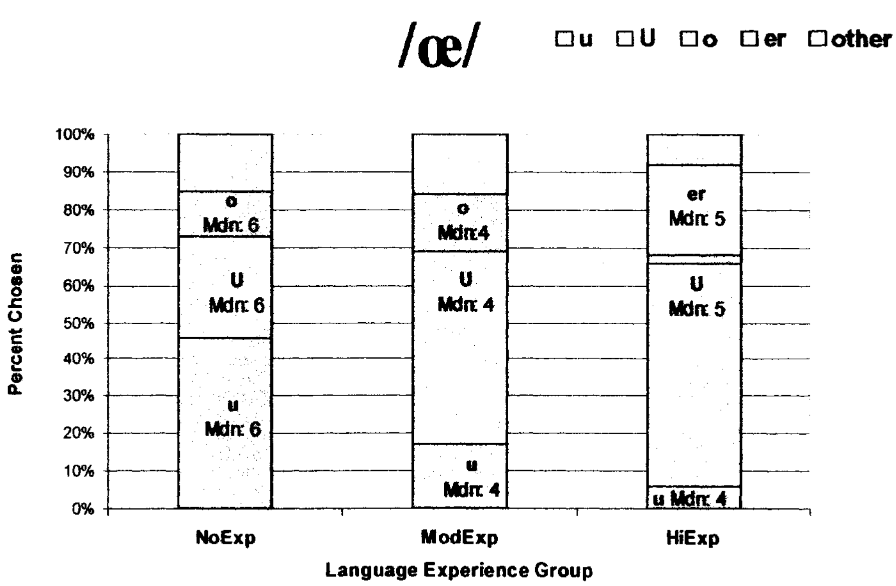
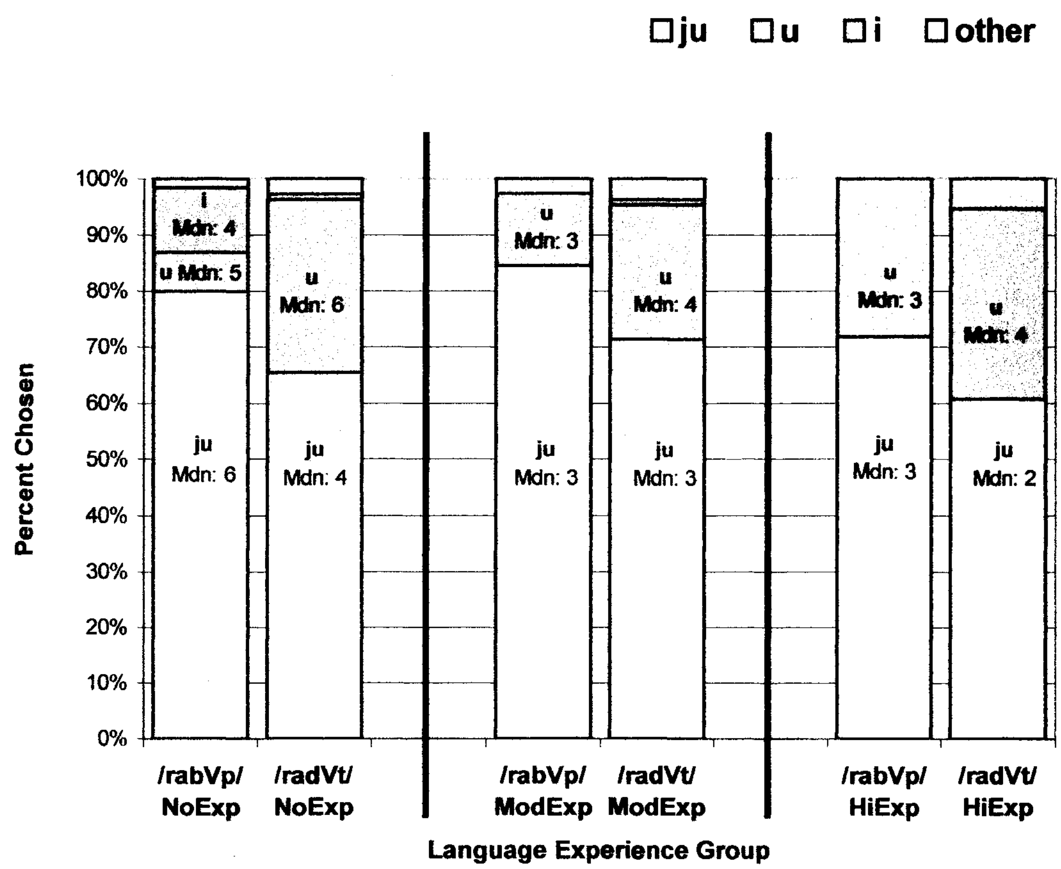
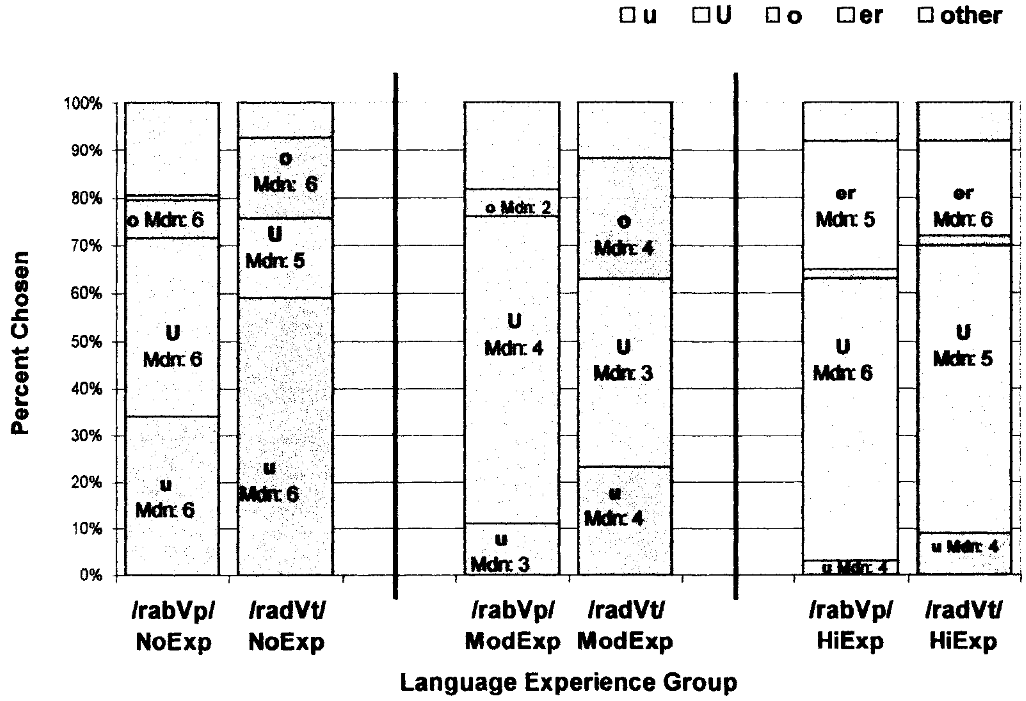


Figure 7. Perceptual assimilation of Parisian French /y/ in bilabial /rabVp/ vs alveolar /radVt/ context by American English listeners with no French experience (NoExp), moderate French experience (ModExp), and extensive French experience (HiExp): Response category distributions and median goodness ratings (within bars).



Internal Consistency	**88%**	**76%**	**91%**	**73%**	**95%**	**78%**

Figure 8. Perceptual assimilation of Parisian French /œ/ in bilabial /rabVp/ vs alveolar /radVt/ context by American English listeners with no French experience (NoExp), moderate French experience (ModExp), and extensive French experience (HiExp): Response category distributions and median goodness ratings (within bars).



Internal Consistency	**59%**	**77%**	**75%**	**57%**	**90%**	**83%**

Figure 9. Perceptual assimilation of Parisian French /y/, /u/, /œ/, /o/ by American English listeners with no French experience (NoExp), moderate experience (ModExp), and extensive experience (HiExp): Response category distributions and median goodness ratings (within bars).

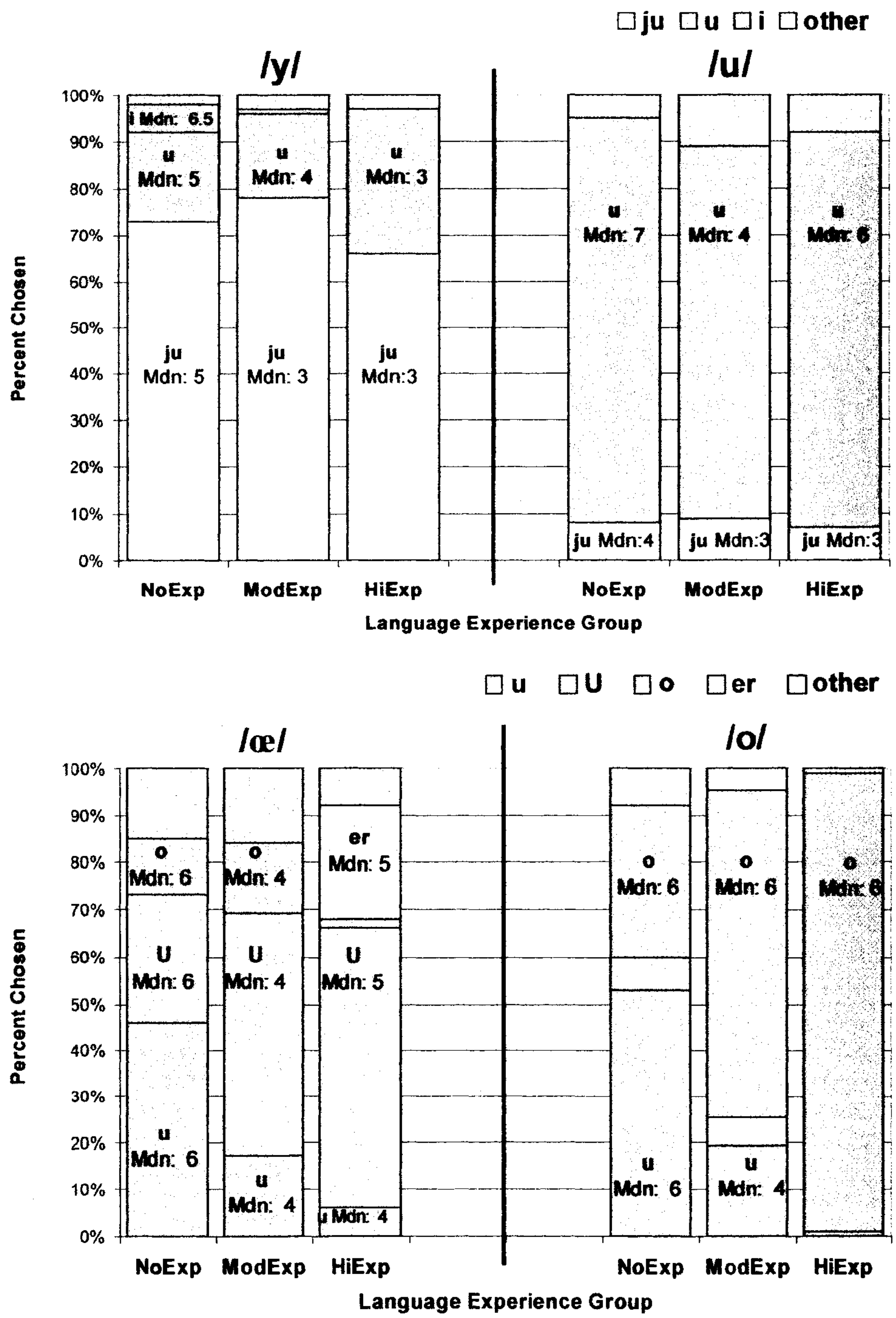


Figure 10. Perceptual assimilation of Parisian French /i/ (top) and /a/ and /ɛ/ (bottom) by American English listeners with no French experience (NoExp), moderate experience (ModExp), and extensive experience (HiExp): Response category distributions and median goodness ratings (within bars).

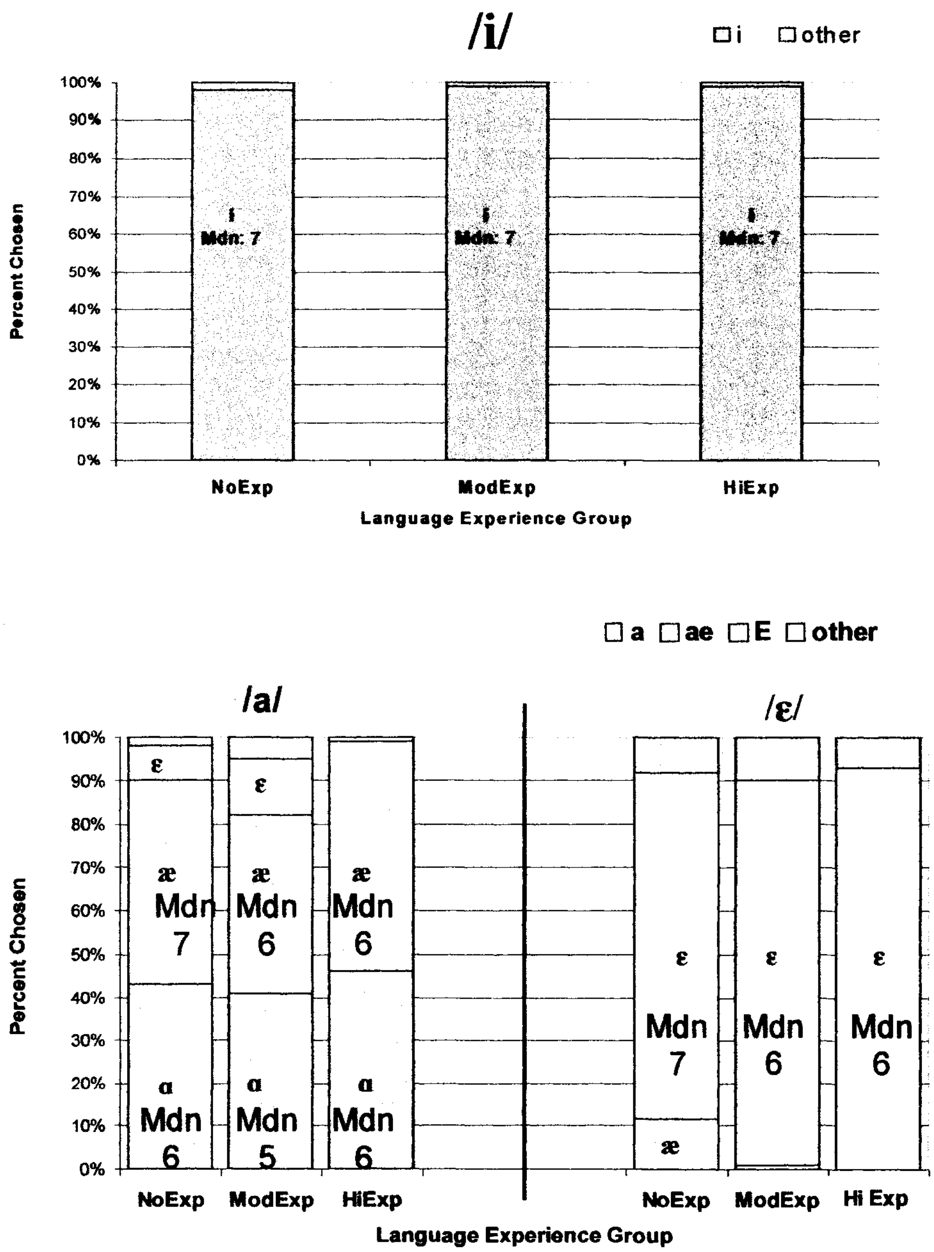


Figure 11. Categorial discrimination of Parisian French (PF) front rounded vowels paired with PF front unrounded vowels (/y-i/, /y-ɛ/, /œ -ɛ/, /œ-i/, collapsed), and PF front rounded vowels paired with PF back rounded (/y-u/, /y-o/, /œ -o/, /œ–u/, collapsed) by American English listeners with no French experience (NoExp), moderate French experience (ModExp), and extensive French experience (HiExp), and by Native French listeners: Percent errors and standard errors.

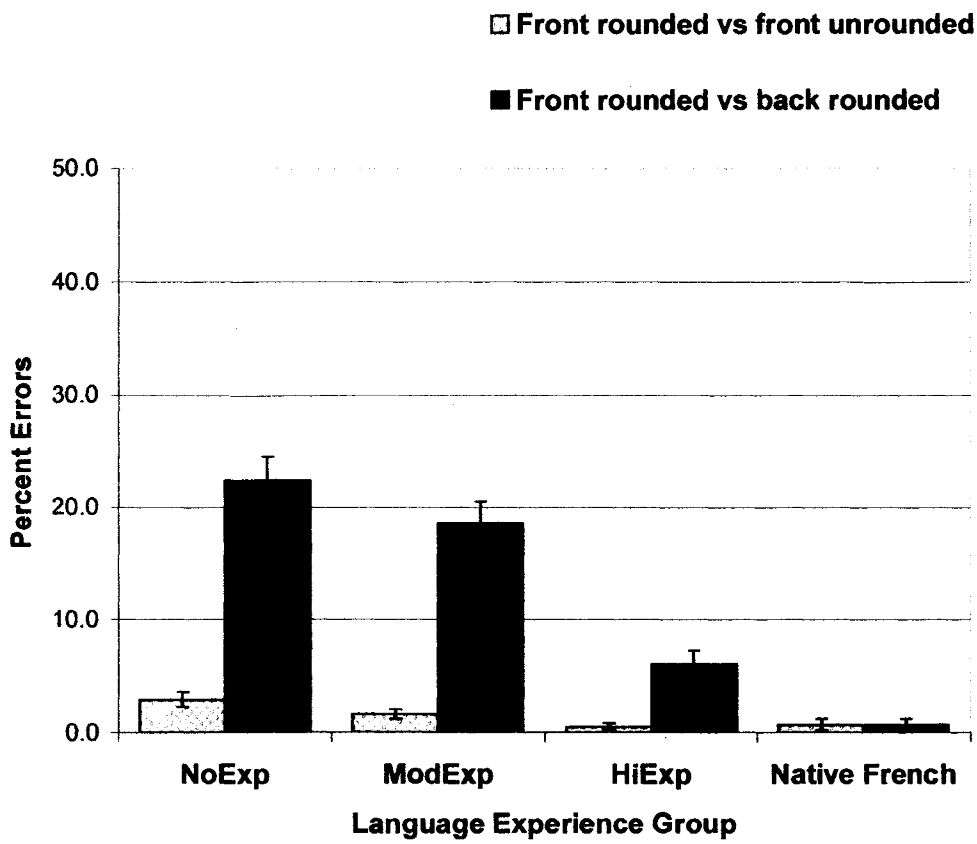


Figure 12. Discrimination accuracy for particular front rounded vowels paired with back rounded vowels. Categorial discrimination of Parisian French (PF) front rounded vowel pairs /y-u/, /y-o/, /œ-o/, /œ-u/ by American English listeners with no French experience (NoExp), moderate French experience (ModExp), and extensive French experience (HiExp): Percent errors and standard errors.

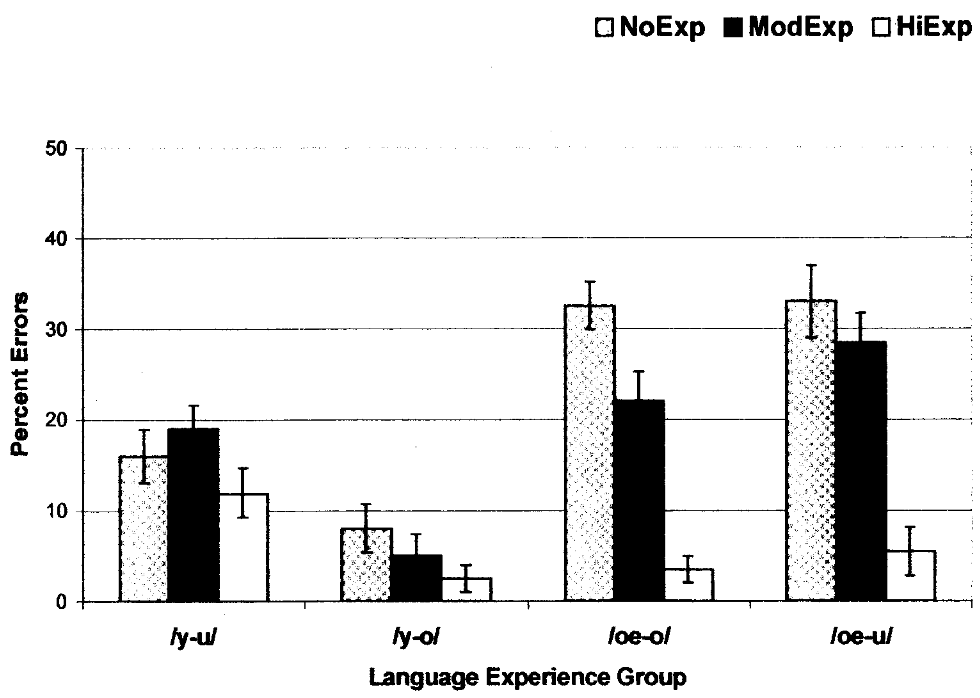


Figure 13. Language and context effects on /y/ discrimination. Categorial discrimination of Parisian French (PF) /y-u/ (top) and /y-o/ (bottom) paired by American English listeners with no French experience (NoExp), moderate French experience (ModExp), and extensive French experience (HiExp): Percent errors and standard errors.

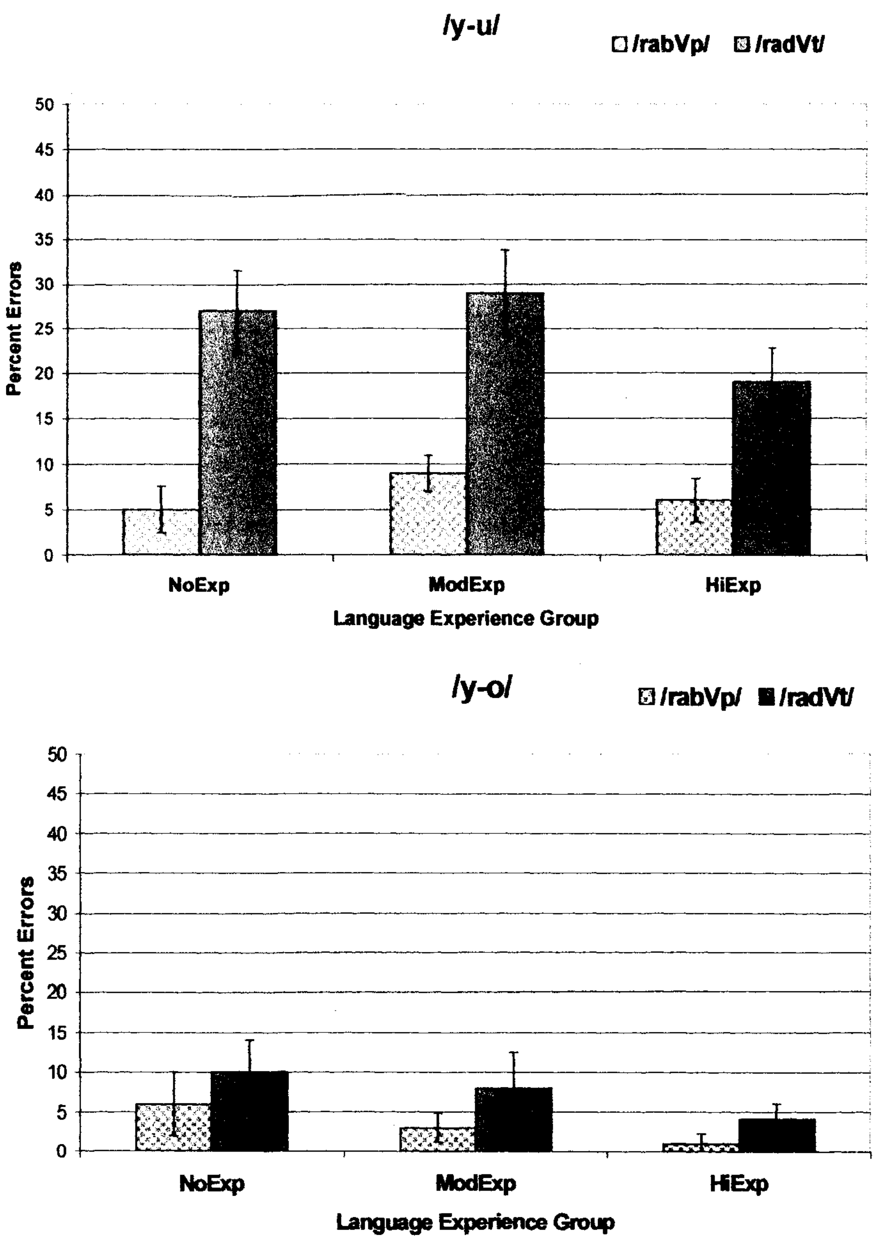
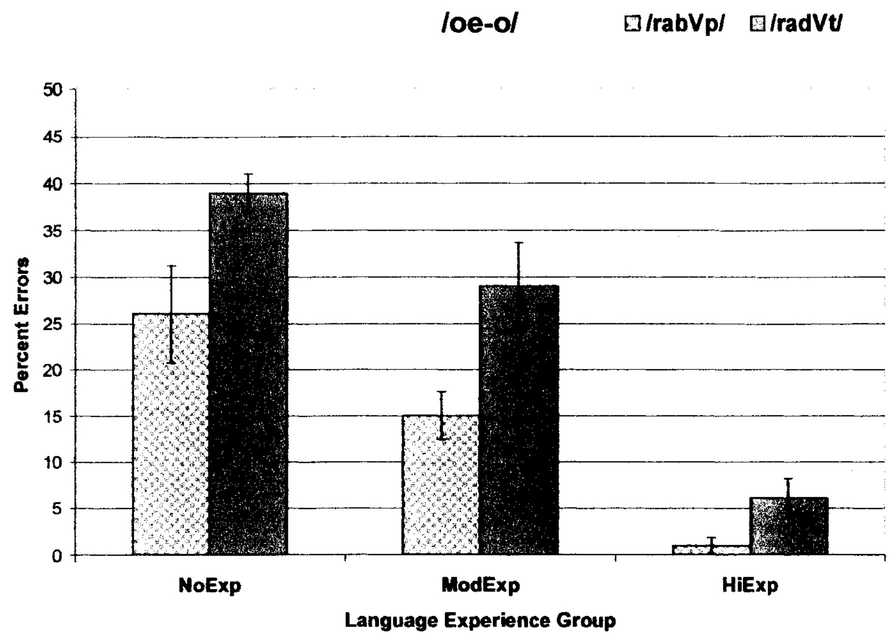


Figure 14. Language and context effects on /œ/ discrimination. Categorial discrimination of Parisian French (PF) /œ-o/ (top) and /œ-u/ (bottom) paired by American English listeners with no French experience (NoExp), moderate French experience (ModExp), and extensive French experience (HiExp): Percent errors and standard errors.



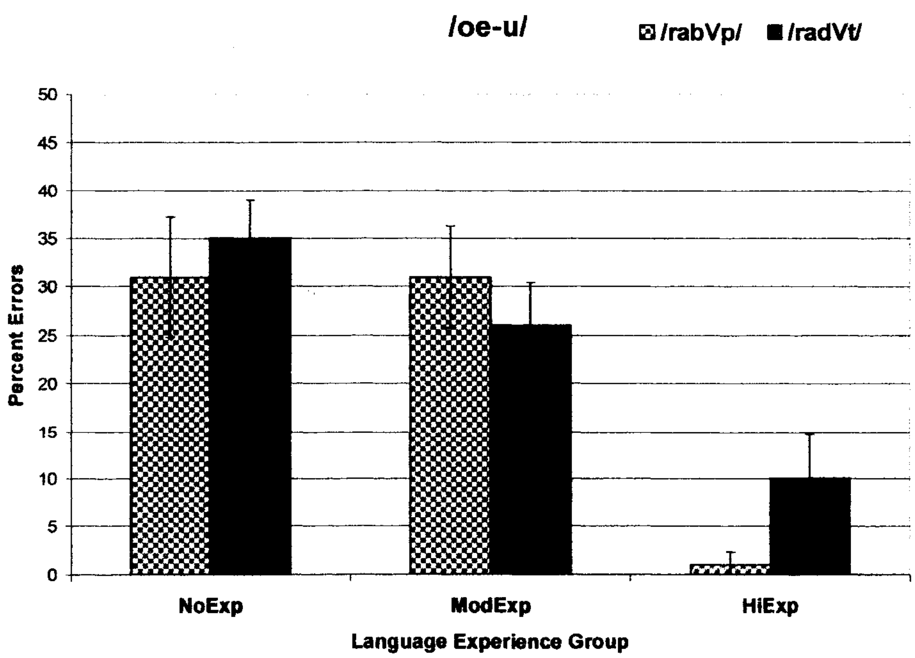
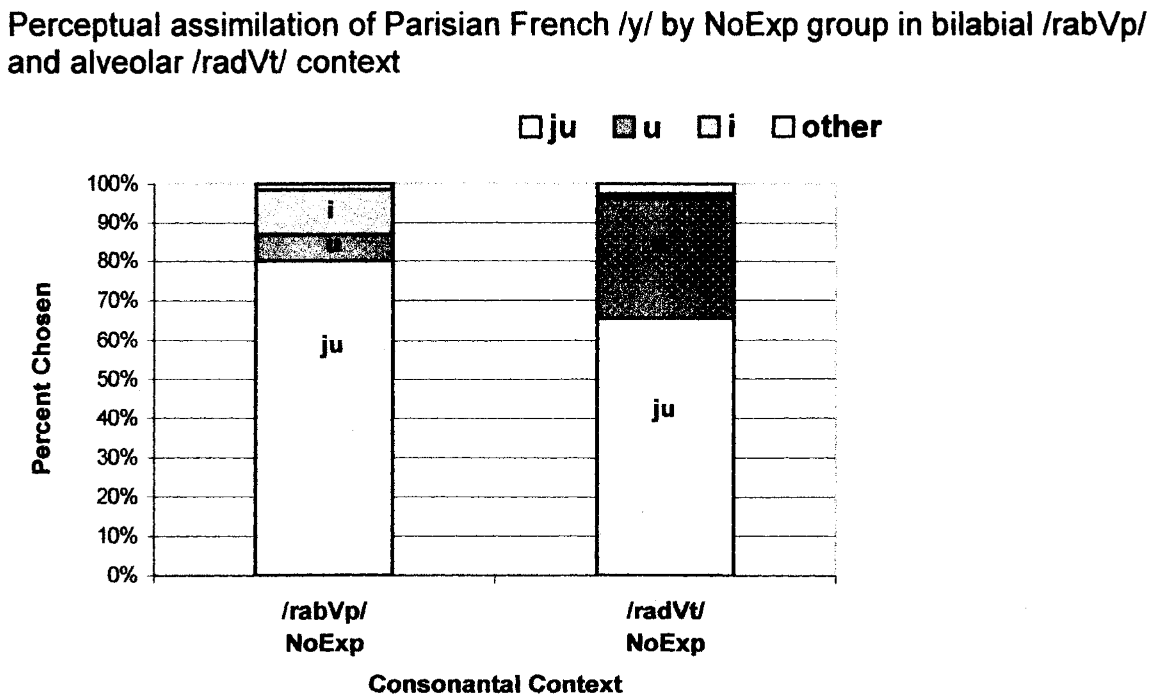


Figure 15. Interaction of vowel pair and context (and experience) for NoExp Group: Perceptual assimilation (top) and categorial discrimination (bottom) by American English listeners.



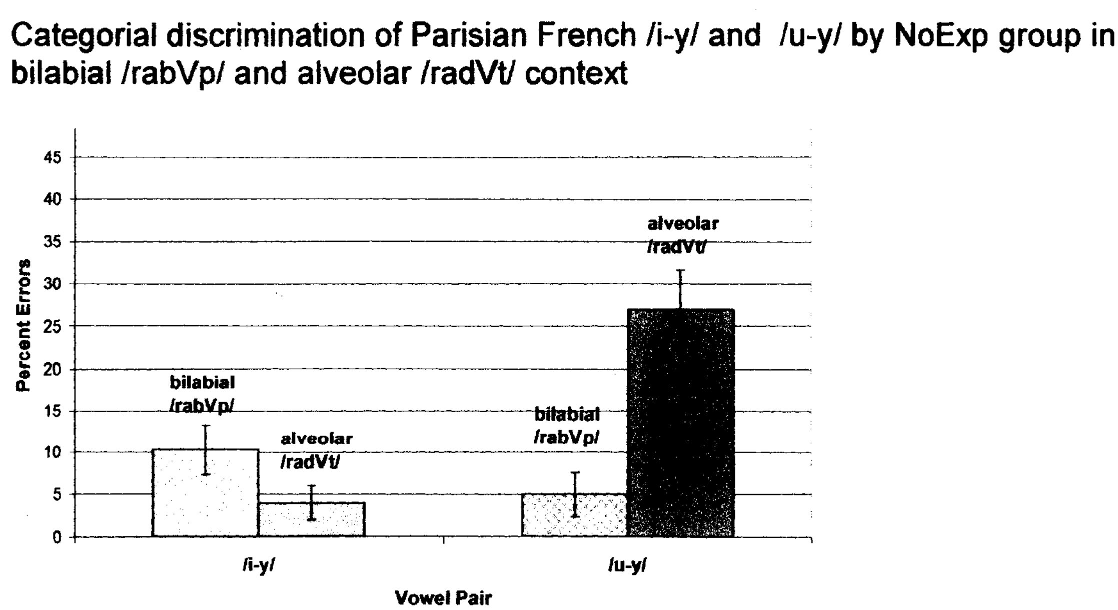


Figure 16. Categorial discrimination of Parisian French (PF) front rounded vowels /y-œ/ by American English listeners with no French experience (NoExp), moderate French experience (ModExp), and extensive French experience (HiExp): Percent errors and standard errors.

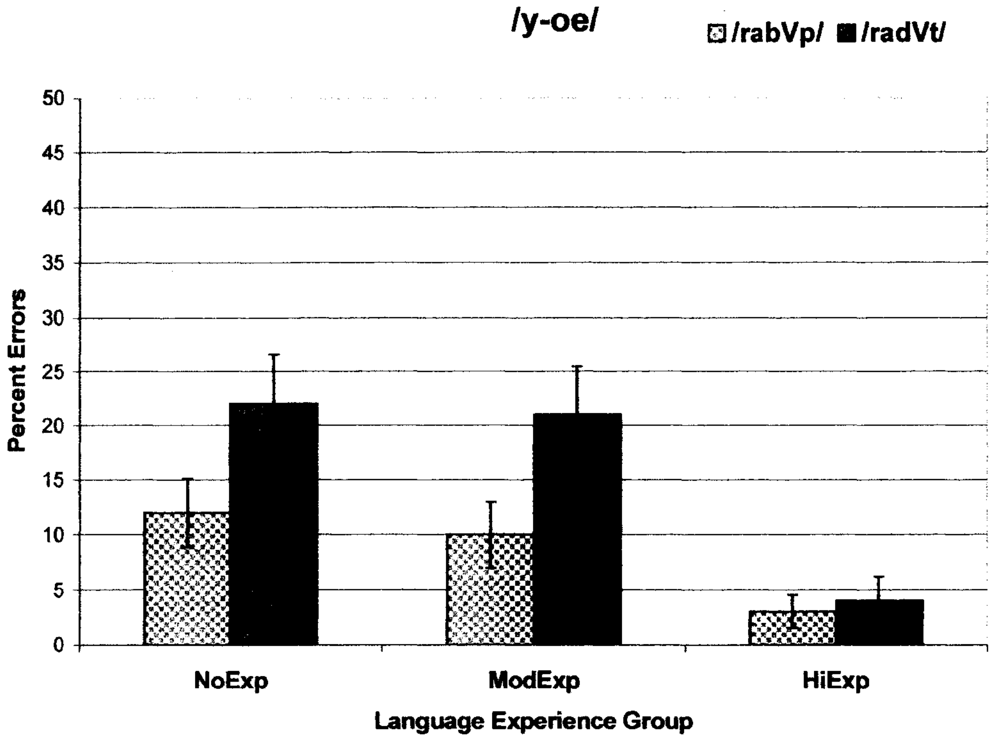


Figure 17. Categorial discrimination of Parisian French (PF) /a-ɛ/, /u-i/ by American English listeners with no French experience (NoExp), moderate French experience (ModExp), and extensive French experience (HiExp): Percent errors and standard errors.

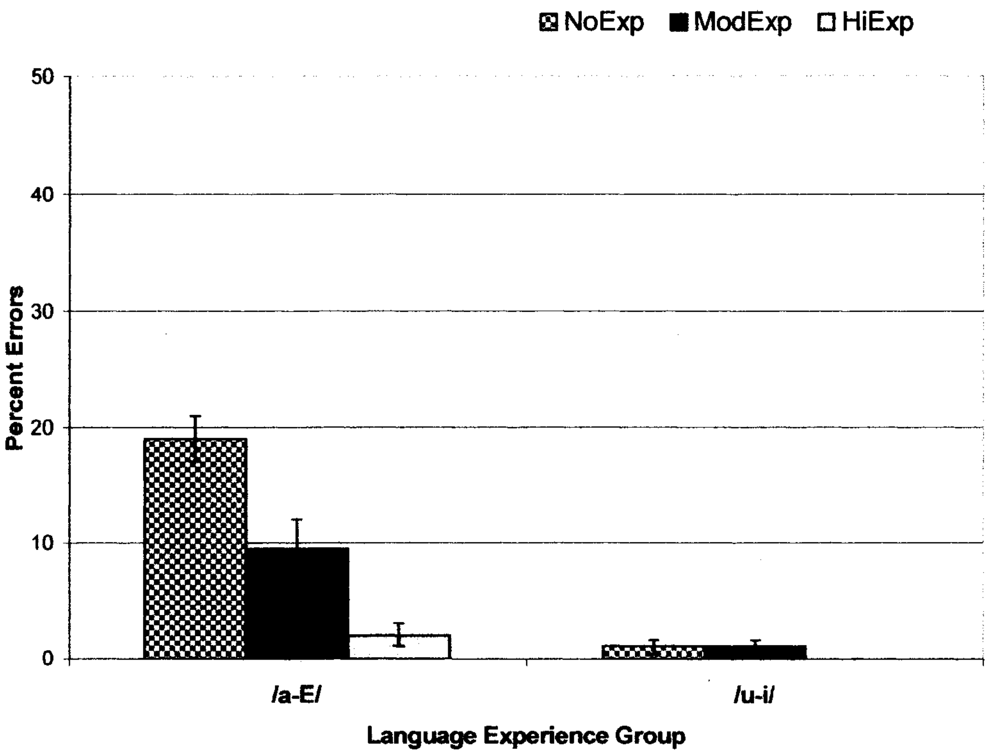


Figure 18. Scatter plot of relation between percent overlap in perceptual assimilation (PA) patterns and percent errors in categorial discrimination (CD) in bilabial /rabVp/ context by NoExp, ModExp, and HiExp groups, with vowel pairs (/y-u/, /œ-o/, /y-o/, /œ-u/, /y-i/,/y-ɛ/, /œ-ɛ/, /œ-i/, /a-ɛ/, /u-i/, /y-œ/) as sampling variable.

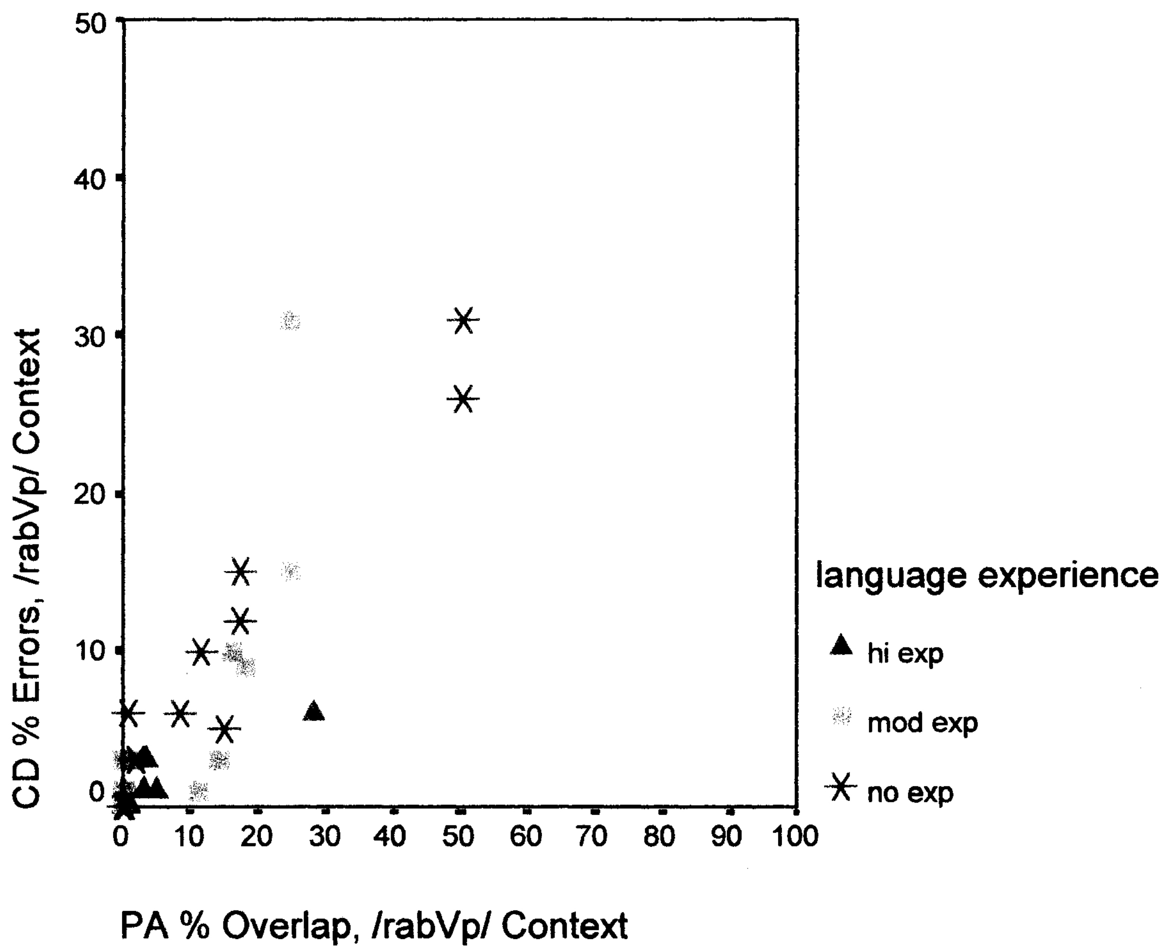


Figure 19. Scatter plot of relation between percent overlap in perceptual assimilation (PA) patterns and percent errors in categorial discrimination (CD) in alveolar /radVt/ context by NoExp, ModExp, and HiExp groups, with vowel pairs (/y-u/, /œ-o/, /y-o/, /œ-u/, /y-i/,/y-ɛ/, /œ-ɛ/, /œ-i/, /a-ɛ/, /u-i/, /y-œ/) as sampling variable.

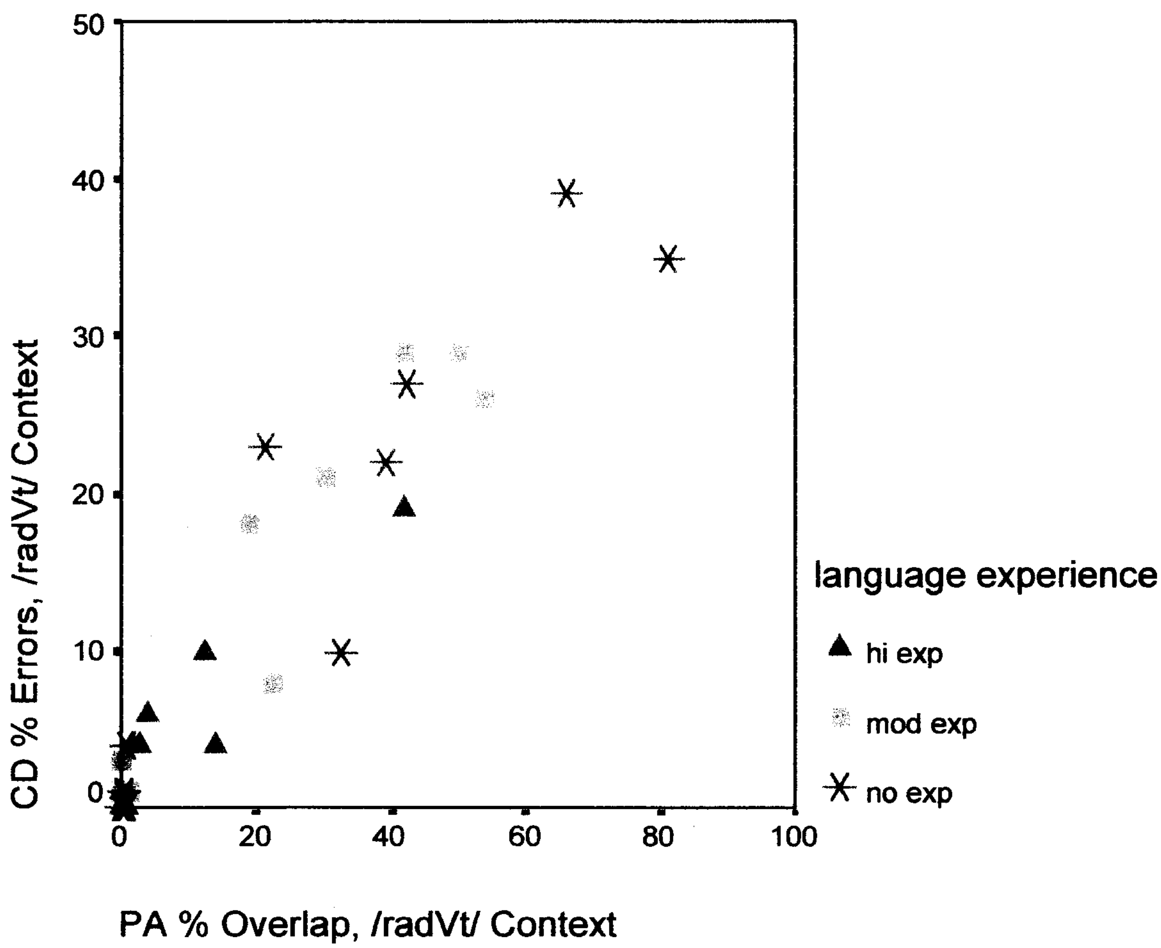
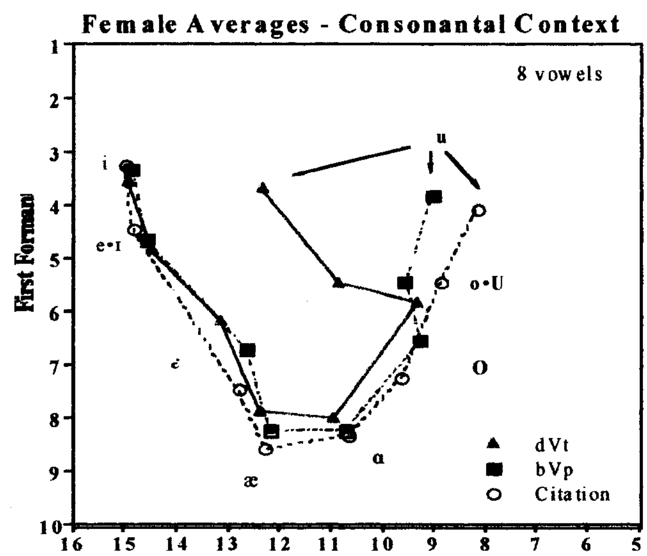
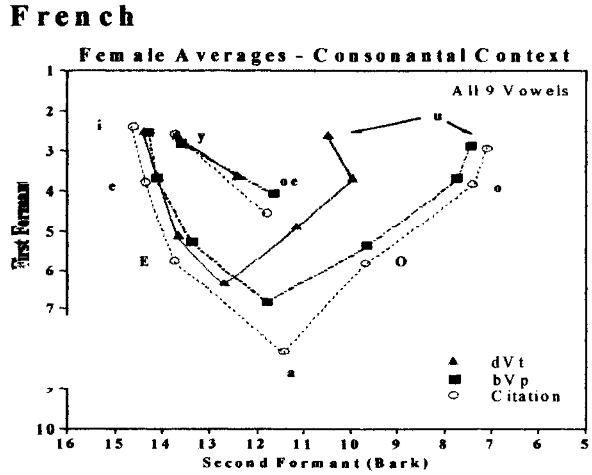


Figure 20: F1/F2 vowel spaces (in Barks) of American English (AE) vowels (top) and Parisian French (PF) vowels (bottom). Averages of 4 tokens from each of 3 monolingual female speakers of each language in bilabial /gabVpa/ context and alveolar /gadVta/ context in sentences and in citation form /hVba/ (AE) and /Vb#a/ (PF) bisyllables (Strange, Weber, Levy, Shafiro, and Nishi, 2002).

American English



Parisian French



7. Appendixes

Appendix A. Terms and Symbols

Phonetic and phonological terms typically used in crosslanguage speech perception research include "distinctive features" (e.g., "high" or "plus high" for high vowels), "phonological categories" or "phonemes" (context free phonological categories), "allophones" (context-sensitive phonetic segments), "phones" or "speech sounds" ("neutral" terms for segments that may or may not be context-sensitive), phonological contrasts (the differing phones in a minimal pair, which yield different meanings) and "acoustic features" (e.g., second formant frequencies).

In this dissertation, all of the above words may appear, often depending on the terminology used in the article being discussed, but the primary terminology implemented here will be "phonological category" denoting an abstract phonemic-level representation, which yields "phonetic segments" as physical/acoustic/allophonic instantiations of a category. As speech researchers improve their understanding of what it is that listeners perceive (and speakers produce), it is hoped that their terminology will also gain clarity.

For simplicity's sake, the term "second language" (or "L2") will refer to any non-native language that an individual has learned or is in the process of learning. Because language histories vary tremendously and individuals may have several native and non-native languages, this "second" language may actually be their third, or fourth language, for example.

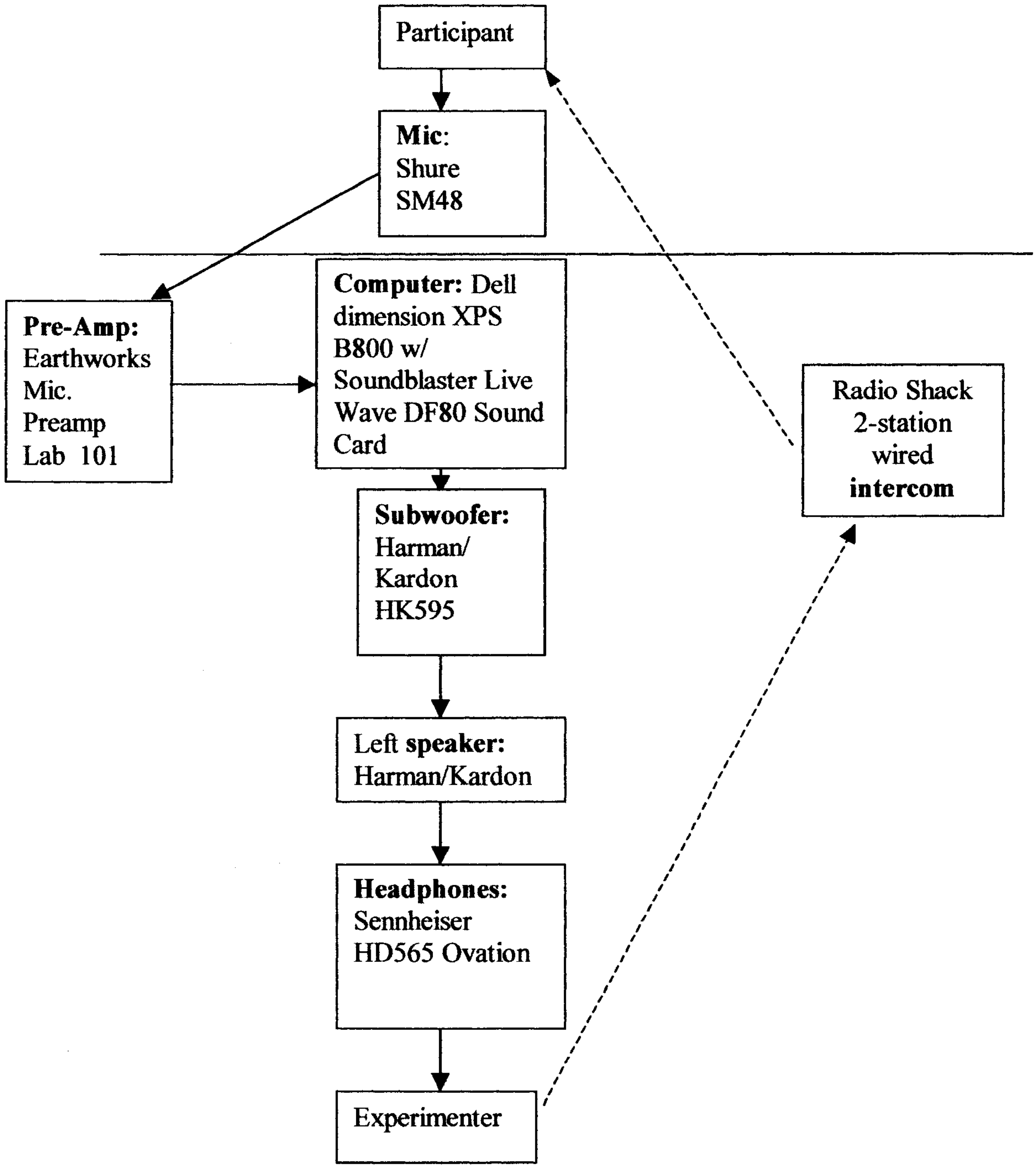
"Parisian French" is defined as a "standard" dialect of French spoken in Paris and the surrounding "Île de France" region.

The PF vowel /œ/: The mid front rounded vowels /ø/ and /œ/ are almost never contrastive in French and are both spelled as "eu" in French orthography. They almost always appear in different consonantal contexts: /ø/ is usually syllable-final (e.g., œufs /ø/ "eggs") or preceding certain consonants (e.g., /t/ or /z/, as in chanteuse /ʃãtøz/ "singer"). Conversely, /œ/ (as in œuf /œf/ "egg") never occurs syllable-finally. The only possible minimal pairs occur when /ø/ or /œ/ is followed by /n/ or /l/. Arguably, a handful of minimal pairs do exist involving these contrasts (e.g., the adjective jeune /ʒœn/ "young" vs the noun jeûne /ʒøn/ "fast"), but French speakers generally do not make the distinction. For the purposes of the current review, these vowels are considered allophones in French, and the symbol /œ/ represented the mid front rounded vowel category, unless otherwise specified by the author of the study being reviewed.

Appendix B. Protocol for Speakers

/rabVp/	/radVt/
4. J'ai dit neuf rabeppes à des amis. [ɛ]	4. J'ai dit neuf radettes à des amis. [ɛ]
15. J'ai dit neuf rabeupes à des amis. [œ]	15. J'ai dit neuf radeutes à des amis. [œ]
1. J'ai dit neuf rabipes à des amis. [i]	1. J'ai dit neuf radites à des amis. [i]
(botte)	*(botte)*
7. J'ai dit neuf raboppes à des amis. [ɔ]	7. J'ai dit neuf radottes à des amis. [ɔ]
13. J'ai dit neuf rabupes à des amis. [y]	13. J'ai dit neuf radutes à des amis. [y]
11. J'ai dit neuf raboupes à des amis. [u]	11. J'ai dit neuf radoutes à des amis. [u]
9. J'ai dit neuf rabaupes à des amis. [o]	9. J'ai dit neuf radautes à des amis. [o]
3. J'ai dit neuf rabé p'à des amis. [e]	3. J'ai dit neuf radé t'à des amis. [e]
12. J'ai dit neuf rabapes à des amis. [a]	12. J'ai dit neuf radates à des amis. [a]
4. J'ai dit neuf rabeppes à des amis. [ɛ]	4. J'ai dit neuf radettes à des amis. [ɛ]

Appendix C. Flowchart of Recording Equipment



Appendix D. Vowel Quadrilateral and Description of Pairs

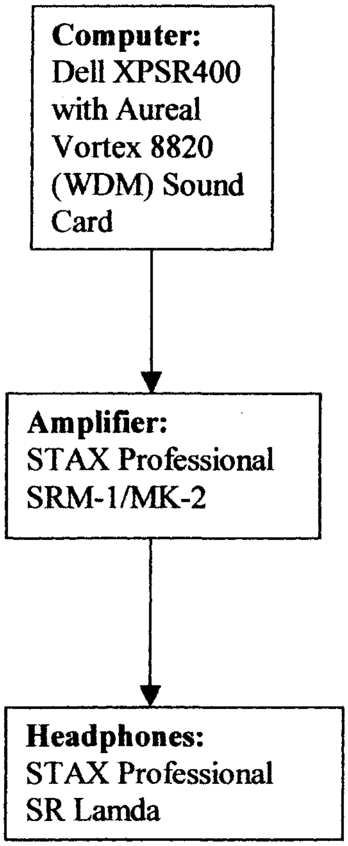
Table D1. PF Vowel Quadrilateral With Vowels Used in Perceptual Assimilation and Categorial Discrimination Tasks

	Front		Back
Hi	**i y**		**u**
Mid		**œ**	**o**
	ɛ		
Low		**a**	

Appendix D2. Places of articulation of pairs for categorial discrimination experiment:

1-Feature (CG or SC or UC)	**2-Feature**
High vowels **/y-i/** (rounded vs unrounded) **/y-u/** (front vs back)	**Controls: Not involving fr. rnded vowels** **/i-u/** (front unrounded vs back rounded) **/a-ɛ/** (low-front vs mid-front) (2-feature, TC, both native)
Mid vowels **/œ-ɛ/** (<u>rounded</u> vs <u>unrounded</u>) **/œ-o/** (<u>front</u> rounded vs <u>back</u> rounded)	**Involving front rounded vowels** **/y-ɛ/** (high front rounded vs mid front) **/œ-i/** (mid rounded vs high unrounded) **/y-o/** (high front vs mid back) **/œ-u/** (mid front vs high back) (2-feature, height diff all involving front rounded vowels, TC, UC)
/y-œ/ (<u>high</u> front rounded vs <u>mid</u> front rounded)	

Appendix E. Flowchart of Equipment for Perceptual Tasks



Appendix F. Design of the Perceptual Assimilation Task

1. Blocked on speaker and context (as in Levy and Strange (2002) and in categorial discrimination experiment)
2. 3 speakers, 7 PF vowels: /i, y, u, ɛ, œ, o, a/, 2 judgments for every token
3. Key word responses for Familiarization and Experiment: AE /hVd/ with 13 AE vowels: (heed, hid, hayed, head, had, hod, hawed, hud, hoed, hood, who'd, hued, and herd)

Key word / Task Familiarization:

1. Key word fam: Experimenter reads key words to participant, participant reads key words to participant/feedback from experimenter
2. Task Fam Block 1: stimuli: 13 "five gadVta/gabVpa this time" (mixed bp/dt contexts, 1 fem speaker) in order in which key words are presented=13 trials with feedback
3. Task Fam Block 2: 2 tokens of 13 stimuli "five gadVta/gabVpa this time" (mixed bp/dt contexts, 1 fem speaker) =26 trials with feedback
4. Task Fam Block 3: Same as block 2=26 trials with feedback. If 100%, go to Stimulus Familiarization.
5. Task Fam Block 4: Same as block 2=26 trials with feedback. If ≤ 2 errors, go to Stimulus Familiarization. If more than 2 errors, continue to Task Fam Block 5.
6. Task Fam Block 5: Same as block 2=26 trials with feedback. If ≤ 2 errors, go to Stimulus Familiarization. If more than 2 errors, disqualified: performs abbreviated version of experiment.

Stimulus familiarization: Before first block of each speaker in each context, 1 block of all 7 vowels (1 token each) by that particular speaker, = 7 trials (will already have experienced stimuli in CD task). Data will be discarded.

Experiment:
Each block: 7 PF vowels X 1 speakers X 3 tokens per speaker (=21 tokens per block). 2 judgment in each context = 6 tokens per speaker. 3 tokens per speaker X 3 speakers X 2 judgments= 18 judgments per vowel per context (so percent perceptual assimilation to a particular category will be number of judgments in one category/18). 2 contexts.
Block structure: 6 blocks of 21 trials in each context

Sequence of blocks for PA
Key word fam: Experimenter reads key words to participant, participant reads key words to participant/feedback from experimenter (13 trials)

Task Fam Block 1:	13 in order (five gabVpa/gadVta this time) + feedback
Task Fam Block 2:	26 random (five gabVpa/gadVta this time) + feedback
Task Fam Block 3:	26 random (five gabVpa/gadVta this time) + feedback

	If 100%, go to Stimulus Familiarization.
Task Fam Block 4:	26 random (five gabVpa/gadVta this time) + feedback
	If ≤ 2 errors, go to Stimulus Familiarization.
	If more than 2 errors, continue to Task Fam Block 5.
Task Fam Block 5:	26 random (five gabVpa/gadVta this time) + feedback
	If ≤ 2 errors, go to Stimulus Familiarization.
	If more than 2 errors, disqualified: performs abbreviated version of experiment.

<u>bp</u>

Stim Fam Spker 1 bp: 7 trials
Spker 1 bp: 21 trials
Spker 1 bp. 21 trials

Stim Fam Spker 2 bp: 7 trials
Spker 2 bp: 21 trials
Spker 2 bp. 21 trials

Stim Fam Spker 3 bp: 7 trials
Spker 3 bp: 21 trials
Spker 3 bp. 21 trials

<u>dt</u>

Stim Fam Spker 1 dt: 7 trials
Spker 1 dt: 21 trials
Spker 1 dt. 21 trials

Stim Fam Spker 2 dt: 7 trials
Spker 2 dt. 21 trials
Spker 2 dt. 21 trials

Stim Fam Spker 3 dt: 7 trials
Spker 3 dt: 21 trials
Spker 3 dt. 21 trials

<u>Possible orders (from left to right) for blocks within a particular context</u> (ideal for 12 listeners). 6 Paradigm ID experiments—one for each speaker in each context: spk 1 bp, spk 2 bp, etc.

1 2 3
2 3 1
3 1 2
1 3 2
3 2 1
2 1 3

All blocks of bp, then all blocks of dt for ½ of subjects, and reverse for other ½.

Appendix G. Instructions for Perceptual Assimilation Task

Familiarization

In this part of the experiment, you will practice using the key words that represent American English vowel sounds. The trick here is to focus on the vowel sounds you hear rather than on the spelling of words.

You will hear an American woman saying nonsense words in the form of "gab-vowel-pa" or "gad-vowel-ta" in phrases. Please listen to the second vowel sound of the word and determine which American English vowel she is saying. Indicate the vowel by choosing one of the following key words:

heed	hod (rhymes with pod)
hid	hawed (rhymes with pawed)
hayed	hoed (rhymes with road)
head	hood (rhymes with should)
had	who'd (rhymes with booed)
herd (rhymes with bird)	hued (rhymes with cued)

Before we start, please read each of the above words aloud to the experimenter, and pronounce the vowel in each word by saying "heed has the sound…., hid has the sound…"

Now that you know the vowels, here is some practice with the task. You will hear a nonsense word of the form "gab-vowel-pa" or "gad-vowel-ta." Choose the key word that contains the second vowel sound in the nonsense word you heard. For example, if you hear "gadetta," the appropriate key word is "head" because "head" has the second vowel sound you heard in "gadetta." The nonsense word "gab-vowel-pa" or "gad-vowel-ta" will be presented in the phrase "five (nonsense word) this time." So if you hear "five gadetta this time," you will choose "head."

After you indicate the vowel, the same word will be presented again and you will see a rating scale from 1-9. The purpose of the scale is for you to indicate how good an example of that American vowel it is. If it sounds like a normal vowel you would hear uttered by a native speaker of American English, choose a point on the scale near "Very American-like (9)." If the vowel is not a good example of a vowel you would hear uttered by a native American English speaker, select a point near the "Very foreign" end of the scale (1). So first listen to the vowel and choose the key word with the American English vowel you heard. Then listen to it a second time and indicate how good an example of the vowel it is.

You will complete 4 blocks of phrases. The first block has 13 trials and the rest have 26 trials. In the first block, the vowel sounds are in the same order as the above key words. In the remaining blocks you will hear the same phrases with nonsense words, but presented in random order.

Do you have any questions?

Experiment, /radVt/ context:

You will hear native French women saying nonsense words in French in the form "rad-vowel-t" in the phrase "neuf (nonsense word) a des amis." You will then see the American English key words you know (e.g., heed, hid, etc.). When you hear the nonsense word, listen to the second vowel (e.g., the second vowel in the word "radettes" in the phrase "neuf radettes a des amis") and choose which American English vowel sound it is most similar to. Then click on the English key word that contains that vowel. You will not receive feedback.

After you indicate the vowel, the same French phrase will be presented again and you will see a rating scale. The purpose of the scale is for you to indicate how similar you feel the French vowel is to the American English vowel you chose. If the sounds are very similar, choose a point on the scale near "Very American-like (9)." If the vowels are very different, select a point near the "Very foreign" end of the scale (1). So first listen to the second vowel of the French nonsense word ("rad-vowel-t") in the phrase and choose the American English key word that has the vowel to which it is most similar. Then listen to it a second time and indicate how good an example of the American English vowel it is.

The first block (7 trials) for each speaker is just for practice and will not be used in the analysis. Go ahead and respond to each word even if you feel unsure of the task. This block is to give you practice with the task and to have you become familiar with the speakers' voices. Following the first block, there will be 2 blocks of 21 trials. You will complete this block structure six times (i.e., two times for each speaker). Please try to use the whole rating scale from 1-9. That is, do not just rate the vowels as very foreign or very English, but rather make detailed judgments about how similar or different the sounds are (use the numbers 2 through 8, too). When you're ready to begin, go ahead and click. Do you have any questions?

Appendix H. Design of the Categorial Discrimination Task

1. 3 speakers per trial
2. Blocked by context
3. Number of trials:
   1-Feature trials: 12 judgts per pair per context X 5 1-feat vowel pairs=60 1-feat. trials per context (X 2 consonantal contexts = 120 1-feature trials)
   2-Feature trials: 6 judgments X 6 2-feature pairs=36 trials per context (X 2 consonantal contexts = 72 2-feature trials)
   Total: 60 1-feature per context + 36 2-feature per context = 96 trials per context (or 120 1-feature + 72 2-feature = 192 total trials)
   Block structure: 4 blocks of 24 per context= 96 trials per context + 1 stimulus fam block of 24 per context

Task familiarization
1 block AE (five gabVpa/gadVta this time)—as in Levy and Strange (2002) with feedback

Stimulus familiarization
A copy of a test block, in random order. No feedback.

Sequence of Blocks for Categorial Discrimination
Task Fam: 1 block AE

Stim Fam 1 bp: 24 trials
Exp Block 1 bp: 24 trials
Exp Block 2 bp: 24 trials
Exp Block 3 bp: 24 trials
Exp Block 4 bp: 24 trials

Stim Fam 1 dt: 24 trials
Exp Block 1 dt: 24 trials
Exp Block 2 dt: 24 trials
Exp Block 3 dt: 24 trials
Exp Block 4 dt: 24 trials

Appendix I. Instructions for Categorial Discrimination Task

Familiarization:

You will hear three phrases, such as "five gabappa this time/ five gabippa this time/ five gabippa this time."

The phrases will be spoken by three different people. Your task is to say whether the vowel in the nonsense (target) word of the middle phrase is the same as the one in the first phrase or the one in the third phrase. For this example, the vowel in "gabippa" in the middle phrase is the same as the vowel in the third phrase "gabippa".

After you hear the three phrases, you will see the numbers "1" and "3" on your screen. If the vowel in the target word of the middle phrase is the same as the one in the first phrase, click on "1". If, on the other hand, it is the same as the one in the third phrase, click on "3". In the example, you would click on "3" because the vowel in "gabippa" in the middle sentence is the same as the vowel in "gabippa" in the third phrase.

This first part of the study will be a practice section in English so that you become familiar with the task. For this section you will see a green light when you answer correctly and a red light when you answer incorrectly. You will hear 24 trials (sets of sentences).

Do you have any questions?

Experiment: /rabVp/ context:

The experimenter will read the next sentence to you:

You will now hear French phrases such as "neuf rab-vowel-p à des amis / neuf rab-vowel-p à des amis / neuf rab-vowel-p à des amis."

Once again, please indicate whether the vowel in the target word of the middle phrase is the same as the one in the first phrase or the one in the third phrase. Again, if the vowel in the target word of the middle phrase is the same as the one in the first phrase, click on "1." If it is the same as the one in the third phrase, click on "3." In this section you will not be shown whether your answer was correct. We won't count the scores on the first block of phrases as you'll be getting used to the sounds. This task may be difficult. Do the best you can and please guess if you are unsure of the answer. You will hear 5 blocks of 24 sentences.

Do you have any questions?

Appendix J: Participant Characteristics

Parti Cipant/ Experi-ence	Age	Gnder	# Yrs educa-tion after HS	Tot. Fr. Study Yrs	Age be-gan Fr	Yrs Hs/ Jr. Hi Fr	Yrs Col-lege Fr	Yrs Grad Sch, etc. Fr	Fr. Immer-sion Experi-ence
101 No	27	M	9	0	n/a	0	0	0	0
102 No	21	F	3	0	n/a	0	0	0	0
103 No	29	M	9	0	n/a	0	0	0	0
104 No	40	M	4	0	n/a	0	0	0	0
105 No	25	F	7	0	n/a	0	0	0	0
106 No	26	M	6	0	n/a	0	0	0	0
107 No	27	F	10	0	n/a	0	0	0	0
108 No	20	F	2	0	n/a	0	0	0	0
109 No	28	F	4	0	n/a	0	0	0	0
110 No	27	F	2	0	n/a	0	0	0	0
111 No	37	F	6	0	n/a	0	0	0	0
112 No	37	M	1	0	n/a	0	0	0	0
113 No	33	F	6	0	n/a	0	0	0	0
201Mod	26	F	6	4	13	1	3	0	5 mo
202Mod	24	F	1	3	19	0	3	0	1 mo
203Mod	22	F	4	3.5	14	3	0.5	0	0
205Mod	37	F	6	2	15	1	1	0	0
206Mod	27	M	5	3	19	1	2	0	1 mo
207Mod	24	F	6	2	21	0	2	0	0
208Mod	23	F	4	3	14	1	2	0	0
209Mod	27	F	4	2	20	0	2	0	0
210Mod	26	F	5	4	14	3	1	0	1 mo
211Mod	25	M	7	2	17	0	2	0	<1 mo
212Mod	32	F	6	3.5	15	2	1.5	0	< 1 mo
213Mod	25	M	2	3	15	1	2	0	1 wk
214Mod	22	F	4	2	13	1	1	0	2 wks
301 Hi	31	F	11	5	17	0	2	3	17 mo
302 Hi	21	M	3.5	7	13	5	2	0	1 yr
303 Hi	43	F	5	5	13	4	0	1	16 yrs
304 Hi	20	M	4	6	13	2	4	0	14 mo
305 Hi	23	F	4	10	13	4	4	2	15 mo
306 Hi	44	F	4	8	13	4	4	0	1 yr
308 Hi	21	F	3.5	7	14	4	3	0	1 yr
309 Hi	43	F	8	9	14	3	4	2	2 yrs
310 Hi	61	M	6	6	12	3	2	1	2.5 yrs
311 Hi	27	M	5	9	12	4	3	5	2 yrs
312 Hi	40	F	12	8.5	16	3	4	1.5	1.5 yrs
313 Hi	45	M	7	13	16	4	4	3	2 yrs
314 Hi	24	F	7	11	13	4	4	3	1 yr

Appendix K: Language Background Questionnaire

Please complete this questionnaire to the best of your knowledge and add any information you feel might be relevant (use the back of the paper if needed).

Name: ______________________________Participant number: ____________
Date: ______________________e-mail address: __________________________
Address: ____
Telephone Numbers: (Home) _______________ (Work) ____________________
Date of Birth: _____________ Gender: ________
Birthplace: _________________________ _____________________________
Town/City State/Country
Occupation: _______________Number of years of education after high school ___
How did you find out about this study? ____________________________________

Places in which you have lived for more than 1 year:

City/State/Country Years

____________________________ from age ______ to age ______
____________________________ from age ______ to age ______
____________________________ from age ______ to age ______
____________________________ from age ______ to age ______

If you have lived in more places please check here ____ and continue on the back.

Parent 1's Birthplace: ____
Languages parent 1 spoke fluently: ______________________________
Parent 2's Birthplace: ____
Languages parent 2 spoke fluently: ______________________________
Parent 3's Birthplace: ____
Languages parent 3 spoke fluently: ______________________________

What languages were spoken in your home when you were growing up? (for example, by parents, guardians, grandparents, or relatives) ______________________________

What languages are spoken in your home now? ______________________________

What languages do you speak fluently and understand without effort?
1. _________________ 2. ___________________ 3. ________________
What language(s) did you speak/understand as a child (before going to school)?
1. _________________2. ___________________ 3. ________________
What language(s) were used in your classrooms in elementary school?
1. _________________2. ___________________ 3. ________________

If you have studied French, please answer the following questions as accurately as you can. If you have <u>not</u> studied French, please continue to the asterisk (*) on Page 4:

How old were you when you started learning French? __________

<u>School</u>

How many years did you take French in high school: ______, college: ______, graduate school: ______ other: ______?

Did you have any native speakers of the language as teachers or tutors? **No____**
Yes____ Don't know ___________
If **yes**, please specify the number of semesters or months with native speakers as teachers or tutors: ________________________________

How many years of French (in total) have you studied? _________

Overall in your French classes, what percent of the time was the focus on pronunciation (on average)? ____

If focus on pronunciation differed in initial years versus in later years, please specify:

____

Overall in your French classes, what percent of the time was devoted to informal activities (i.e., natural conversation in real-life situations)? ____________ Please explain: ____

____

How long ago did you last take a French class? _______________

<u>Experience in French-speaking country</u>

How many months have you spent in French-speaking countries and what did you do while you were you there? ______________________________________

____

How long ago were you last in a French-speaking country and how long did you stay there? ____

____

If you were in a French-speaking country, what percent of the time was spent speaking French with French-speaking friends/colleagues? (Please explain) __________________

____

French experience in the United States

In the past, how often have you spoken French in the United States and in what capacity? _

____

____

How many hours per week (if any) do you currently speak French and in what capacity?

____

What percent of this time is spent communicating with friends or colleagues who are native speakers of French? (Please explain) ______________________

____

In the United States, approximately how many hours per week do you listen to French media/radio/television? (Please explain) ______________________

____

How important is it to for your professional success to know French? (Please explain)

____

Rating

On a scale from 1-5 (with 1 being "like a native French person" and 5 being "very foreign") how would you rate your French in terms of:

	Like native French				**Very foreign**
a. General proficiency:	1	2	3	4	5
b. Pronunciation:	1	2	3	4	5
c. Grammar:	1	2	3	4	5
d. Comprehension:	1	2	3	4	5
e. Reading:	1	2	3	4	5

Comments if you have any:______________________

____

On a scale from 1-5 (with 1 being "It is very important to me" and 5 being "It is not important at all to me") how would you rate your desire to be as proficient as possible in the following areas of French?

	Very important to me				**Not at all important to me**
f. General proficiency:	1	2	3	4	5
g. Pronunciation:	1	2	3	4	5
h. Grammar:	1	2	3	4	5
i. Comprehension:	1	2	3	4	5
j. Reading:	1	2	3	4	5

Comments if you have any:______________________

____

***What (other) language(s) did you study as a foreign language in school?**
A. ____________ **B.** ____________ **C.** ____________

Please answer the following questions about the languages you listed above:

Regarding Language A: How old were you when you started learning it? __________
How many years total (approximately) did you study it? __________
On a scale from 1-5 (with 1 being "like a native speaker of the language" and 5 being "very foreign") how would you rate your skills today in the foreign language in terms of:

	Like native speaker				Very foreign
a. General proficiency:	1	2	3	4	5
b. Pronunciation:	1	2	3	4	5
c. Grammar:	1	2	3	4	5
d. Comprehension:	1	2	3	4	5
e. Reading:	1	2	3	4	5

Comments if you have any: ____________________

Regarding Language B:
On a scale from 1-5 (with 1 being "like a native speaker of the language" and 5 being "very foreign") how would you rate your skills today in the foreign language in terms of:

	Like native speaker				Very foreign
a. General proficiency:	1	2	3	4	5
b. Pronunciation:	1	2	3	4	5
c. Grammar:	1	2	3	4	5
d. Comprehension:	1	2	3	4	5
e. Reading:	1	2	3	4	5

Comments if you have any: ____________________

Regarding Language C:
On a scale from 1-5 (with 1 being "like a native speaker of the language" and 5 being "very foreign") how would you rate your skills today in the foreign language in terms of:

	Like native speaker				Very foreign
a. General proficiency:	1	2	3	4	5
b. Pronunciation:	1	2	3	4	5
c. Grammar:	1	2	3	4	5
d. Comprehension:	1	2	3	4	5
e. Reading:	1	2	3	4	5

Comments if you have any: ____________________

Talent

On a scale from 1-5 (with 1 being "very talented" and 5 being "not talented at all") how would you rate your talent for the following skills?:

	Very talented				**Not talented at all**
Ability to imitate sounds in foreign languages	**1**	**2**	**3**	**4**	**5**
Talent in learning languages	**1**	**2**	**3**	**4**	**5**
Musical talent	**1**	**2**	**3**	**4**	**5**

Comments: ____

____

Have you ever studied Phonetics (the scientific study of speech sounds)? **YES / NO**

If YES, have you ever done phonetic transcription? **YES / NO**

If YES, how much? ______________________

Do you have normal hearing (as far as you know)? **YES / NO**

Did you at any time have therapy for a speech, reading or other language problem?______ Please specify: ______________________________

Which hand do you write with? (circle one):	Right	Left	Either
Which hand do you throw a ball with?	Right	Left	Either
Which hand do you wave good-bye with?	Right	Left	Either
Which hand do you hold a spoon in?	Right	Left	Either
Which of these do you consider yourself?	Right-handed	Left-handed	Ambidextrous

Comments if any ______________________________________

What do you consider your racial/ethnic background to be? Check all that apply.
(Optional: You need not answer)

Caucasian ___ Native American ___
African American ___ Pacific Islander _____
Hispanic ___ Asian American _____
Other—please specify ____________________

Appendix L. ANOVA for Internal Consistency of /y/

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Intercept	17566.204	1	17566.204	1814.006	.000
Language experience	10.922	2	5.461	.564	.574
Error	348.612	36	9.684		

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
y context	150.037	1	150.037	28.298	*.000
context X language	5.170	2	2.585	.488	.618
Error	190.873	36	5.302		

Appendix M. ANOVA for Internal Consistency of /œ/

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Intercept	13561.696	1	13561.696	1040.450	.000
Language experience	208.819	2	104.409	8.010	.001
Error	469.240	36	13.034		

Planned Comparisons (Simple Contrasts) on Language Experience

	Difference	Standard Err	Significance
NoExp vs ModExp	-.226	1.001	.823
ModExp vs HiExp	-3.578	1.001	*.001
NoExp vs HiExp	-3.352	1.001	*.002

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
œ context	3.766	1	3.766	.628	.433
context X Language	142.370	2	71.185	11.876	*.000
Error	215.781	36	5.994		

Appendix N. ANOVA for Front Rounded Vowels Paired with Back Vowels
(/y-u/, /œ-o/, /y-o/, /œ-u/)

Tests of Within-Subjects Effects (Vowel Pair)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Vowel Pair	6343.308	3	2114.436	28.850	*.000
Vwl Pair X Lang Experience	3833.808	6	638.968	8.718	*.000
Error (Vwlpair)	7915.385	108	73.291		

Tests of Between-Subjects Effects (Language Experience)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	38226.692	1	38226.692	222.547	*.000
Language Experience	7679.115	2	3839.558	22.353	*.000
Error	6183.692	36	171.769		

Planned Comparisons (Simple Contrasts) on Language Experience

	Difference (Estimate-Hypothesized)	Standard Err	Significance
NoExp vs ModExp:	3.8269	2.5703	.145
ModExp vs HiExp	-12.5962	2.5703	*.000
NoExp vs HiExp	16.4231	2.5703	*.000

Planned Comparisons (Simple Contrasts) on Vowel Pair

	Type III Sum of Squares	DF	Mean Square	F	Significance
/y-u/ vs /œ-u/	1602.564	1	1602.564	7.851	*.008
/œ-o / vs /œ-u/	315.923	1	315.923	2.288	.139
/y-o/ vs /œ-u/	11067.923	1	11067.923	90.988	*.000
/y-u/ vs /y-o/	4247.410	1	4247.410	24.757	*.000
/œ-o/ vs /y-o/	7644.00	1	7644.00	116.429	*.000

Appendix O. ANOVA For /y-u/ Pair

Tests of Between-Subjects Effects (/y-u/)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	7981.038	1	7981.038	2904.453	000
Language Experience	8.538	2	4.269	1.554	.225
Error	98.923	36	2.748		

Tests of Within-Subjects Effects (/y-u/)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
yu context	92.628	1	92.628	49.261	*.000
yu X Language	4.179	2	2.090	1.111	.340
Error (yu)	67.692	36	1.880		

Appendix P. ANOVA for /y-o/ Pair

Tests of Between-Subjects Effects (/y-o/)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	2516.013	1	2516.013	5352.245	.000
Language experience	1.564	2	.782	1.664	.204
Error	16.923	36	.470		

Tests of Within-Subjects Effects (/y-o/)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
y-o context	1.038	1	1.038	2.150	.151
y-o X Language	7.692E-02	2	3.86E-02	.080	.924
Error (yo)	17.385	36	.483		

Appendix Q. ANOVAs for /œ-o/ Pair

Tests of Between-Subjects Effects (/œ-o/)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	7308.013	1	7308.013	3045.548	.000
Language experience	160.103	2	80.051	33.361	*.000
Error	86.385	36	2.400		

Planned Comparisons (Simple Contrasts) on Language Experience

	Difference (Estimate-Hypothesized)	Standard Err	Significance
NoExp vs ModExp	1.231	.430	*.007
ModExp vs HiExp	-2.231	.430	*.000
NoExp vs HiExp	-3.462	.430	*.000

Tests of Within-Subjects Effects (/œ-o/)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
œ-o context	30.782	1	30.782	18.881	*.000
CntxtX Language	5.026	2	2.513	1.541	.228
Error (œ-o)	58.692	36	1.630		

2X2 analysis without HiExp group

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Language experience	19.692	1	19.692	6.095	*.021
Error	77.538	24	3.231		

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
œ-o context	33.923	1	33.923	14.782	*.001
CntextXLanguage	.0	1	.0000	.000	1.000
Error (œ-o)	55.077	24	2.295		

Appendix R. ANOVA for /œ-u/ Pair

Tests of Between-Subjects Effects (/œ-u/)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1698.667	1	1698.667	1635.753	.000
Language experience	38.949	2	19.474	18.753	*.000
Error	37.385	36	1.038		

Planned Comparisons (Simple Contrasts) on Language Experience

	Difference	Standard Err	Significance
NoExp vs ModExp	.269	.283	.347
ModExp vs HiExp	-1.346	.283	*.000
NoExp vs HiExp	-1.615	.283	*.000

Tests of Within-Subjects Effects (/œ-u/)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
œ-u context	.462	1	.462	.486	.490
œ-u X Language	2.385	2	1.192	1.257	.297
Error (œ-u)	34.154	36	.949		

2X2 analysis without HiExp group

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Language experience	.942	1	.942	.780	.386
Error	29.000	24	1.208		

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
œ-u context	1.923E-02	1	1.923E-02	.016	.900
CntextXLanguage	.942	1	.942	.792	.382
Error (œ-u)	28.538	24	1.189		

Appendix S. Perceptual Assimilation and Categorial Discrimination Performance on Parisian French /i-y/ by American English Individuals with no French Language Experience in Present Experiment

PRESENT STUDY

Lang. group name	Cons. context	Vowel pair	Partici-pant	Percent /y/ PA to /i/	Discrim percent errors	Discrim worse (-), better (+) or equal (=) in bp vs dt
No Exp	bp	y i	101	0	16.7	-
No Exp	dt	y i	101	0	0.0	
No Exp	bp	y i	102	6	25.0	-
No Exp	dt	y i	102	0	8.3	
No Exp	bp	y i	103	0	0.0	=
No Exp	dt	y i	103	0	0.0	
No Exp	bp	y i	104	17	8.3	=
No Exp	dt	y i	104	6	8.3	
No Exp	bp	y i	105	6	8.3	-
No Exp	dt	y i	105	0	0.0	
No Exp	bp	y i	106	17	16.7	+
No Exp	dt	y i	106	6	25.0	
No Exp	bp	y i	107	0	0.0	=
No Exp	dt	y i	107	0	0.0	
No Exp	bp	y i	108	0	8.3	=
No Exp	dt	y i	108	0	8.3	
No Exp	bp	y i	109	0	16.7	-
No Exp	dt	y i	109	0	8.3	
No Exp	bp	y i	110	0	0.0	=
No Exp	dt	y i	110	0	0.0	
No Exp	bp	y i	111	100	33.3	-
No Exp	dt	y i	111	0	0.0	
No Exp	bp	y i	112	6	0.0	=
No Exp	dt	y i	112	0	0.0	
No Exp	bp	y i	113	0	0.0	=
No Exp	dt	y i	113	0	0.0	

5 X worse, 1 X better, 7 X equal

Appendix T. Categorial Discrimination Performance on Parisian French /i-y/ Contrast by American English Individuals with no French Language Experience in Levy & Strange (2002)

LEVY & STRANGE, 2002

Lang. group name	Cons. context	Vowel pair	Partici-pant	Discrim score	Discrim percent errors	Discrim worse (-), better (+) or equal (=) in bp vs dt
Inexp	bp	y i	01eebp	9	25.0	-
Inexp	dt	y i	01eedt	11	8.3	
Inexp	bp	y i	02eebp	12	0.0	=
Inexp	dt	y i	02eedt	12	0.0	
Inexp	bp	y i	03eebp	10	16.7	-
Inexp	dt	y i	03eedt	12	0.0	
Inexp	bp	y i	05eebp	9	25.0	-
Inexp	dt	y i	05eedt	12	0.0	
Inexp	bp	y i	06eebp	11	8.3	-
Inexp	dt	y i	06eedt	12	0.0	
Inexp	bp	y i	07eebp	6	50.0	-
Inexp	dt	y i	07eedt	10	16.7	
Inexp	bp	y i	08eebp	8	33.3	+
Inexp	dt	y i	08eedt	6	50.0	
Inexp	bp	y i	09eebp	6	50.0	-
Inexp	dt	y i	09eedt	11	8.3	
Inexp	bp	y i	10eebp	11	8.3	-
Inexp	dt	y i	10eedt	12	0.0	
Inexp	bp	y i	11eebp	9	25.0	-
Inexp	dt	y i	11eedt	12	0.0	

8 X worse, 1 X better, 1 X equal

Appendix U. ANOVA for /y-œ/ Pair

Tests of Between-Subjects Effects (/y-œ/

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Intercept	8683.705	1	8683.705	3791.021	.000
LANGUAGE	41.333	2	9.022	9.022	*.001
Error	82.462	36			

Tests of Within-Subjects Effects (/y-œ/)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
y-œ context	15.705	1	15.705	8.390	*.006
y-œ X Language	4.410	2	2.205	1.178	.319
Error (œ-y)	67.385	36	1.872		

Planned Comparisons (Simple Contrasts) on Language Experience

	Difference (Estimate-Hypothesized)	Standard Err	Significance
NoExp vs ModExp	-1.346	3.515	.704
ModExp vs HiExp	-1.462	3.515	*.001
NoExp vs HiExp	-1.615	3.515	*.000

2X2 Analysis Without HiExp Group

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Language experience	23.558	1	23.558	.116	.737
Error	4454.385	24	185.599		

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
y-œ context	1391.558	1	1391.558	7.498	*.011
CntextXLanguage	5.558	1	5.558	.030	.864
Error (y-œ)	4454.385	24	185.599		

Appendix V. ANOVAs for /a-ε/ Pair

Tests of Between-Subjects Effects (/a-ε/)

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Intercept	2261.538	1	2261.538	6573.913	.000
Language experience	14.077	2	7.038	20.460	*.000
Error	12.385	36	.344		

Planned Comparisons (Simple Contrasts) on Language Experience

	Difference (Estimate-Hypothesized)	Standard Err	Significance
NoExp vs ModExp	-9.577	2.711	*001
ModExp vs HiExp	7.692	2.711	*007
NoExp vs HiExp	17.269	2.711	*000

Tests of Within-Subjects Effects (/a-ε/)

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
/a-ε/ context	66.205	1	6.2.5	11.300	*.002
CntxtX Language	2.026	2	1.013	1.844	.173
Error (a-ε)	19.769	36	.549		

2X2 analysis without HiExp group

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Language experience	1192.327	1	1192.327	9.210	*.006
Error	3107.000	24	129.458		

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
/a-ε/ context	1908.173	1	1908.13	9.020	*.006
CntextXLanguage	272.327	1	272.327	1.287	.268
Error (œ-o)	5077.000	24	211.542		

Appendix W. Calculation of Perceptual Assimilation Overlap

1. /y-u/ **PA Overlap calculation**	**PA Overlap score**	**CD % Errors**	**PA Overlap calculation**	**PA Overlap score**	**CD % Errors**
NO EXP BP y→ju 79.9% u **6.8%** u→ju **6.4%** u 90.2% both→ i **.4%** U **1.7**	**15.3**	**5**	**NO EXP DT** y→ju 65.4% u **30.8%** u→ju **9.4%** u 83.8% both→ i **.4** U **1.7%**	**42.3**	**27**
MOD EXP BP y→ju 84.6% u **12.8%** u→ju **3.4%** u 84.6% both→ i. % **.4** U **1.7%**	**18.3**	**9**	**MOD EXP DT** y→ju 71.4% u **23.9%** u→ju **14.5%** u 75.2 both→ U **3.4%**	**41.8**	**29**
HI EXP BP y→ju 71.8% u **%28.2** u→ju **%0** u %77.8	**28.2**	**6**	**HI EXP DT** y→ju 60.7% u **33.8%** u→ju **4.7%** u 91.5 both→ U **3.4%**	**41.9**	**19**

2. /y-o/ **PA Overlap calculation**	**PA Overlap score**	**CD % Errors**	**PA Overlap calculation**	**PA Overlap score**	**CD % Errors**
NO EXP BP both→u **6.8** U **1.7**	**8.5**	**6**	**NO EXP DT** both→u **30.8** U **1.7**	**32.5**	**10**
MOD EXP BP both→u **12.8** U **1.7**	**14.5**	**3**	**MOD EXP DT** both→u **19.2** U **3.4**	**22.6**	**8**
HI EXP BP both→u U	**.9**	1	HI EXP DT both→u 0 U **1.7**	**1.7**	**4**

3. /œ-o/ PA Overlap calculation	PA Overlap score	CD % Errors	PA Overlap calculation	PA Overlap score	CD % Errors
NO EXP BP œ→o **7.7** o→o 23.9 both to u **33.8** ε **.4** ʌ **.4** U **8.1**	**50.4**	**26**	**NO EXP DT** œ→o **16.7** o→o 40.6 both to u **43.2** **U 6**	**65.9**	**39**
MOD EXP BP œ→o **5.6** o→o 71.4 both to u **11.1** ʌ **1.3** U **6.8**	**24.8**	**15**	**MOD EXP DT** œ→o **25.2** o→o 69.2 both to u **19.2** ʌ **.9** U **4.7**	**50**	**29**
HI EXP BP œ→o **1.7** o→o 98.7 both to u **.9** U **.4**	**3**	**1**	HI EXP DT œ→o **2.1** o→o 97.9 both to U **1.7**	**3.8**	**6**

4. /œ-u/ PA Overlap calculation	PA Overlap score	CD % Errors	PA Overlap calculation	PA Overlap score	CD % Errors
NO EXP BP œ→u **33.8** u→u 90.2 both to o **7.7** ε **.4** ʌ **.4** U **8.1**	**50.4**	**31**	**NO EXP DT** œ→u **58.5** u→u 83.8 both to o **16.7** U **6**	**81.2**	**35**
MOD EXP BP œ→u **11.1** u→u 84.6 both to o **5.6** ʌ **1.3** U **6.8**	**24.8**	**31**	**MOD EXP DT** œ→u **23.1** u→u 75.2 both to o **25.2** ʌ **.9** U **4.7**	**53.9**	**26**

HI EXP BP œ→u 3 u→u 77.8 both to o 1.7 U .4	5.1	1	HI EXP DT œ→u 8.5 u→u 91.5 both to o 2.1 U 1.7	12.3	10

5. /y-i/ PA Overlap calculation	PA Overlap score	CD % Errors	PA Overlap calculation	PA Overlap score	CD % Errors
NO EXP BP y→i 11.5 i→i 98.3	11.5	10	NO EXP DT y→i .9 i→i 97	.9	4
MOD EXP BP y→i .4 i→i 99.1	.4	1	MOD EXP DT y→i 1.3 i→i 97.9	1.3	1
HI EXP BP y→i 0 i→i 99.6	0	0	HI EXP DT y→i 0 i→i 98.7	0	0

6. /y-ε/ PA Overlap calculation	PA Overlap score	CD % Errors	PA Overlap calculation	PA Overlap score	CD % Errors
NO EXP BP y→ε 1.7 ε→ε 79.1 both to i .4	2.1	3	NO EXP DT y→ε 0 ε→ε 76.5 both to i .4	.4	0
MOD EXP BP y→ε 0 ε→ε 85.5	0	1	MOD EXP DT y→ε 0 ε→ε 90.2	0	1
HI EXP BP y→ε 0 ε→ε 88.9	0	0	HI EXP DT y→ε 0 ε→ε 94.9 both to i .9	.9	0

7. /œ-ε/ PA Overlap calculation	PA Overlap score	CD % Errors	PA Overlap calculation	PA Overlap score	CD % Errors

NO EXP BP œ→ε .4 ε→ε 79.1 both to ɪ .4	**.8**	**6**	**NO EXP DT** œ→ε **.4** ε→ε 76.5 both to ɪ **.4**	**.8**	**0**
MOD EXP BP œ→ε **1.3** ε→ε 85.5 both to ɪ **.4**	**1.7**	**3**	**MOD EXP DT** œ→ε **0** ε→ε 90.2 both to ɪ **.4**	**.4**	**1**
HI EXP BP œ→ε **0** ε→ε 88.9	**0**	**1**	HI EXP DT œ→ε .9 ε→ε 94.9	**0**	**1**

8. /œ-i/ **PA Overlap calculation**	**PA Overlap score**	**CD % Errors**	**PA Overlap calculation**	**PA Overlap score**	**CD % Errors**
NO EXP BP 0 overlap	**0**	**0**	**NO EXP DT** 0 overlap	**0**	**0**
MOD EXP BP 0 overlap	**0**	**3**	**MOD EXP DT** 0 overlap	**0**	**3**
HI EXP BP 0 overlap	**0**	**0**	HI EXP DT 0 overlap	**0**	**1**

9. /y-œ/ **PA Overlap calculation**	**PA Overlap score**	**CD % Errors**	**PA Overlap calculation**	**PA Overlap score**	**CD % Errors**
NO EXP BP Both to U **1.7** u **6.8** ju **9**	**17.5**	**12**	**NO EXP DT** Both to U **1.7** u **30.8** ju **6.8**	**39.3**	**22**
MOD EXP BP Both to U **1.7** u **11.1** ju **3.4**	**16.2**	**10**	**MOD EXP DT** Both to U **3.4** u **23.1** ju **3.8**	**30.3**	**21**
HI EXP BP Both to U **.4** u **3**	**3.4**	**3**	**HI EXP DT** Both to U **5.6** u **8.5**	**14.1**	**4**

10. /a-ɛ/ **PA Overlap calculation**	**PA Overlap score**	**CD % Errors**	**PA Overlap calculation**	**PA Overlap score**	**CD % Errors**
NO EXP BP a→ɛ **5.1** ɛ→ɛ 79.1 both to æ **12.4**	**17.5**	**15**	**NO EXP DT** a→ɛ **11.5** ɛ→ɛ 76.5 both to æ **9.8**	**21.3**	**23**
MOD EXP BP a→ɛ **8.1** ɛ→ɛ 85.5 both to æ **3**	**11.1**	**1**	**MOD EXP DT** a→ɛ **18.4** ɛ→ɛ 90.2 both to i **.4** æ **0**	**18.8**	**18**
HI EXP BP a→ɛ **.9** ɛ→ɛ 88.9 both to æ 0	.9	**0**	HI EXP DT a→ɛ **1.7** ɛ→ɛ 94.9 both to æ **.9**	**2.6**	**4**

11. /u-i/ **PA Overlap calculation**	**PA Overlap score**	**CD % Errors**	**PA Overlap calculation**	**PA Overlap score**	**CD % Errors**
NO EXP BP Both to u: **0** i: **.4**	**.4**	**0**	**NO EXP DT** Both to u: **0** i: **.4**	**.4**	**1**
MOD EXP BP Both to u: **0** i: **0**	**0**	**0**	**MOD EXP DT** Both to u: **0** i: **0**	**0**	**1**
HI EXP BP Both to u: **0** i: **0**	**0**	**0**	HI EXP DT Both to u: **0** i: **0**	**0**	**0**

Appendix X. Correlation in Bilabial /rabVp/ Context

No Exp Group			**PA % Overlap /rabVp/ Context**	**CD % Errors /rabVp/ Context**
Spear-man's rho	overlap bp	Correlation Coefficient	1.000	.913
		Sig. (2-tailed)	.	.000
		N	11	11
	errors CD bp	Correlation Coefficient	.913	1.000
		Sig. (2-tailed)	.000	.
		N	11	11

** Correlation is significant at the .01 level (2-tailed).

ModExp Group			**PA % Overlap /rabVp/ Context**	**CD % Errors /rabVp/ Context**
Spear-man's rho	overlap bp	Correlation Coefficient	1.000	.848
		Sig. (2-tailed)	.	.001
		N	11	11
	errors CD bp	Correlation Coefficient	.848	1.000
		Sig. (2-tailed)	.001	.
		N	11	11

** Correlation is significant at the .01 level (2-tailed).

Hi Exp Group			**PA % Overlap /rabVp/ Context**	**CD % Errors /rabVp/ Context**
Spear-man's rho	overlap bp	Correlation Coefficient	1.000	.785
		Sig. (2-tailed)	.	.004
		N	11	11
	errors CD bp	Correlation Coefficient	.785	1.000
		Sig. (2-tailed)	.004	.
		N	11	11

** Correlation is significant at the .01 level (2-tailed).

Appendix Y. Correlation in Alveolar /radVt/ Context

No Exp Group			**PA % Overlap /radVt/ Context**	**CD % Errors /radVt/ Context**
Spear-man's rho	overlap dt	Correlation Coefficient	1.000	.929
		Sig. (2-tailed)	.	.000
		N	11	11
	errors CD dt	Correlation Coefficient	.929	1.000
		Sig. (2-tailed)	.000	.
		N	11	11

** Correlation is significant at the .01 level (2-tailed).

Mod Exp Group			**PA % Overlap /radVt/ Context**	**CD % Errors /radVt/ Context**
Spear-man's rho	overlap dt	Correlation Coefficient	1.000	.875
		Sig. (2-tailed)	.	.000
		N	11	11
	errors CD dt	Correlation Coefficient	.875	1.000
		Sig. (2-tailed)	.000	.
		N	11	11

** Correlation is significant at the .01 level (2-tailed).

HiExp Group			**PA % Overlap /radVt/ Context**	**CD % Errors /radVt/ Context**
Spear-man's rho	overlap dt	Correlation Coefficient	1.000	.860
		Sig. (2-tailed)	.	.001
		N	11	11
	errors CD dt	Correlation Coefficient	.860	1.000
		Sig. (2-tailed)	.001	.
		N	11	11

** Correlation is significant at the .01 level (2-tailed).

8. References

Best, C. T. (1990). Adult perception of nonnative contrasts differing in assimilation to native phonological categories. *Journal of the Acoustical Society of America, 88,* S177.

Best, C. T. (1994). The emergence of native-language phonological influences in infants: A perceptual assimilation model. In J. Goodman & H. C. Nusbaum, (Eds.), *The development of speech perception: The transition from speech sounds to spoken words,* Cambridge, MA: MIT Press.

Best, C. T. (1995). A direct realist view of cross-language speech perception. In W. Strange (Ed.), *Speech perception and linguistic experience: Issues in cross-language research.* Baltimore: York Press.

Best, C. T., Faber, A., & Levitt, A. (1996, May). *Perceptual assimilation of non-native vowel contrasts to the American English Vowel System.* Paper presented at the meeting of the Acoustical Society of America, Indianapolis, IN.

Best, C. T., McRoberts, G. W., & Sithole, N. N. (1988). The phonological basis of perceptual loss for non-native contrasts: Maintenance of discrimination among Zulu clicks by English-speaking adults and infants. *Journal of Experimental Psychology: Human Perception and Performance, 14,* 345-360.

Best, C. T., & Strange, W. (1992). Effects of phonological and phonetic factors on cross-language perception of approximants. *Journal of Phonetics, 20,* 305-330.

Bradlow, A. R., Pisoni, D. B., Akahane-Yamada, R., & Tohkura, Y. (1997). Training Japanese listeners to identify English /r/ and /l/: IV. Some effects of perceptual learning on speech production. *Journal of the Acoustical Society of America, 101,* 2299-2310.

Bradlow, A. R., Pisoni, D. B., Akahane-Yamada, R., & Tohkura, Y. (1999). Training Japanese listeners to identify English /r/ and /l/: Long-term retention of learning in perception and production. *Perception & Psychophysics, 61,* 977-985.

Flege, J. E. (1987). The production of "new" and "similar" phones in a foreign language: Evidence for the effect of equivalence classification. *Journal of Phonetics, 15,* 47-65.

Flege, J. E. (1995). Second language speech learning: Theory, findings, and problems. In W. Strange (Ed.), *Speech perception and linguistic experience: Issues in cross-language research.* Baltimore: York Press.

Flege, J. E. & Hillenbrand, J. (1984). Limits on phonetic accuracy in foreign language speech production. *Journal of the Acoustical Society of America, 76,* 708-721.

Gottfried, T. L. (1984). Effects of consonant context on the perception of French vowels. *Journal of Phonetics, 12,* 91-114.

Guion, S. G., Flege, J. E., Akahane-Yamada, R., & Pruitt, J. C. (2000). An investigation of current models of second language speech perception: The case of Japanese adults' perception of English consonants. *Journal of the Acoustical Society of America, 107,* 2711-2724.

Hillenbrand, J. M, Clark, M. J., & Nearey, T. M. (2001). Effects of consonant environment on vowel formant pattern. *Journal of the Acoustical Society of America, 109,* 748-763.

Jenkins, J. J. & Yeni-Komshian (1995). Cross-language speech perception: Perspective and promise. In W. Strange (Ed.), *Speech perception and linguistic experience: Issues in cross-language research.* Baltimore, MD: York Press.

Levy, E. & Strange, W. (2002). Effects of consonantal context on perception of French rounded vowels by American English adults with and without French language experience. *Journal of the Acoustical Society of America, 111,* 2361-2362.

Lisker, L., & Abramson, A. S. (1964). A cross-language study of voicing in initial stops: Acoustical measurements. *Word, 20,* 384-422.

Pisoni, D. B., Lively, S. E. & Logan, J. S. (1994). Perceptual learning of nonnative speech contrasts: Implications for theories of speech perception. In J. Goodman & H. C. Nusbaum, (Eds.), *The development of speech perception: The transition from speech sounds to spoken words,* Cambridge, MA: MIT Press.

Polka, L. (1995). Linguistic influences in adult perception of non-native vowel contrasts. *Journal of the Acoustical Society of America, 97,* 1286-1296.

Polka, L. & Bohn, O.-S. (1996). A cross-language comparison of vowel perception in English-learning and German-learning infants. *Journal of the Acoustical Society of America, 100,* 577-592.

Polka, L. & Werker, J. F. (1994). Developmental changes in perception of non-native vowel contrasts. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 421-435.

Rochet, B. L. (1995). Perception and production of second-language speech sounds by adults. In W. Strange (Ed.), *Speech perception and linguistic experience: Issues in cross-language research.* Baltimore: York Press.

Rvachew, S. (1994). Speech perception training can facilitate sound production learning. *Journal of Speech and Hearing Research, 37:* 347-57.

Rvachew, S. & Jamieson, D. G. (1995). Learning new speech contrasts: Evidence from adults learning a second language and children with speech disorders. In W.

Strange (Ed.), *Speech perception and linguistic experience: Issues in cross-language research.* Baltimore: York Press.

Southwood, M. H. & Flege, J. E. (1999). Scaling foreign accent: Direct magnitude estmation vs interval scaling. *Clinical Linguistics and Phonetics,* 13, 335-449.

Stevens, K. N., Liberman, A. M., Studdert-Kennedy, M., & Öhman, S. (1969). Cross-language study of vowel perception. *Language and Speech 12,* 1-23.

Strange, W. (1992). Learning non-native phoneme contrasts: Interactions among subject, stimulus, and task variables. In Y. Tohkura, E. Vatikiotis-Bateson, & Y. Sagisaka, (Eds.), *Speech perception, production and linguistic structure.* Tokyo, Japan: Ohm Publishing Co. Ltd.

Strange, W., & Akahane-Yamada, R. (1997). Effects of identification training on Japanese adults' perception of American English vowels. *Journal of the Acoustical Society of America, 102,* 3137.

Strange, W., Akahane-Yamada, R., Kubo, R., Trent, S.A., & Nishi, K. (2001). Effects of consonantal context on perceptual assimilation of American English vowels by Japanese listeners. *Journal of the Acoustical Society of America, 109,* 1691-1704.

Strange, W., Bohn, O-S., Trent, S.A., & Nishi, K. (2004). Acoustic and perceptual similarity of North German and American English vowels. *Journal of the Acoustical Society of America, 115,* 1791-1807.

Strange, W., Bohn, O-S., Nishi, K., & Trent, S.A. (forthcoming). Contextual variation in the acoustic and perceptual similarity of North German and American English vowels. *Journal of the Acoustical Society of America.*

Strange, W., Levy, E., Weber, A., Lehnhoff Jr., R., & Law II, F. (in progress). Perceptual assimilation of French and German vowels by American English listeners: Acoustic similarity does not predict perceptual similarity. *Journal of the Acoustical Society of America* (abstract forthcoming).

Strange, W., Weber, A., Levy, E. S., Shafiro, V., & Nishi, K. (2002). Within- and across-language acoustic variability of vowels spoken in different phonetic and prosodic contexts: American English, Northern German, and Parisian French [Abstract]. *Journal of the Acoustical Society of America, 112,* 2384.

Trofimovich, P., Baker, W., & Mack, M. (2001). Context- and experience-based effects on the learning of vowels in a second language. *Studies in the Linguistic Sciences,* 31, 167-186.