# PERCEPTION OF CANADIAN-FRENCH WORD-FINAL VOWELS IN LEXICAL AND MORPHOSYNTACTIC MINIMAL PAIRS BY CANADIAN ENGLISH LEARNERS OF FRENCH

by

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**Abstract**

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This study investigated the perception of Canadian French word-final vowels by English-dominant and French-dominant bilinguals living in Montreal. In a modified identification task, listeners selected the response that rhymed with the target word, embedded in a carrier sentence. Minimal sets of real and nonsense target words were used, contrasting in word-final vowel /i, e, ɛ, a, o, u, y, ø/ preceded by labial, coronal and back stop consonants and /ʁ/, as well as morphosyntactic verb minimal pairs contrasting in word-final /e-ɛ/ following /ʁ/ (e.g., *parlerai* "I will talk" v. *parlerais* "I would talk"). Differences in accuracy and speed for identifying experimental vowels /e, ɛ, o, u, y, ø/ were investigated, relative to control vowels /i, a/, expected to be easiest and fastest to identify by both groups. Of interest was performance on front-rounded vowels /y, ø/, which are non-phonemic in English, and /e-ɛ/, which are phonologically contrastive in both languages, but /ɛ/ is disallowed word-finally in English.

Both groups were highly accurate in identifying experimental vowels, although the French-dominant group was comparatively more accurate and faster. For the English-dominant group, overall accuracy correlated with participants' perceived accentedness and fluency in French. The French-dominant group was more accurate than the English-dominant group in identifying /e-ɛ/ in both lexical and morphological tokens. The English-dominant group was slower than the French-dominant group in identifying /y/ and /e/. Mouse cursor movements were captured trial-by-trial to analyze online perceptual processing. For instance, mouse track patterns of both groups was less-direct when identifying /y/, and participants of both groups often moved the cursor towards the response button for /u/ before correctly identifying /y/. The findings in this study contribute to the understanding of phonological processing by bilinguals, in exploring automaticity in vowel perception relative to language dominance. The fast, accurate perception of /ø/ by English-dominant participants is evidence of the development and stability in perception of this phoneme. The English-dominant group demonstrated less-automatic perception of most experimental vowels. However, even performance speed and mouse patterns of the French-dominant group varied among native vowel categories, implying possible interactions between automaticity and auditory salience of particular vowel contrasts.

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# Chapter 1: Literature Review

## 1.1. Introduction

Previous studies have shown that late learners of a second language (L2) have persistent problems in differentiating certain non-native vowel pairs, due to interference from highly over-learned, automatic patterns of perception in their primary language (L1) (see for review: Munro & Bohn, 2007; Strange, 2010, 1995). These studies have explored the effects of L1 interference on vowel perception at the phonological/phonetic level of processing using real or nonsense-word minimal pairs and tasks that focus the listeners' attention to the phonetic identity of the vowels. There are certain vowel contrasts phonemic in French that are known to be difficult for English listeners to distinguish, even after extensive experience with French. The present study investigated the cross-linguistic speech perception patterns of English-French bilinguals who consider themselves English-dominant, focusing specifically on the perception of French vowels in word-final position. An identification task was employed, using L2 responses that are phonemically transcribed as the target vowels (e.g., response "ai" is transcribed /e/). Percent correct was used as a dependent measure. In addition, reaction time, reaction-time difference scores and per-trial mouse tracking patterns were collected as more sensitive measures of the perception process. Effects of word type (real v. nonsense) and preceding consonantal context on perceptual patterns were explored.

Whereas many studies focus on specific non-native contrasts, this study explored all eight oral vowels that can occur word-finally in Canadian French: /i, e, ɛ, a, o, u, y, ø/. The word-final phonotactic position was chosen because consonant-vowel (CV) syllable structure is preferred in French (Delattre, 1953); over 80% of all syllables in French end in a vowel (Léon, 1966) and over 70% of printed words in French end phonetically in a vowel (Juilland, 1965). Moreover, vowels in word-final position are lexically, as well as morphologically, contrastive. For instance, French /e-ɛ/

distinguishes lexical (e.g., *fée* /fe/ "fairy" v. *fais* /fɛ/ "you (sg.) make"), as well as morphological (e.g. *je parlerai* /e/ "I will talk" v. *je parlerais*/ɛ/ "I would talk") contrasts. In English, only 44% of syllables end in a vowel (Dauer, 1983). Many experiments reviewed below have investigated L2 perception of French vowels only in CVC context (e.g., Levy, 2009b; Levy & Strange, 2008). Although English vowels (including tense vowels) are more easily identified and discriminated in closed syllables than in open syllable by native listeners (Gottfried, 1982), French vowels are more easily perceived in open-syllable context by native French listeners, as well as by naïve English and bilingual French-English speakers (Gottfried, 1984). By exploring perception of French vowels in word-final context, the present study broadens the understanding of L2 perceptual patterns.

In exploring the perceptual patterns of these eight vowels by French-English bilinguals, it was of interest to determine whether these listeners would be influenced by their English perceptual patterns, leading to difficulties in differentiating the non-phonemic French front-rounded vowels from each other (i.e., confusions between French /y-ø/), as well as confusions between these front-rounded vowels and back-rounded vowels (i.e., /y-u/ and /ø-u/) and front vowels (i.e., /i-y/) (Levy, 2009b). Furthermore, even though the vowels /e, ɛ, o/ are phonemic in both French and English, English listeners tend to perceive these vowels in French as a spectrally higher English vowel (e.g., French /e/ is heard as English /i/: (Levy, 2009a; Strange, Levy, & Law II, 2009). Consequently, some listeners might have difficulty in reliably identifying these vowels in French. Furthermore, /ɛ/ is phonotactically disallowed word-finally in English, making the /e-ɛ/ contrast even more difficult in this phonotactic environment. This contrast is preserved in word-final position for Canadian French, with /ɛ/ often lowering to maintain the distinction (Boshoer, 2004; Harley & Swain, 1978; Martin, 2002; Walker, 1984). Participants were predicted to have relatively little difficulty in identifying French vowels /i/ and /a/, due to their perceived similarity to phones in both languages (Gottfried, 1984; Strange et al., 2009).

The theoretical framework for the present study and perception studies on French vowels are outlined, with supporting data from methodologies that include discriminant analysis, perceptual assimilation, and discrimination of French vowels. It should be noted that, even though results from discrimination studies discussed below will be used to form hypotheses for the present study, an identification task does not explicitly ask the listener to choose between only two phonemes. Therefore, perceptual confusions are expected to be even more evident in the present study, as vowels will not be presented pairwise in a contrastive fashion, but the participant must chose among all eight possible vowels in each experimental trial. It is even more likely, for instance, that the spectrally higher French vowels will be misperceived more often than in a discrimination task. This perceptual difficulty was more evident in perceptual assimilation studies that also do not expressly test perception of vowel contrasts (Escudero & Polka, 2003; Levy, 2009a; Strange et al., 2009). Evidence of interactions of perceptual accuracy with experience with the non-native language, phonetic/phonotactic context, and stimulus complexity is also discussed.

### 1.2. Perception of French vowels by English Listeners

The Perceptual Assimilation Model (Best, 1994, 1995) is a useful framework for predicting which vowel contrasts will be difficult for an L2 learner to discriminate and which will be relatively easy. In perceptual assimilation experiments, the participant is asked to categorize the phonemes of the L2, using the phonological labels of the listener's L1. A novel phoneme can be either *categorizable* (i.e., consistently assimilated to the same native category), *uncategorizable* (i.e., not consistently assimilated to any one native category), or *nonassimiated* (i.e., not perceived as speech-like).

If two L2 phones are both consistently categorized to a *single* native category, it is hypothesized that discrimination between the non-native phonemes will be very difficult. If both are assimilated to the same native category, but one non-native phoneme is a better fit to the native category than the other phoneme, this is described as a *category-goodness* assimilation pattern. Discrimination of this nonnative contrast can range from relatively difficult to relatively easy, depending on how poor a fit the non-native phoneme is to the native category. If the two non-native phonemes are consistently categorized as two different native categories (i.e., the native language biases are sufficient for labeling each phoneme in terms of different native categories), this would be described as a *two-category* assimilation. Because the two non-native phonemes are assimilated to two different categories, it is hypothesized by the model that non-native phonemes with this assimilation pattern would be relatively easy for the non-native listener to discriminate. If only one of the two novel phonemes is uncategorizable, this would also be a two-category assimilation pattern. If both novel phonemes are uncategorizable, difficulty in discrimination would be predicted based on physical (articulatory/acoustic) similarity.

French has a moderate sized vowel inventory with phonemic contrasts that are known to be difficult for native English-speaking L2 learners to master. It was hypothesized that perceptual assimilation patterns of French vowels by English-dominant listeners might be predicted, at least in part, by their relative spectral similarity to English vowel categories. However, perceptual assimilation patterns of naïve listeners for vowels cannot always be predicted by cross-language acoustic similarity, with respect to static spectral parameters, such as formant frequency measures at the vocalic midpoint (Polka, 1995; Strange, Bohn, Trent, & Nishi, 2004). Thus, the studies based on English perceptual assimilation patterns of French vowels were used to predict relative difficulty of French vowel discrimination.

### 1.2.1. Perception of non-native contrasts involving French front-rounded vowels

It has been well established that perception of non-phonemic front-rounded vowels is notoriously difficult for English L2 learners (Flege, 1987; Flege & Hillenbrand, 1984; Levy, 2009b; Polka, 1995; Strange et al., 2004); whereas French has front-rounded /y, ø/[1], front-unrounded /i, e/ and back-rounded /o, u/ vowels, English has front-unrounded and back-rounded, but no front-rounded vowels. Figure 1 illustrates the F1-F2 spectral comparison of French and English vowels. Strange, et al. (2007) used discriminant analysis to quantify spectral similarity of target formant values between French and English vowels. Discriminant analysis is a multivariate regression technique that was used in this study to model perceptual assimilation, based solely on acoustic measurements at syllable centers. Multiple productions of each French oral vowel produced in citation form (i.e., /Vb(ə)/) were used, as well as multiple productions of French vowels in labial and coronal contexts within nonsense words, in word-medial stressed position. These nonsense words were embedded in a carrier phrase. Discriminant analysis was used to classify each token as one of the 11 monophthongal, non-rhotic English vowel categories. The results of discriminant analysis on citation-form materials confirmed that French front-rounded vowels are spectrally most similar to English front vowels (see Figure 1). All tokens of French /y/ were assimilated to English front vowels, as were most tokens of French /œ/. The same was true for discriminant analysis of front-rounded tokens in sentence materials, collapsing across labial and coronal contexts: French /y/ and /œ/ were often classified as front vowels, /y/ in particular. However, discriminant analysis

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[1] The /œ-ø/ distinction is neutralized in most dialects of French. As this study examines vowels in word-final position, the symbol /ø/ will be used to represent the mid front-rounded French vowel. However, the symbol /œ/ is commonly used when discussing the French mid front-rounded vowel in closed syllable position. This convention will be used when discussing studies investigating this vowel in closed-syllable position, although the conclusions drawn from these studies will be applied to predictions for perception of /ø/ in word-final position.

of only sentence materials in coronal context classified many French /y/ and /œ/ tokens as English back vowels, which are allophonically fronted in coronal context.

As a model of perceptual assimilation of French vowels to English vowel categories, discriminant analysis results suggest that English listeners would assimilate French front-rounded vowels to acoustically similar English front-unrounded vowels because both have a relatively high, front tongue position, although English front vowels are always unrounded. However, English listeners tend to perceptually assimilate front-rounded vowels to English back vowels, due to the fact that lip-rounding and tongue backing are redundant cues in English, suggesting that lip-rounding is the dominant articulatory cue for back vowels in English (Rochet, 1995). Strange, Levy, and Law (2009) further investigated the perceptual assimilation patterns of French vowels by participants with no prior knowledge of French, using a subset of the data and the same 11 English vowels used for classification in Strange, et al. (2007). Participants were asked to categorize the French vowels in terms of English categories and to judge how English-like the vowels were. The perceptual patterns of the listeners were different from the discriminant analysis of the citation-form materials, in that French vowels /y/ and /ø/ were predominantly classified as English back vowels, although rated as foreign-sounding. As French back-rounded vowels were also assimilated to English back-rounded vowels, almost all listeners had a category-goodness perceptual assimilation pattern for French front-rounded v. back-rounded vowels (cf. a similar finding for a comparable non-phonemic contrast in German: Polka, 1995; Strange et al., 2004; Strange et al., 2009). Only one English listener (out of eleven) consistently categorized French front-rounded /y/ as English front-unrounded /i/, suggesting that this listener assimilated based on tongue position, rather than lip-rounding. In regard to perceptual assimilation of vowels presented in sentence materials by a different group of participants, the French front-rounded vowels were again predominantly assimilated to English back vowels in both labial and coronal context. French /y/ was classified as a relatively good exemplar of English /u/, although two participants (out of 16) consistently categorized French /y/ as English /i/ in labial context. French /œ/ was predominantly labeled an English back vowel, but was not consistently categorized as a single English category in either citation or sentence materials; the authors posited that /œ/ may be thought of as an uncategorized back vowel. In this way, perceptual assimilation of French vowels in labial context again differed from the discriminant analysis model in Strange, et al. (2007), which found French front-rounded vowels to be spectrally more similar to front-unrounded English vowels.

Levy (2009a) used a similar methodology to Strange, Levy, and Law (2009) and a modified subset of the sentence stimuli used in Strange, et al. (2007). The participant population included participants with no knowledge of French, (hereafter referred to as an Inexperienced group), as well as a group of participants with formal French instruction (hereafter Modexperience), and a group of participants with French immersion experience who were regularly using French in their daily lives (hereafter Experienced). The vowels were embedded in nonsense words and had no semantic relevance for any of the groups tested. The participants classified the French vowels using the 11 English monophthongal vowels and two additional English vowel categories (/$^{j}$u/ and /ɝ/) as response alternatives. In both labial and coronal context, French /y/ was predominantly classified as English /$^{j}$u/ by all language groups. English /u/ was the second most common classification for French /y/ by all groups, except the Inexperienced group in labial context, for whom English /i/ was the second-most common classification. As in Strange, Levy, and Law (2009), French /œ/ was assimilated predominantly to English back vowels, though not predominantly to any one category. An emergence of English /ɝ/ as a common response (i.e., > 10%) was present only for the Experienced group, showing that, at least for some Experienced listeners, French /œ/ is not always assimilated to an English back vowel, but sometimes to a spectrally more similar mid-central vowel.

In summary, naïve English listeners tend to assimilate front-rounded vowels to English back-rounded vowels (Levy, 2009a; Polka, 1995; Rochet, 1995; Strange et al., 2004; Strange et al., 2009), leading to the prediction that L2 learners may readily confuse French /y-u/, /y-ø/, and /ø-u/. In addition, /y-i/ might be difficult for some, but not a majority of listeners, given the vowels' spectral similarity (Strange et al., 2007). Also, as mentioned above, Strange, Levy, and Law (2009) and Levy (2009a) did report assimilation of French /y/ to spectrally similar English /i/ for some listeners. Confusions between French /y/ and /o/ would not be expected, as French /y/ was not assimilated to English /o/ in any of the perceptual assimilation studies summarized above.

Gottfried (1984) designed the first cross-speaker categorial ABX discrimination experiment with French vowels produced in either /tVt/ or /#V#/ (i.e., isolated vowel) context. Gottfried included two experimental groups differing in French experience: Inexperienced and Experienced, in addition to a native French control group. The Inexperienced group made many errors in discrimination of /y-œ/ in both /tVt/ and /#V#/ contexts. This group also made errors on /y-u/ in /tVt/ context; the Experienced group made more errors than the control group but fewer than the Inexperienced group.

A cross-speaker categorial AXB discrimination study of French vowels by Levy (2009b) included three groups, divided by levels of L2 French experience (Inexperienced, Modexperience and Experienced). All language groups made few errors in discriminating front-rounded v. unrounded vowel pairs. Regarding discrimination of front v. back, rounded vowels, all groups performed above chance but not at native-like levels of accuracy on /y-u/and there was no significant difference among groups. The Experienced group made few errors in discriminating all other front-rounded v. back-rounded vowel contrasts, whereas the other two groups made comparatively more errors on all front-rounded v. back-rounded contrasts except /y-o/. Levy

(2009b) also calculated *cross-language assimilation overlap scores*, in order to quantify the proportion of times that two French vowels were assimilated to the same English category. Pairing cross-language assimilation overlap scores with discrimination accuracy for each vowel contrast revealed that a larger cross-language assimilation overlap score was correlated with more discrimination errors, both when calculated across groups and when computed on individual data.

In conclusion, these perception studies support the prediction that front-rounded v. back-rounded vowel contrasts are indeed troublesome for English learners to master, and that certain contrasts (e.g., /y-u/) are more difficult than others, even after extensive French experience.

### 1.2.2. Perception of non-native contrasts involving vowels with phonetically similar native correlates: cross-language phonetic differences

French and English vowels /i, e, ɛ, o, u/ are transcribed using the same International Phonetic Alphabet symbols; however, there are phonetic differences in production that can affect cross-language perceptual patterns. French /i/ and /u/ are acoustically very similar to their English counterparts, especially in labial context (Strange et al., 2007) and are reliably assimilated to them in both labial and coronal contexts (Levy, 2009a; Strange et al., 2009)[2]. As will be expanded upon, French /e, ɛ, o/ are not always assimilated to their English correlates, but are sometimes assimilated to higher English vowels (i.e., higher tongue position, lower F1 value).

In investigating the spectral similarity between French and English /e, ɛ, o/ using the discriminant analysis methodology described above, Strange, et al. (2007) found that for citation-form stimuli, French /e, ɛ, o/ were often classified as spectrally higher English categories. Although

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[2] French /a/ is more centralized than English /ɑ/; nonetheless, French /a/ is overwhelmingly assimilated to English /ɑ/ (Strange et al., 2009).

a majority of French /e/ tokens were classified as English /e/, more than 10% of the French /e/ tokens were classified as English /i/. French /ɛ/ was most often classified as English /ɪ/ and half of French /o/ tokens were classified as English /u/. For discriminant analysis of sentence materials collapsing across phonetic contexts, the pattern of classification to spectrally-higher English phonemic categories was even more pronounced: French /e/, /ɛ/, and /o/ tokens were all classified most often to spectrally higher English vowel categories (French /e/ → English /i/, /ɛ/ → /ɪ/, and /o/ → /u/ or /ʊ/). Note in Figure 1 that the French vowels /e, ɛ, o/ are higher than their English correlates.

Discriminant analysis is much better at modeling the perceptual patterns of French /e, ɛ, o/, in that these vowels were not always classified as their English counterparts, but sometimes to spectrally higher categories (Levy, 2009a; Strange et al., 2009). This pattern was evident in assimilation of citation-form, as well as in sentence materials by Inexperience, Modexperience and Experienced groups.

Escudero and Polka (2003) described a similar pattern of acoustic and perceptual similarity for Canadian English (CE) and Canadian French (CF) vowels in CVC context as those reported above for American English and Parisian French. Results from acoustical analysis revealed that CF vowel productions were spectrally higher (i.e., had lower F1 values) than CE productions and varied more in duration within-category, due to the fact that vowel length is not phonologically contrastive in French, as it is in English (i.e.; tense v. lax vowels). These phonetic differences affected the assimilation patterns of CE listeners naive to CF. The vowels phonemic to both languages were labeled most often as their English counterparts. However, many tokens were labeled as a spectrally higher English vowel (e.g., CF /ɛ/ was often labeled CE /ɪ/). Although these French vowels were each mapped to two CE vowel categories, they were given similar goodness ratings, regardless of the category to which they were mapped. Thus, the various productions of a single CF category were perceived as equally good instances of both CE vowel categories. Further analysis of this perceptual pattern showed that the CE listeners were influenced by characteristics specific to CE phonemic boundaries. That is, when a particular CF vowel was produced with a high F1 and with a duration that would be appropriate for CE, it was labeled as the same phonemic category in both languages. However, when that same CF vowel was produced with a relatively low F1 and shorter duration, it was more often labeled as a spectrally higher phoneme. Tokens with F1 and duration values intermediate between the values of typical CE productions were not consistently assimilated to a single CE category. The authors concluded that L2 learners of CF would have to learn that phonologically equivalent vowel categories are spectrally higher phonetically in CF compared to CE. In addition, the L2 learners must learn that duration is not a reliable cue for vowel identity in CF.

To summarize, French /i/ and/u/ are almost always perceived as their equivalent English counterparts and the French vowels /e/, /ɛ/, and /o/ are often labeled as spectrally higher English phonemes by naïve listeners. Given the phonetic differences across languages and the perceptual assimilation patterns described above, it is possible that naïve listeners will have trouble in differentiating the French vowel contrasts /i-e/, /e-ɛ/, and/o-u/, despite the fact that these contrasts are also phonemic in English.

In his discrimination study, Gottfried (1984) reported some confusion between French /i-e/ in /tVt/ context even by native French listeners. However, acoustical analysis revealed that a particular token of French /i/ in this context had formant values more similar to French /e/. In /#V#/ context, the native French control participants performed more accurately in /i-e/ discrimination, whereas the Experienced group had extreme difficulty in discriminating this contrast. Regarding French /e-ɛ/, although Gottfried (1984) found that, in general, French vowels were easier to discriminate when in an open syllable, the Inexperienced group did not reliably discriminate this contrast and the Experienced group had the highest error rate for this contrast of all eight pairs tested. Both groups were more accurate in discriminating /e-ɛ/ in /tVt/ context. Gottfried suggested that this converse interaction (harder in /#V#/ than in /tVt/) may be due to the lack of a duration difference for /e-ɛ/ in French. French is a syllable-timed language, in that all syllables are produced without phonologically relevant duration differences, whereas English is stress-timed and the length of the vocalic nucleus changes systematically. In French, the duration difference between /e/ and /ɛ/ is minimal, with /ɛ/ having a slightly longer duration. The opposite trend is true for English, for which/e/ is a tense vowel with longer duration and /ɛ/ is a lax vowel with shorter vocalic duration. Thus, French /e-ɛ/ was a relatively difficult contrast to discriminate in /#V#/ context. Furthermore, English does not allow /ɛ/ to occur in open syllables. Strange, Levy, and Law (2009) suggested that /e-ɛ/ has a two-category assimilation pattern when in word-medial position, which is a phonotactically appropriate environment for the English correlates. Yet, this is evidently not the case when in an open syllable, given the high degree of confusion in /#V#/ context reported in Gottfried's study. It is therefore likely that English phonotactic expectations biased English listeners to confuse /ɛ/ and /e/ when in an open syllable, but not when a syllabic coda was present.

None of the studies mentioned above tested discrimination of /o-u/ directly, but it is possible that some English listeners may have difficulty with this contrast, especially listeners with less experience with French, as is evident from the numerous instances in which French /o/ was assimilated to English /u/ by naïve listeners in the perceptual assimilation studies (Levy, 2009a; Strange et al., 2009).

### 1.2.3. Interactions that may affect perceptual difficulty

#### 1.2.3.1. Effects of Language Experience

PAM provides a framework for determining how a non-native phoneme will be assimilated to a listener's L1 phonology. PAM-L2 extends PAM in an effort to explain how an L2 phonology is learned, modeling resultant perceptual patterns of an experienced L2 listener (Best & Tyler, 2007). Given the perceptual assimilation patterns of French front-rounded vowels described in Section 1.2.1, PAM-L2 would predict less accurate discrimination by English learners of French for non-native vowel contrasts involving front-rounded vowels, even with extensive experience with French. Indeed, Gottfried (1984) showed that both Inexperienced and Experienced listeners made more errors than native control participants on contrasts involving front-rounded vowels and did not differ significantly from each other; L2 experience did not yield more accurate discrimination of /y-u/ or /y-œ/[3]. Regarding phonotactic context, the Experienced group was more accurate in discrimination of vowels than the Inexperienced group in /tVt/ context. In comparing group performance on vowel pairs that did not involve a front-rounded vowel, the Experienced group did not differ from the control group.

In Levy and Strange (2008), the Experienced group made fewer errors overall than the Inexperienced group. However, there was no significant difference between groups on accuracy in discriminating French /y/ and /u/. The Inexperienced group performed less accurately on vowel discrimination in coronal context, compared to labial context. The perceptual patterns of the

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[3] Gottfried (1984) summarizes that all three groups made errors on /œ-ø/, but this pair was not removed from the analysis comparing performance on vowel pairs involving front-rounded vowels. For reference, for discrimination of /œ-ø/ in /tVt/ context, controls made an average of 27% errors, Experienced: 40%, Inexperienced: 36%. In /#V#/ context, controls made an average of 26% errors, Experienced: 31%, Inexperienced: 24%. It is assumed that most of the group difference was due to performance on the vowel pairs of interest to this study: /y-œ/ and /y-u/.

Experienced group were not affected by phonetic context for any of the vowel pairs tested. Presumably, the Experienced group had learned the coarticulatory patterns of French.

If it is indeed the case that listeners have learned L2-specific phonological patterns, it is probable that experienced listeners will also make fewer errors in discriminating phonetically similar vowels /i-e/ and /o-u/. Although not explicitly tested in Gottfried (1984), there was a trend for the Inexperienced group to have greater difficulty in discriminating /i-e/ than the Experienced group. In fact, compared to the other contrasts tested, the Inexperienced group had the lowest accuracy in discriminating /i-e/ in /#V#/ context, second lowest in /tVt/context. It remains to be seen whether language experience can help to overcome L1 phonotactic expectations in discriminating /e-ɛ/ when the vowels are presented in an open syllable, given the poor performance of the Experienced group on discriminating this contrast in /#V#/ context (Gottfried, 1984).

In the discrimination study by Levy (2009b), the Experienced group performed more accurately than the Modexperience and Inexperienced groups on discrimination of /y-œ/, /u-œ/, and /œ-o/. The Modexperience group performed more accurately than the Inexperienced group only on /œ-o/. It is possible that the Experienced group was more accurate in discriminating vowel contrasts involving /œ/ and French back vowels because French /œ/ was more often assimilated to an English central vowel by this group than either French /o/ or /u/, therefore showing less cross-language assimilation overlap between /œ/ and other French back vowels for the Experienced group, compared to the other language groups (Levy, 2009a). In addition, except for /y-u/, the Experienced group performed overall at ceiling, and were less affected by phonetic context, as also described in Levy and Strange (2008).

In light of PAM-L2 (Best & Tyler, 2007), it is possible that experienced listeners of French have acquired /œ/ as an L2 phonological category, and have learned phonetic and phonotactic patterns associated with the L2 phoneme, although this category is not completely stable and even experienced listeners may sometimes erroneously perceive French /œ/ as a back vowel (Levy, 2009a; Strange et al., 2009). Experienced listeners still have trouble discriminating /e-ɛ/ in a phonotactic environment that violates English phonotactic rules (Gottfried, 1984). These listeners still have not mastered discrimination of /y-u/, meaning that they still have not developed a stable L2 phonological category for French /y/ that is akin to a native French listener's phonological category.

As the L2 learner acquires L2-specific phonological contrasts, the learner sometimes develops non-native perception strategies and will weigh cues in the speech input differently from native listeners (e.g., English vowel production by non-native speakers: Flege, Bohn, & Jang, 1997; /r-l/ discrimination by Japanese listeners: Yamada & Tohkura, 1992). For instance, according to PAM (Best, 1994, 1995), a non-native contrast with a two-category assimilation pattern will be less difficult to discriminate. Listeners with no experience with French tend to assimilate French /y/ and /u/ to two *separate* English categories in labial context; they were more likely to classify French /y/ as English /$^j$u/ and French /u/ as English /u/ (Levy, 2009a). These Inexperienced listeners thus exhibited a two-category or perhaps a category-goodness pattern of assimilation for French /y-u/. The Experienced group in the same study was more likely than the Inexperienced group to classify *both* French /y/ and /u/ as English /u/ in labial context. Furthermore, the Experienced group had a much higher cross-language assimilation overlap score for /y-u/ than either the Inexperienced or Modexperience groups, suggesting that the Experienced group exhibited a category-goodnesss or even single-category perceptual pattern for /y-u/ (Levy, 2009b). Immersion experience was thus associated with merging two non-native phonemes to a single category. PAM (Best, 1994, 1995) and PAM-L2 (Best & Tyler, 2007) would predict that differentiating /y/ and /u/ would become more difficult with experience, even though these phonemes may have initially been perceived as two separate categories. This merger of French /y/ and /u/ to a single category is not a successful way to attain native-like perception of this phoneme, as indicated by the fact that more language experience was not associated with more accurate /y-u/ discrimination (or production) in any of the studies described (Gottfried, 1984; Levy, 2009b; Levy & Law II, 2010; Levy & Strange, 2008).

#### 1.2.3.2. Effects of Phonetic Context

Even though discriminant analysis and listeners' perceptual patterns differ, depending on the phonetic context in which the vowel was produced, some studies have described L2 phoneme learning in a context-independent fashion. For example, Flege and Hillenbrand (1984) concluded that French /y/ as a "new" vowel category was easier for English speakers to learn than PF /u/, which was a "similar" vowel to English /u/, using the terminology of the Speech Learning Model (SLM, Flege, 1987, 1995). However, Levy and Law (2010) argued that Flege and Hillenbrand assumed context-independent perception of non-native phonemes when they concluded that French /y/ is a "new" phoneme for English learners. Levy and Law (2010) replicated Flege and Hillenbrand's results in coronal context, but observed an opposite pattern of difficulty in labial context: /u/ was more accurately produced, whereas /y/ was not. This context-dependent pattern of difficulty is likely due to the fact that in English, /u/ is "fronted" in coronal context, but not in labial context. The authors thus concluded that neither French /u/ nor /y/ is a "new" vowel. Both are "similar" to the English phoneme /u/, although the degree of similarity is dependent upon the phonetic context in which they are perceived or produced; English /u/ is more similar to French /u/ in labial context, but is more similar to French /y/ in coronal context.

The results of Levy and Law's production study are in line with the discriminant analysis and perception studies reported above; French front-rounded vowels are more similar spectrally to allophonically fronted English back vowels in coronal context (Strange et al., 2007) and French front-rounded v. back-rounded vowels are more difficult to discriminate in coronal than in labial context (Levy, 2009b; Levy & Strange, 2008). In labial context, French /y/ and /u/ are less likely to be confused, but some listeners do tend to confuse French front vowels /y/ and /i/, as French /y/ is acoustically more similar to English /i/ and not /u/ in labial context (Levy, 2009b; Levy & Strange, 2008). Thus, in some cases, predicting relative difficulty of L2 phoneme perception must take into consideration the phonetic context of the L2 phoneme and possible L1 or L2 phonological changes (e.g., fronting) that arise as a consequence of phonetic context.

As described above, Levy (2009b) measured cross-language assimilation overlap in order to predict relative difficulty of vowel pairs. In that study, it was hypothesized that vowel discrimination would be more difficult in coronal context than in labial context, which was borne out in the discrimination results. Although this was not directly tested in the study, an examination of the data in the appendix revealed that a higher degree of cross-language assimilation overlap was more associated with coronal context than with bilabial context ($p = 0.001$ by a Sign test evaluated by the binomial expansion).

#### 1.2.3.3. Selective attention and stimulus complexity

PAM and PAM-L2 present a generalized framework for L2 phoneme perception and do not account for complexity of stimulus materials or task demands. Yet, these variables are important to take into consideration. According to the Tetrahedral Model of Cross-Language Perception Studies (Strange, 1992), changes in stimulus and task variables will alter the way in which information is extracted from the speech signal, and thus will affect performance outcomes. In other words, keeping the *Subject Variables* constant, changing *Orienting Task Variables* (e.g., directing participants' focus to the sentence-level versus the single-word-level) will have an effect on *Criterial Task* *performance*. Changing the Orienting Tasks will change the focus and the demand on attentional resources of the subject; the interaction between the Orienting tasks and Criterial tasks will affect participants' performance.

The Automatic Speech Perception (ASP) model (Strange, 2010; Strange & Shafer, 2008) takes these factors into consideration when describing L2 perception. According to the model, perception of one's native language is automatic, over-learned; selective attention is no longer necessary to perceive linguistically contrastive information. The listener is able to perceive the language on a phonological level, selectively attending to meaningful information, while ignoring irrelevant differences in the input signal. The ASP model refers to this subconscious, automatic process as *selective perception*. The listener develops selective perception routines (SPRs), which then allow attentional resources to be allocated to other information, such as paralinguistic information, semantic information, etc. (Strange, 2010). When processing non-native phonemes, the listener may utilize either a phonological mode or a phonetic mode of processing. The phonological mode describes when the more automatic SPRs are employed. However, these SPRs are language-specific and may not be ideal for L2 phoneme perception. Given certain stimuli and task demands, it is possible for the listener to allocate more attention to the speech signal and perceive information in the phonetic mode, allowing for perception of phonetic differences that would not have been detected if processed in the phonological mode. For instance, phonological perception patterns traditionally found in categorical perception tasks were not replicated in (Carney, Widin, & Viemeister, 1977), due to differences in Orienting Task variables that allowed participants to evaluate the speech stimuli at an acoustic-phonetic level.

According to PAM-L2 (Best & Tyler, 2007) and SLM (Flege, 1987, 1995), it is possible for a second-language learner to acquire new phonemes of the L2 in certain circumstances. Yet, it is not clear whether these new categories are truly robust enough to be perceived in an automatic fashion, as are phonemes in their L1. It is especially difficult to learn a novel contrast that differs on an articulatory/acoustic dimension that is not important for perception in the native language (e.g., Francis & Nusbaum, 2002; Miyawaki et al., 1975). Perhaps to some degree, processing of such contrasts may always need to be through the phonetic mode and L2 phonological mode in tandem, making L2 perception less automatic and more susceptible to being influenced by Orienting Task Variables than native phoneme perception. The proposed study therefore used a stimulus set that is more akin to continuous speech in order to explore whether the listener has developed an L2 phonological mode that would be adequate for speech perception in everyday environments.

### 1.3. Eye Tracking and Mouse Tracking

Typically, perceptual assimilation and discrimination tasks have relied on percent-correct and Likert-scale judgment ratings as dependent variables. However, these measures are unable to capture online perceptual processing. Reaction time is also explored as a more sensitive measure, but cannot offer much insight into the perception process. Eye tracking has been used as a way to explore on-line speech perception and how the decision process unfolds over time. The first use of this methodology explored lexical access by monolingual English speakers (Allopenna, Magnuson, & Tanenhaus, 1998). When the participants were presented with a target's label aurally (e.g. *candle*), they would often look at a phonologically similar competitor present (e.g., a picture of *candy*) before selecting the picture of the candle. Dale, et al. (2007) referred to these glances to distractors as *microdecisions* that occur before the final decision is made. In this example, the participants eventually made the correct final decision, and therefore, information about the microdecision process was reflected in the participants' eye tracking, but not in the percent-correct score.

Weber and Cutler (2004) used eye tracking to examine how L1 and L2 phonologies interact and interfere when processing the L2 speech signals. Their results show that even when the Dutch-

English bilingual listeners were able to identify correctly the English target word, they were often distracted by an object whose label differed in a non-native vowel contrast that is known to be difficult for Dutch listeners to discriminate. For example, /ɛ/ is phonemic in both English and Dutch, whereas /æ/ is not phonemic in Dutch and Dutch listeners often confuse English /æ/ and /ɛ/. Therefore, upon hearing the word *panda*, the Dutch listeners were distracted by the picture of the *pencil*, due to the perceived similarity of the /ɛ/ in pencil with the /æ/ in *panda*. Moreover, there was an asymmetry, in that the non-native phoneme that was more dissimilar from the native phoneme was not an effective distractor (e.g. /æ/ in *panda* is more dissimilar to the Dutch vowel category and was not a distractor when the subject heard the /ɛ/ in *pencil*).

Although fewer studies to date have used mouse tracking in speech perception experiments, mouse tracking is highly correlated with eye tracking (Chen, Anderson, & Sohn, 2001; Rodden & Fu, 2007). Mouse tracking may yield an even more accurate account of the perception process as it has better temporal resolution and allows for longer experimental sessions with more trials, whereas eye-tracking studies are more taxing on the participant, requiring the participant to wear the eye-tracking apparatus. In addition, the subject is more or less unaware that mouse movements are being recorded, and uses a methodology that requires equipment with which the subject is already familiar. Spivey, et al. (2005) made the argument that analysis of eye-tacking experiments requires averaging across discreet information in order to derive a continuous measure of processing. For instance, Weber and Cutler (2004) compared the number of eye fixation points to the distractor to the number of fixation points to the target in order to derive a proportion score of fixation points over sequential points in time. Any description of continuous perceptual processing must therefore be derived from group data. However, the underlying measure is inherently bimodal; either the distractor receives a direct fixation or it does not. This is not the case with mouse tracking data, which directly tracks continuous movement of the mouse from trial to trial for each participant.

Spivey and colleagues further assert that, in contrast to eye movements, many arm movements are "non-ballistic." While making a decision, the arm may redirect the mouse's trajectory mid-trial. As this change in direction is not random, it is not necessary to require the mouse cursor to fixate on the competitor. In fact, it would be possible to analyze for graded effects of competing decisions; the closer the mouse is moved toward the competitor, the longer that competitor was considered as a viable choice. Indeed, mouse tracking studies were able to track online phonological processing of auditory stimuli in making a decision (Spivey et al., 2005) and mouse tracking has even been used in analyzing decisions made based on higher levels of linguistic processing, such as semantic categorization (Dale et al., 2007) and syntactic decision making (Farmer, Cargill, Hindy, Dale, & Spivey, 2007).

### 1.4. Research Questions

In summary, L2 learners have difficulty in perception of French front-rounded vowels and tend to confuse them with back-rounded vowels (Gottfried, 1984; Levy, 2009b). They must also attend to different cues from their L1 when perceiving certain phonemes that are phonologically contrastive in both languages, but differ phonetically in the L2 (Escudero & Polka, 2003). In addition, phonetic and phonotactic context can influence L2 perceptual patterns (Gottfried, 1984; Levy, 2009b). The current study investigated the perception of Canadian French vowels in word-final position, using an identification task with rhyming keywords as response alternatives. Performance by English-dominant bilinguals with varying degrees of French proficiency was examined, as well as the performance of a French-dominant bilingual control group. Analysis of each participant's percent-correct, reaction time, and mouse tracking as dependent measures was employed to address the following research questions and predictions:

1. Are there effects of language dominance and proficiency on perception of vowels in word final position? It was expected that more accurate performance would be associated with greater French proficiency, with French dominant participants performing at ceiling. It was expected that overall percent-correct would be well above chance for all participants, showing that L2 phonetic categories are reliably established and functional across phonetic contexts. Highly proficient English-dominant bilinguals may not differ from French-dominant bilinguals in percent-correct, but may be slower in their reaction time to particularly difficult vowels, and show confusions between certain pairs of vowels in their mouse tracking patterns, even when they eventually selected the correct response alternative.
2. What is the overall effect of phonetic context on L2 vowel perception? Is there any difference in perception of vowels in word-final position when preceded by a labial, coronal, or back stop? It was expected that perception of rounded vowels would be most difficult for English-dominant bilinguals when preceded by a coronal stop, especially for listeners with relatively low French proficiency.

In comparing perceptual patterns of English-dominant bilinguals on specific vowel categories, the following was predicted: Percent-correct in identifying /y/ and /u/ may be lower than for other vowel contrasts, which would be consistent with previous research that /y-u/ is not discriminable at a native-like level, even by experienced L2 listeners. French/e/ and /ɛ/ may also have lower percent-correct scores, due to the L1 phonotactic violation of /ɛ/ in word-final position. Specifically looking at identification of /e/ and /ɛ/ in lexical minimal pairs, it was predicted that these vowels would be confused more often when preceded by the back fricative /ʁ/ than in other phonetic contexts, due to the phonetic lowering of /e/ when preceded by /ʁ/, making /e/ and /ɛ/

spectrally more similar. It was not clear whether /e-ɛ/ would be more confusable when this contrast was used to distinguish morphosyntactic contrasts versus when the contrast distinguished lexical contrasts. In the morphosyntactic tokens, the vowels are also preceded by /ʁ/, also resulting in the phonetic lowering of /e/. In addition, the morphosyntactic words are three syllables. This not only increases the stimulus complexity, but vowel duration tends to be shorter in longer words (Martin, 2002) and the length distinction of /e-ɛ/ is minimized in morphosyntactic context (Law II & Strange, 2008). Vowels /i/ and /a/ were expected to be identified with very high accuracy, given their highly reliable assimilation to English correlates in perceptual assimilation studies (Levy, 2009a; Strange et al., 2009) and were used as a baseline comparison with other French vowel categories. It was predicted that reaction time would be slower than baseline in perception of front-rounded vowels, especially /y/, trials involving /e/ and /ɛ/, and trials involving front and back rounded vowels in coronal context.

Regarding mouse tracking, the response alternatives were strategically placed such that potentially confusable vowels (e.g., /e/ and /ɛ/) were placed as far apart from each other as possible. Trials in which the mouse path was not directly from the start position to the response button were explored. If the participant moved the cursor away from the correct response and very close to the response button of the confusable vowel, this would show evidence that the participant briefly considered selecting the confusable vowel before ultimately selecting the correct response.

An additional factor under analysis was whether the phoneme was embedded in a nonsense word or within a semantically meaningful word. All studies cited above either used vowels embedded in nonsense words (Levy, 2009a, 2009b; Levy & Strange, 2008; Strange et al., 2009), or did not control for whether the vowel was presented in a real or nonsense word (Gottfried, 1984). Non-natives are better able to discriminate non-native phoneme contrasts in nonsense words than in real words (Pallier, Colomé, & Sebastián-Gallés, 2001). There is evidence that real words are usually processed at a lexical level and nonsense words at a sublexical level (Vitevitch & Luce, 1998, 1999). However, if the real words and nonsense words are mixed within a block, they tend to be processed in the same fashion; on a sublexical level (Vitevitch & Luce, 1999). In order to minimize lexical effects, real and nonsense words were not blocked, but were interspersed within a block. However, if there were a significant difference, it would be expected that non-native phonemic contrasts would be easier to discriminate in nonsense words than when presented in real words.

# Chapter 2: Experimental Design and Methodology

## 2.1. Participants

Participants recruited for the study were divided into two groups: an English-dominant bilingual group and a French-dominant bilingual group, determined by self-report of language dominance. No participant was fluent in any language except French and English nor had any history of speech therapy. All participants completed all of their education in Quebec or Ontario. If they lived outside of Quebec (where French is required in school), they were enrolled in a French Immersion program at some point during their academic training. Thirty-two participants were tested in total, 16 French-dominant bilinguals (6 men, 10 women, median age: 29 yrs., range 19-54 yrs.) and 16 English-dominant bilinguals (6 men, 10 women, median age: 26 yrs., range 21-43 yrs.). All participants opted to use the mouse with the right hand, although this was not a requirement. Additional information about the participants can be found in Appendix A.

The participants' hearing was screened using 500, 1000, 2000, and 4000 Hz. pure tones presented to each ear at approximately 25 dB HL, presented using Paradigm®v1.0.2.479 software (Tagliaferri, Turner, & James, 2010). Table 1 lists the corresponding dB SPL levels that were used, calculated based on RETSPL values obtained from ANSI S3.6-1996 standards (Harris, 2004) and double-checked using a sound-level meter. The pure tones were presented randomly at varying temporal intervals and the participants selected the ear in which they heard the tone by selecting the appropriate button displayed on the computer screen. The participants repeated the hearing screening once if they missed a tone. All participants scored over 80% on familiarization blocks, although some had to repeat one or both blocks in order to attain this level of accuracy. Two individuals failed the hearing screening and one person failed the familiarization task. These three were not included in the final group of 32 participants.

### 2.1.1. Measuring French proficiency

Each participant completed three tasks in order to establish his or her relative level of French proficiency. The participants completed a listening comprehension test, consisting of eight listening passages. The range of difficulty included intermediate (five passages), high-intermediate (two passages), and advanced levels (one passage). The audio dialogs and questions were obtained from materials used by the Caron Professional & Linguistic Training Centre (2010) and were adapted to be presented using a graphical user interface designed in MATLAB®. The participants answered three multiple-choice questions for each of the intermediate and advanced-intermediate passages, five for the advanced passage.

In addition, a spontaneous speech sample was obtained from each participant, using a narration task. The participants first watched a two-minute clip from the movie *City Lights* (Chaplin, 1931) with French intertitles to get a sense of the plot. They then watched the clip a second time while simultaneously describing the events of the movie clip in French. A narration task was used because the experimenter was a non-native speaker of French, which could have affected the speech register in a traditional interview format. In addition, the movie clip required all participants to talk about the same topic, similar to the picture book task used to elicit speech samples from children in developmental studies (see for example: Gutiérrez-Clellen & Simon-Cereijido, 2009; Reilly, Losh, Bellugi, & Wulfeck, 2004). Three French-dominant listeners then evaluated these recordings in order to determine accentedness and fluency ratings.

The participants also completed a sentence completion task, in which they selected the correct form of the verb (1$^{st}$ pers. sing. conditional or 1$^{st}$ pers. sing. future) that was required to complete the sentence. For a given trial, the sentence was presented visually, with two forms of the verb underneath the sentence. The participant chose the appropriate form of the verb by clicking on that verb on the screen, using the mouse.

In this manner, measures of auditory comprehension, spontaneous production, and grammatical knowledge were gathered in order to ascertain each participant's relative proficiency in French. All participants also filled out an extensive language background questionnaire, in which they reported their daily use of French and English (see Appendices B, C & D).

**2.2. Stimuli**

The productions of two monolingual speakers were used for stimulus materials. Speaker A was male, born in Jonquière, Quebec, 23 years old at the time of recording and Speaker B was female, born in Montreal, Quebec, 18 years old. They produced both real (i.e., semantically meaningful) and nonsense target words embedded in carrier phrases. The real target words formed three minimal sets: the eight word-final vowels /i, y, e, ɛ, a, ø, o, u/ were phonemically contrastive within each set. For a given minimal set, each vowel was preceded by a stop consonant with a labial, coronal, or back place of articulation. Real target words were monosyllabic whenever possible, with some exceptions. The nonsense target words used also formed three minimal sets. Each nonsense word was disyllabic, constructed in the following manner: the first syllable was "gis" /ʒis/, and the second syllable was /CV/, where the consonant was either /p/, /t/, or /k/ and the vowel was one of the eight vowels of interest.

For the real words, voiceless consonants preceded the target vowel whenever possible, due to the fact that in French there are more real monosyllabic words preceded by voiceless than voiced consonants; thus fewer near-minimal pairs were needed. As an example a near minimal pair, the token word used for /ɛ/ preceded by a back stop was *guet* /gɛ/, as /kɛ/ is not a real word. All other back token words were preceded by a voiceless back stop. Similarly, a two-syllable word was used for /e/ preceded by a labial stop: *épée* /epe/, as /pe/ is also not a word in French. All other labial token words were one syllable and were preceded by a voiceless labial stop. All target vowels in nonsense words were preceded by voiceless consonants.

In addition, four morphological minimal verb pairs were included (three real, one nonsense), for which each minimal pair differed only by the morphological suffix. These suffixes are phonologically contrastive word-final vowels: /e/and /ɛ/. The three real verbs were chosen because each was a different example of the three types of regular verbal conjugation in French (i.e., the regularly conjugated verbs that end in either "-er", "-ir", or "-re"). The nonsense verb "gister" /ʒiste/ was created based on the form of the most common French conjugation: "-er". Finally, two additional real words were included where /e/ and /ɛ/ were preceded by /ʁ/.

In total, 58 target words were recorded (26 real words, 24 nonsense words, and 8 verbs). The target words are listed in Appendix E. Each target word was produced in two carrier phrases:

| | |
|---|---|
| Je dis le mot ______ tout le temps. | *trans:* I say the word ______ all the time. |
| Je dis le mot ______ pour lui. | I say the word ______ for him. |

Two carrier phrases were used, such that each target word was followed by either a coronal stop or a labial stop, although acoustical analysis revealed few coarticulatory effects of the following consonant on the vocalic nucleus. Two repetitions of each sentence were recorded for a total of 232 sentences (58 target words recorded in 2 carrier phrases, 2 repetitions each). In one case where Speaker A produced an obvious error (i.e., producing the target vowel incorrectly), the sentence was discarded and the other repetition was selected for both repetitions during the perception experiment. The eight vowels of Canadian French were well distinguished in word-final position, independent of phonetic context by both speakers (see Figures 2-5). The speakers exhibited fronting of back vowels when preceded by coronal consonants and backing of /a/ when preceded by labial consonants. For both Speaker A and B, there was no overlap in /e-ɛ/ for lexical or verb productions, although Speaker B did exhibit coarticulatory lowering of /e/ when preceded by /ʁ/ for both lexical and verb tokens (see Figure 3 & Figure 4). The two speakers differentiated /e/ from /ɛ/ in terms of duration as well; /ɛ/ was approximately 15 ms. longer than /e/. As mentioned above, in English, /ɛ/ is a lax vowel and is therefore shorter than /e/.

There were no major temporal or spectral differences between real and nonsense words. Speaker B had more spectral variability in real-word productions compared to nonsense, suggesting perhaps that some speakers may be more precise in production of nonsense words, which have no top-down support. However discriminant analysis was used to conclude that these spectral differences between real and nonsense words were minimal, in that vowel classification of nonsense words by a model based on real words was highly accurate (see the following for details on recording procedures and detailed acoustic analysis: Law II & Strange, 2008, 2009).

All stimuli were normalized for average RMS intensity and adjusted for any DC offset. A period of silence was inserted at the beginning of each stimulus so that the beginning of periodicity for the target vowel commenced at 1255 ms. after the beginning of each trial.

## 2.3. Procedures

### 2.3.1. Task and Experimental Trial set-up

The participants were instructed to pick the response alternative that rhymed with the target word (see full instructions and translation in Appendix F). The response alternatives are real French words whose pronunciations would be transcribed phonetically as the eight target vowels (listed in Table 2).

The experiment was conducted on a Dell Studio™ Hybrid PC and an LG W2361VG 23", 1920 x 1080 monitor using Paradigm® software (Tagliaferri et al., 2010), set up in a sound-attenuated chamber. The participants sat in front of the computer monitor, wearing Sennheiser HD280 Pro headphones. The sentences were presented at approximately 80 dB SPL. The participants made selections on the computer screen using a Microsoft SideWinder™ laser mouse, which was calibrated to move at a speed of 1600 dpi. As the stimuli were presented over headphones, the corresponding sentence was simultaneously presented in orthographic form on the computer screen, with a blank where the target word would be. Below the sentence, the response alternatives were displayed in a semicircle fashion, around the position of the mouse cursor at the start of the trial. The buttons were arranged such that the center of each response button was 350 pixels from the mouse cursor. The order of response alternatives along the semicircle was reversed for half of the participants in each language group, in order to counterbalance for effects of mouse tracking and reaction time due solely to motor control (See Figure 6 for screen layout).

### 2.3.2. Familiarization

There were two familiarization blocks to aid the participant in understanding the nature of the experiment and to allow the participant to be well acquainted with the layout of the response alternatives. The stimuli used in the familiarization blocks were productions of a different speaker from those used in the experiment and these stimuli were not included in the experimental blocks.

The first familiarization block was composed of 32 trials. In order to acclimate the subject with the layout of the response alternatives, target real words excised from sentence productions were presented to the participant in the same order as the response alternatives displayed on the computer screen (first eight familiarization trials), followed by excised target nonsense words presented in the same order as the response alternatives (next eight familiarization trials). The last 16 trials were excised real and nonsense target words, presented in random order. The second familiarization block consisted of 32 trials with the same real and eight nonsense target words as in the first familiarization block, but this time in carrier phrases, each presented twice in random order.

Participants were given trial-by-trial feedback during familiarization trials. The screen flashed green for correct responses. If the participant answered incorrectly, the screen flashed red, the correct response was displayed on the screen, and the stimulus was replayed before advancing to the next trial. If the subject scored below 80% (less than 26 out of 32) on a particular familiarization block, that block was repeated. Repeating a familiarization block could occur only once. The subject then automatically advanced to the next block.

### 2.3.3. Experimental Blocks

Experimental blocks were designed such that all 58 words were presented once per block, which equated to approximately 55% real words and 45% nonsense words, with roughly equal distribution of preceding context (~28% each for labial, coronal, and back stops, ~17% for /ʁ/) and vowel (~10% for /i, y, a, ø, o, u/, ~19% for /e/ and /ɛ/) within a given block. Because four sentences were recorded for each target word (two sentence contexts, two repetitions each), four blocks were constructed such that each block contained one of the four sentences for a given target word and each block had equal distribution of first-repetition tokens and second-repetition tokens, as well as an equal distribution of the two carrier phrases. Stimuli were randomized within a given block so that real and nonsense tokens, as well as phonetic context varied from trial to trial. Each participant heard each block three times, for a total of 12 experimental blocks (696 trials per speaker). This allowed for 12 within-subject judgments of each of the 58 word tokens for each speaker, collapsing across sentential context and repetition order. In order to encourage vigilance and to minimize fatigue effects, participants were given a summary of their performance throughout the experiment--their mean percent correct and reaction time were displayed at the conclusion of each familiarization and experimental block.

### 2.3.4. Layout of Experimental Session

The order of the experimental session was as follows: the participant completed the hearing screening and familiarization blocks, followed by 12 experimental blocks for the first speaker. Then, the participant completed the listening comprehension task and repeated the familiarization blocks, followed by the 12 experimental blocks for the second speaker. The order of which speaker was presented first was counterbalanced across participants. The participant then performed the sentence completion and narration tasks. Finally, the participants were recorded reading the sentences from the sentence completion task. The entire session took approximately 2.5-3 hours to complete and participants were paid $36CAD for their time.

## 2.4. Methodology: Analysis of Reaction Time and Mouse Tracking

During each trial, the position of the mouse cursor was recorded approximately every 2 ms. It was necessary to ensure that the mouse cursor was in the same position (i.e., equidistant from each response alternative) at the onset of each stimulus presentation for calculating accurate reaction time and mouse tracking. Restriction of mouse control was also implemented in order to prevent extraneous mouse movement that was clearly not related to the decision process. In order to accomplish this, a Dock button between trials was always positioned at the axis of the semicircle of response alternatives. The participant would make a selection, and then press the Dock button to advance to the next trial. Once the Dock button was pressed, the mouse cursor was automatically repositioned to the center of the button before the onset of sentence presentation. Movement of the mouse cursor was then restricted by the experimental software such that the participant could not move the cursor until 1255 ms. after the beginning of each trial. This allowed the subject to have control of the mouse only after periodic phonation of the target vowel began. The experiment was self-paced, in that the participant chose when to advance to the next trial by clicking the Dock button.

For analysis of reaction time and mouse tracking, the trials of the latter eight blocks for each speaker were included in the analyses. It was assumed that the participants would have a more consistent pattern by the fifth block of the experiment, as can be seen in the trend lines by block in Appendix G. Furthermore, the experiment was designed in such a way that four blocks were repeated three times to form a twelve-block experiment for each speaker. Using the final eight blocks allowed an equal and relatively reliable number of trials per token word (eight per speaker) to be considered for analysis. Only the correct responses in the final eight blocks for each speaker were included for analyses of both mouse tracking and reaction time. Using only the correct responses for analysis allowed for exploration of possible simultaneous activation of two phonemes; incorrect responses would clearly demonstrate activation of the wrong phoneme, and would be evident through the values in the off-diagonals of the confusion matrices.

The reaction time for a given trial was measured, starting from the onset of periodic phonation of the target vowel (i.e., the point at which the participant had control of the mouse), and ending with the participant selecting a response. The reaction times were converted to the natural logarithmic scale, in order to correct for their skewed distribution. For each participant, trials with reaction times that deviated more than 2.33 standard deviations of the natural-log mean of responses for all lexical-token trials were considered outliers and removed from analysis. The cutoff of 2.33 standard deviations of the mean encompasses 99% of a one-tailed normal distribution curve and has been used in other perception studies as a cutoff in investigating reaction time (see Gilichinskaya, Law II, & Strange, 2007; Ito et al., 2007; Rosas, Barias, Gilichinskaya, & Strange, 2009).

The following method was used to analyze the mouse tracking data: whether a subject entertained the possibility of choosing a different phoneme was determined by whether the mouse cursor ventured outside a region that would be within reason for only considering the correct response. This region was defined by the perimeter that encompassed the edges of the Dock button, the left edge of the button to the left of the correct response, and the right edge of button to the right. The response buttons were positioned such that any two adjacent buttons were unlikely to be confused perceptually with each other. If the participant moved the cursor from the starting position directly to the correct response, the mouse track pattern would not cross the border of the specified perimeter. If the mouse track pattern ventured outside of this region for a particular trial, the participant did not take the most direct path in selecting a response; this is referred to as an anomalous mouse track. The percentage of anomalous mouse tracks for a given vowel category was calculated by dividing the total number of correct trials by the number of correct trials for which there was an anomalous mouse track. This percentage was used for analysis. The data for a participant were removed for a particular speaker if the participant had anomalous mouse tracks on more than 50% of the trials for one of the control vowels /i/ or /a/ for that speaker. These participants were considered to have particularly inconsistent patterns, in that they did not have a direct mouse track for the vowels that are unlikely to be confusable with other vowels. The mouse tracking data from 14 English-dominant participants and 13 French-dominant participants were included for Speaker A, 12 English-dominant and 15 French-dominant for Speaker B.

As outlined in the introduction, the following French contrasts are known to be difficult for English listeners: /y-u/, /y-i/, /y-ø/, /ø-u/, /o-u/, /i-e/, and /e-ɛ/. In order to determine whether the participant possibly considered selecting a confusable vowel before ultimately making the correct response, each anomalous mouse track was analyzed by determining the place at which the participant moved the cursor farthest from the correct answer before switching direction. This was possible, due to the fact that the response buttons of six of the seven vowel contrasts were placed on the opposite side of the screen from the correct response. Because of limitations in the number of permutations for ordering the buttons, the contrast /ø-u/ was handled separately. Because the starting point of the cursor was equidistant from all responses, if the participant was deciding between two responses, at some point, the participant would have to switch the direction of the cursor towards the correct response, away from the perceptually confusable alternative, which would be captured by a change in direction of the mouse track. The furthest position of the mouse cursor from the correct response along the X-axis was defined as the turning point. The distances between the turning point and the four response buttons on the opposite side of the screen from the correct response were then calculated. The closest response that was less than 96 pixels (2.54 cm. or 1 in.) from the center of an alternate response button was labeled as a possible response that the participant considered before choosing the correct response. If no button was within 2.54 cm. of the turning point, no alternative vowel was flagged as being considered. Ninety-six pixels from the center of the response button was a rather conservative inclusion criterion, because the response button was 101 × 56 pixels; a turning point considered as identifying an alternate response would be at most 68 pixels (1.8 cm. or 0.71 in.) from the response button of interest. It is possible that the participant might have considered multiple alternatives within a single trial, or that the participant waivered back and forth between two responses. The analysis technique used here would only capture the single alternative response to which the participant moved the mouse closest, at whatever point in time during the trial.

The response buttons for /u/ and /ø/ were both on the same side of the computer screen but were separated by a large distance along the Y-axis, and the criteria for analyzing the turning points were adjusted accordingly and calculated separately from the turning points described above. Given that a turning point for considering /u/ when identifying /ø/ would still require a change in direction along the X-axis, turning points were considered on the same side as the correct response that were within 96 pixels of the response button for /u/. Conversely, a turning point for considering /ø/ when identifying /u/ would manifest in a turning point along the Y-axis; any turning point in the vertical dimension within 96 pixels of /ø/ was included. The notation for indicating the relationship between the correct response and the confusable vowel closest to the turning point is as follows: /Vowel A/ → /Vowel B/, where Vowel A is the correct response and Vowel B is the confusable vowel. See Appendices H and I for examples of mouse tracks and turning points.

**Chapter 3: Results**

A summary account of overall performance is as follows: the French-dominant group achieved a mean accuracy of 99% on the task, summing across all token types presented (range: 96-100%). This group was extremely accurate in identifying the productions of both speakers (Speaker A, mean = 98%, Speaker B mean = 99%). Although there was more variability in performance by the English-dominant participants, they performed relatively well (Overall correct: mean = 97%, Speaker A: 96%, Speaker B: 97%). There were no large fatigue or learning effects across French-dominant participants, whereas the English-dominant participants improved somewhat across blocks (on average from 94% on Block 1 to 98% on Block 12. See

Appendix J for block-by-block performance accuracy for both groups.)

The perceptual patterns of the French vowels in the lexical minimal sets by English-dominant and French-dominant bilinguals included only the trials on lexical minimal pairs in which the vowels were preceded by a labial, coronal, or back stop consonant; trials including lexical words preceded by /ʁ/ were analyzed separately. The following three questions were investigated for each dependent variable (percent correct, reaction time, and mouse tracking):

1. Were there effects of language experience and proficiency on perceptual performance? This was examined by assessing differences between French- and English-dominant groups on all three dependent variables in Sections 3.2-3.3. In Section 3.5, correlations between language proficiency and performance measures for the English-dominant participants are reported.
2. Was there any difference in perception of real v. nonsense words?
3. What were the overall effects of phonetic context on L2 vowel perception?

### 3.1. Performance Accuracy on Lexical Tokens (Percent-Correct)

Confusion matrices of the patterns of vowel classification for the lexical tokens only were used to provide an overview of the perceptual patterns of the participants. Tables 3 and 4 present confusion matrices for identification of lexical tokens by each group, collapsed across independent variables of contexts and speakers. Each row of the confusion matrix corresponds to the speakers' intended vowel. The columns correspond to the vowel category that the production was labeled as, in percent of total opportunities, summed across participants, within groups (French-dominant in Table 3, English-dominant in Table 4). The diagonal values show the percentage of trials in which the target productions of the speaker were correctly identified by the participants. The confusion matrices are collapsed across speaker, but the diagonal values for each speaker are also displayed on the right. As can be seen in the confusion matrices, participants identified /i/ and/a/ with a high degree of accuracy, although some participants misidentified some of the /i/ tokens by Speaker A (96% overall accuracy by French-dominant, 91% by English-dominant; this is discussed further in the Discussion section).

The number of errors by each participant was used for analysis in lieu of percentage, given the large number of trials; there were 576 trials involving lexical tokens and misidentifying one trial corresponds to roughly a 0.2% error rate. Due to the fact that there was an overall low error rate, interpreting performance in terms of error rate offered a more straightforward interpretation of the dataset. However, it was necessary to use non-parametric techniques, given that the French-dominant group made few errors, leading to leptokurtic distributions. Mann-Whitney *U* tests were used to compare overall errors between language experience groups on lexical items, summed across all eight vowel categories, separated by speaker. A Mann-Whitney *U* test is the non-parametric equivalent of a t-test for independent samples. Results of Mann-Whitney *U* tests confirmed that the English-dominant group made more errors overall than the French-dominant group in identifying the vowels for Speaker A, and marginally more errors for Speaker B [Speaker A: *U* = 72.0, z = -2.117, *p* = 0.0175; Speaker B: *U* = 86, *z* = -1.587, *p* = 0.0595 (one-tailed)].

The Mann Whitney *U* test was also used to explore differences in error rates between the two groups for each vowel category, again calculated separately for each speaker. Results showed that the English-dominant group was less accurate than the French-dominant only in identifying /e/ for Speaker B (see Appendix K for significance values).

### 3.2. Reaction time on Lexical Tokens

Given the near-ceiling performance for both groups, analyses based on reaction time provided more fine-grained measures than percent-correct in determining whether there were effects of language dominance and proficiency on automaticity of vowel perception. A repeated-measures ANOVA on the reaction time measures with language dominance as a between-subjects factor and speaker, word type (i.e., real v. nonsense), and vowel category as within-subjects effects was calculated. A Greenhouse-Geisser correction for degrees of freedom was used in interpreting the within-subjects measure of vowel reaction time, given that this variable failed Mauchly's test of sphericity [$\chi^2(27) = 50.812$, $p = 0.004$, $\varepsilon = 0.64$] (i.e., there was heterogeneity of variance). The results revealed a main effect of language dominance [Univariate Test: $F(1,30) = 7.674$, $p = 0.01$, partial-$\eta^2 = 0.204$]; overall, the French-dominant group responded faster than the English-dominant group. Also, there was a significant main effect of Speaker; participants were faster in identifying the vowels of Speaker B than those of Speaker A [$F(1,30) = 4.604$, $p = 0.04$, partial-$\eta^2 = 0.133$]. The effect of word type was not significant [$F(1,30) = 0.162$, $p = 0.69$, partial-$\eta^2 = 0.005$]; participants were not different overall at correctly identifying real versus nonsense words. The main effect of vowel category was significant [$F(4.48,134.42) = 25.531$, $p< 0.001$, partial-$\eta^2 = 0.46$]; the results of pairwise comparisons of vowel category led to the conclusion that participants were significantly faster at identifying the control vowels /i/ and /a/ than all other vowels, but no significant difference in speed for identifying /i/ and /a/. As summarized in the introduction, French /i/ and /a/ are perceived as similar to English /i/ and /ɑ/ respectively and are not readily confused with any other French category. Hence, French /i/ and /a/ were used as baseline measures of speed in identification for further analyses described below. Identification of /y/ was significantly slower than all other vowel categories. No other pairwise comparison was significant for vowel category (see Appendix L). There was an interaction between speaker and vowel category, although the pattern of relative speed by vowel category was the same [$F(5.66,169.93) = 5.703$, $p< 0.001$, partial-$\eta^2 = 0.16$].

A separate RANOVA collapsing across word type determined that there was no main effect of context [$F(2,60) = 1.99$, $p = 0.82$, partial-$\eta^2 = 0.007$]. Main effects of speaker, vowel, and language experience were significant, as expected, given the results of the first RANOVA analysis described above. Because it was predicted that there may be an effect of preceding phonetic context on perception of rounded vowels, an additional repeated measures ANOVA was calculated on just the four vowels /y, ø , u, o/. In this analysis, there was still no main effect of context [$F(2, 60) = 2.141$, $p = 0.126$, partial-$\eta^2 = 0.067$], but there was a significant three-way interaction of language dominance × vowel × context [$F(6, 30) = 4.132$, $p = 0.001$, partial-$\eta^2 = 0.121$]. Upon closer inspection, it appears that the English-dominant group identified front-rounded vowels faster in coronal context relative to labial and back context, and that they identified back-rounded vowels slower in coronal context than in labial and back context. However, these mean differences were relatively small, given the non-significant main effect of context (see Appendix M for a graph of this interaction).

Due to the non-significant main effects of preceding phonetic context and word type (i.e. real v. nonsense tokens), subsequent analyses are based on mean reaction times averaged across these variables. All statistical tests were calculated separately for language groups and for speakers. The mean reaction times on each of the eight vowels for each language group, collapsed across consonantal context and word type, are displayed in Appendix N, separated by speaker.

As there was an interaction between speaker, vowel, and language group, *t*-tests for paired samples were used as planned comparisons to determine whether certain French vowels were perceived in a more automatic fashion than others. The mean reaction-time scores on the six experimental vowels /e, ɛ, u, y, ø, o/ were compared to performance on control vowels /i/ and /a/. If there was interference from English phonological patterns, English-dominant participants would be even slower (or less automatic) in identifying experimental vowels, compared to their own baseline. In order to account for possible differences in speed due to relative motoric differences in moving a computer mouse to the left or to the right (i.e., moving the arm toward the body v. away from the body), /i/ and /a/ were placed on opposite sides of the starting position of the mouse cursor. Speed in identifying experimental vowels was compared to the speed in identifying the ipsilateral control vowel. That is, mean reaction times for /ɛ, ø, u/ were compared to the mean reaction time for /i/ and /e, y, o/ were compared to /a/ (see Figures 7a & b for screen layout and Appendix N for mean reaction times). Paired-sample *t*-tests were thus calculated separately by speaker and by language group, comparing each experimental vowel to its corresponding control vowel category. For Speaker A, the French-dominant group identified /ɛ/, /y/, and /o/ slower than baseline, but not /e/, /u/, or /ø/. For Speaker B, the French-dominant group was slower compared to baseline in identifying all vowels, except /e/.The English-dominant group was slower in identifying all vowels except /ø/ for Speaker A, and all experimental vowels for Speaker B, compared to baseline(see Appendix O for results of *t*-tests).

The speed in vowel identification was also analyzed in terms of reaction time difference scores. This analysis allows for a comparison of the degree of difference in speed of accuracy of experimental vowels, relative to baseline, controlling for between-participant variation in overall speed.

Figure 8 displays the reaction time difference scores of the experimental vowel categories, compared to baseline, in box-and-whisker plots, paneled by speaker (rows) and language group (columns). The asterisks below the boxes demarcate the vowel categories that were slower in overall reaction time from baseline, which is indicated by the dotted line.

The reaction time difference scores for the experimental vowels were compared within language group, to determine the relative processing time among these vowels for each group, relative to baseline. The difference scores were then analyzed across groups to explore whether the English-dominant group was slower than the French-dominant group in identification of particular vowels. In calculating the reaction time difference scores, the reaction times were again converted to natural log values. Outliers were screened separately for baseline vowels and experimental vowels. All natural-log mean values for each vowel category were converted back to a linear scale before calculating difference scores. Due to the fact that there was a main effect of speaker and a significant interaction of speaker and vowel, in addition to possible order and sequencing effects, the baseline and subsequent difference scores were calculated separately by speaker for each participant.

A Friedman's test was used to compare difference scores within language group, which is the non-parametric equivalent of a repeated-measures ANOVA, allowing for exploration of differences in processing time among the six vowel categories, controlling for between-subject variability in overall reaction time. For both language groups, there were significant differences in processing time among vowel categories for both Speaker A [French-Dominant: $N = 16$ $\chi^2 = 33.893$ $df = 5$, $p < 0.001$; English-Dominant: $N = 16$ $\chi^2 = 29.321$ $df = 5$, $p < 0.001$] and Speaker B [French-Dominant: $N$

= 16 $\chi^2$= 22.714 *df* = 5, *p*< 0.001; English-Dominant: *N* = 16 $\chi^2$= 15.571 *df* = 5, *p* = 0.008]. Wilcoxon signed-ranks tests (non-parametric equivalent of a paired-sample t-test) with Bonferroni correction for multiple comparisons were used to compare the difference scores of these experimental vowels, pairing them in terms of phonologically contrastive vowel pairs that are known to be difficult for English learners: front-rounded v. back-rounded /y-u/ and /ø-u/, front-rounded high v. mid /y-ø/, and phonetically similar /e-ɛ/, and /o-u/. For both Speaker A and Speaker B, the French-dominant group identified /ɛ/slower than /e/. In addition, for Speaker A, /y/ was slower than both /u/ and /ø/. Also, /o/ was slower than /u/. The English-dominant group was slower in identifying /y/ than both /u/ and /ø/ for both Speaker A and Speaker B (Appendix P). These significant differences are displayed by the asterisks above the boxes in Figure 8.

In comparing reaction time difference scores across groups, a Mann-Whitney *U* (non-parametric equivalent of an independent samples *t*-test) revealed that the French-dominant difference scores were smaller than the English dominant group for /y/ and /e/ for both speakers. Whereas the French-dominant group identified /e/ as fast as baseline for both Speakers, the English-dominant group identified both /e/ and /ɛ/ slower than baseline and there was no significant difference in processing time (i.e. reaction time difference scores) between the two. Similarly, the French-dominant group identified /u/ no slower than baseline for Speaker A; the English-dominant group was slower than the French-dominant group (see Appendix Q for Mann-Whitney *U* values).

In summary, both language groups were slower than baseline in identifying /ɛ/, /y/, and /o/ for both speakers. Although both groups were slow in identifying /y/, the English-dominant group was slower than the French-dominant group for in identifying /y/ for both speakers. For the French-dominant group there was no difference in the speed of identification between /e/ and baseline; the English-dominant group was significantly slower in identifying this vowel. In fact, the

English-dominant group were equally slow in identifying /e/ and /ɛ/, whereas the French-dominant group displayed an asymmetry; they were faster in identifying /e/ than /ɛ/.

### 3.3. Mouse Tracking Analysis on Lexical Tokens

Mouse tracking data were collected in order to gain insight on the decision process involved in identifying the phoneme that was presented. Reaction time measures whether the participants slowed down systematically while making their decisions; mouse tracking reflects *why* they may have slowed down. Only mouse tracks from the final eight blocks for each speaker were included: the maximum possible correct responses for a given vowel category presented in lexical tokens category was 48 (3 contexts × 2 carrier phrases × 2 word types × 2 productions × 2 repetitions).

Given the small sample size and the fact that some of the vowel categories had skewed distributions of anomalous mouse tracks across participants, nonparametric statistics were used to assess differences across vowels, groups and speakers. A Friedman's test revealed that there was an overall significant difference in proportion of anomalous mouse tracks across vowel categories for both groups and both speakers [$p < 0.001$ for all tests]. The proportion of anomalous mouse tracks for experimental vowels was compared to the proportion of anomalous tracks for the corresponding control vowels as a baseline, using a Wilcoxon Paired-Ranks test in a similar fashion described for reaction time. The proportion of anomalous mouse tracks for /ɛ, ø, u/ was compared to the proportion of anomalous tracks for /i/ and /e, y, o/ were compared to /a/. Results confirmed that both groups had significantly more anomalous mouse tracks for multiple experimental vowels compared to baseline and there was no overall difference between groups. Both groups had more anomalous mouse tracks in identifying /y/ for both speakers, compared to baseline. For the English dominant group, there were more anomalous mouse tracks for all experimental vowels except /ø/ relative to baseline for Speaker A, but only /y/ and /e/ for Speaker B. Figure 9 shows the box-and-whisker plots of the relative proportion of anomalous mouse tracks for the six experimental vowels, compared to baseline. These plots are again paneled by language group (columns) and speaker (rows). Vowel categories that had significantly more anomalous mouse tracks compared to baseline are indicated by the asterisks below the boxes in Figure 9. See Appendix R for complete results of Friedman and Wilcoxon Signed-ranks tests.

It was predicted that the English-dominant group would have more difficulty overall in differentiating particular pairs of vowels, which was expected to translate to systematic differences in mouse tracking patterns. Therefore, in addition to the above analysis of anomalous mouse tracks, the number of turning points toward the response buttons of specific vowels predicted to be confused with the correct response was investigated. First, a Mann-Whitney *U* test was used to compare the number of turning points between language groups that were within 2.54 cm. of a confusable vowel, collapsing across on lexical tokens of experimental vowels for each participant. The Mann-Whitney *U* test revealed no significant difference between groups, likely due to the fact that for many participants, none of the turning points of their anomalous mouse tracks were close enough to any button that would suggest that they considered that button as a possible response (see Appendix S). It was predicted that the English-dominant group would have some difficulty in identifying front-rounded vowels, as well as the vowels that are produced with a higher tongue position in French than in English. Figure 10 displays the distribution of interesting turning points when the correct response was a front-rounded vowel /y/ or /ø/ and Figure 11 displays the distribution of turning points when the correct response was a lower vowel, separated by speaker and by language group. In exploring the interesting turning points in trials involving front-rounded vowels, both groups exhibited many anomalous mouse tracking patterns for /y/. It was possible that participants could confuse /y/ with /u/, /ø/, or /i/. Turning points for trials involving /y/ where the turning point was close to the response button was close to /u/, /ø/, and /i/ were summed for each participant. A majority of participants in both groups moved the mouse towards a confusable vowel upon hearing /y/ at least once for both speakers, as determined by the median number of interesting turning points for trials involving /y/ and the results of Binomial tests, confirming that the number of participants with at least one interesting turning point was greater than chance, (see Appendix U). There was no significant difference between language groups, determined by a Mann-Whitney $U$ test of the summed interesting turning points by participant, calculated for each speaker [Speaker A: $U = 66$, $z = -1.218$, $p = 0.239$; Speaker B: $U = 84.5$, $z = -0.27$, $p = 0.792$]. Most of the participants had turning points that suggested they moved the mouse towards the button for /u/ when /y/ was presented. Many participants in both language groups moved the mouse at least once in this fashion, although in some cases, the sample size was too small to assume with any certainty that the number of participants with this pattern was greater than chance [Binomial test for Speaker A: French-dominant: 10 out of 13, $p = 0.0923$; English-dominant:12 out of 14, $p = 0.0129$; Binomial test for Speaker B:French-dominant: 12 out of 15, $p = 0.0352$, English-dominant: 9 out of 12, $p = 0.146$]. Some participants in each group did move the mouse towards /y/ when /ø/ was presented, and vice versa. Very few subjects of either group moved the mouse toward /i/ when /y/ was presented, or to /u/ when /ø/ was presented (Median = 0 turning points for both /y/ → /i/ and /ø/ → /u/. See Appendix T for all binomial tests calculated).

Both groups often moved the mouse toward the buttons of spectrally higher vowels when /e/, /ɛ/, and /o/ were presented (Figure 11), which was again predicted for the English-dominant group but not the French-dominant group. This was particularly apparent for /ɛ/ → /e/ [Binomial test for Speaker A: French-dominant: 12 out of 13, $p = 0.0034$; English-dominant: 11 out of 14, $p =$

0.0574; Binomial test for Speaker B: French-dominant: 13 out of 15, $p = 0.0074$, English-dominant: 10 out of 12, $p = 0.0386$] (see Appendix T).

Finally, whereas the confusion patterns of some vowel contrasts were predicted to be unidirectional (i.e., /e/ → /i/, /o/ → /u/, /y/ → /i/, but not vice versa), vowels in the following contrasts could possibly be confused with each other: /y/ ↔ /u/, /y/ ↔ /ø/, /ø/ ↔ /u/, and /e/ ↔ /ɛ/. Wilcoxon Signed-Ranks tests were again used to pair the number of interesting turning points in each direction for each vowel pair (e.g./Vowel A/ → /Vowel B/ v. /Vowel B/ → /Vowel A/), separately for each language group, by speaker. The results were as follows: the French group more often moved the mouse towards /e/ upon hearing /ɛ/ than vice versa for both speakers. The English group more often moved the mouse toward /ø/ upon hearing /u/ than vice versa for Speaker A, and marginally so for Speaker B. All other comparisons were non-significant. Figure 12 illustrates the relative number of interesting turning points for each of the four vowel pairs. See Appendix V for results of the Wilcoxon Signed-Ranks tests.

To summarize the main findings of the mouse tracking data, both language groups often had more anomalous mouse track patterns for a subset of experimental vowel categories, relative to baseline. Specifically, both groups had more anomalous mouse tracks when identifying /y/, compared to baseline for both speakers. A majority of participants in both groups moved the mouse cursor close to a confusable vowel (i.e., /ø/, /i/, or /u/), with 70 % (or 84 out of 120) of the interesting turning points for /y/ being close to /u/, collapsing across speaker for the French-dominant group, 69% (or 120 out of 175) for the English-dominant group. Analysis of any asymmetry of interesting turning points suggests that the two groups both readily confused /y-u/. Regarding /e-ɛ/, both groups often moved the mouse toward /e/ before correctly selecting /ɛ/for both speakers, although the converse was true only for the English-dominant group--the French-dominant group moved the mouse toward /ɛ/ less often when hearing /e/ than vice versa, whereas the English-dominant group wavered between the two responses at an equal rate.

### 3.4. Comparison of Performance on /e-ɛ/ in Lexical v. Morphological Tokens

This section explores perception of /e-ɛ/ in morphological tokens by the two language groups, following the same structure of analysis for lexical items; comparison of errors in identification, overall mean reaction time by vowel category, reaction time difference scores relative to the ipsilateral control vowel, anomalous mouse tracking, and interesting turning points.

Both lexical tokens and morphological tokens preceded by /ʁ/ were included in the stimulus set. However, there was only one lexical token preceded by /ʁ/ for each vowel, allowing for only 12 opportunities to identify the vowel, per participant. Accuracy in identifying this subset of lexical tokens was at-ceiling; the French-dominant group identified all of these tokens correctly for both speakers. All English-dominant participants identified 92% (one error) of lexical /e/ tokens preceded by /ʁ/ or better by either speaker, with most participants identifying all tokens correctly. The results were similar for the English-dominant group's performance on /ɛ/ preceded by /ʁ/; thirteen participants identified 92% or better for speaker A, fourteen participants for Speaker B. Given this high rate of accuracy, these tokens were not similar to either the larger set of lexical tokens or the morphological tokens (see Tables 5 & 6 for confusion matrices of lexical tokens preceded by /ʁ/). The reaction time difference scores also showed no consistent pattern for lexical tokens preceded by /ʁ/. A Wilcoxon Signed-Ranks test revealed that both groups identified lexical /ʁɛ/ faster than other lexical tokens, but there was no difference in processing time between these tokens and morphological tokens. A Wilcoxon Sign-Ranks Test was use as a post-hoc test to compare the speed in identifying lexical tokens preceded by /ʁ/ with the lexical tokens preceded by a labial, coronal, or back stop. In many cases identification of /ʁɛ/ lexical tokens was fastest. In contrast, there was no significant difference in processing time between /ʁe/ lexical items and the other lexical tokens with /e/, nor morphological tokens of /e/. The lack of consistent pattern leads to the conclusion that there is not ample evidence to determine perceptual patterns of /e/ and /ɛ/ preceded by /ʁ/ in lexical items, as the pattern tended to be specific to identification of those specific tokens and was not generalizable to either the patterns of the morphological tokens, nor the other lexical items (see Appendix W and Appendix X for Wilcoxon Signed-Ranks results).

The lexical tokens used in the subsequent analyses were ones in which /e/ and /ɛ/ were preceded by a labial, coronal, or back stop consonant in order to compare further the perception of /e-ɛ/ in lexical versus morphological tokens. Separate confusion matrices for identification of /e-ɛ/ in morphological tokens can be found in Tables 7 and 8. As with the lexical items, both groups were able to identify the morphological items relatively accurately. Most mistakes in identifying /e-ɛ/ were instances in which participants labeled /e/ as /ɛ/ and vice versa, as can be seen for the off diagonals of the confusion matrices in Tables 7 and 8. It was therefore possible to analyze identification of /e-ɛ/ in terms of A', a non-parametric test that allows for an analysis of correct identification that corrects for any response bias to choose one vowel category over another. Figure 13 displays the distribution of A' scores for perception of /e-ɛ/ in lexical and morphological tokens, separated by language group and speaker. The A' scores calculated from the accuracy rate of each vowel presented in lexical tokens v. morphological tokens were paired for each participant, and calculated within language group, for each speaker separately, using a Wilcoxon Signed-Ranks test. All four tests were non-significant, leading to the conclusion that participants were not different overall in identifying /e-ɛ/, whether lexically or morphologically distinctive [Speaker A: French-dominant: $N = 16$, $T+ = 5$, $z = -0.943$, $p = 0.345$, English-dominant: $N = 16$, $T+ = 8$, $z = -0.664$, $p = 0.507$; Speaker B: French-dominant: $N = 16$, $T+ = 6$, $z = -1.402$, $p = 0.161$, English-dominant: $N = 16$, $T+ = 8$, $z = -1.023$, $p = 0.307$].

Across-group differences in identification accuracy of /e/ and /ɛ/ were also explored. Mann-Whitney *U* tests were calculated to compare the A' scores of the two language groups. Lexical and morphological tokens were analyzed separately, as was each speaker. The results led to the conclusion that the French-dominant group was more accurate than the English group at identification of /e/ and /ɛ/ in both lexical and morphological tokens for both speakers [Speaker A: Lexical: $U= 53.5$, $z = -3.002$, $p = 0 .002$, Morphological: $U= 78.5$, $z = -1.974$, $p = 0 .0305$; Speaker B: Lexical: $U= 58$, $z = -2.734$, $p = 0 .0035$, Morphological: $U= 66$, $z = -2.428$, $p = 0 .0095$, all one-tailed].

In order to compare the speed in correctly identifying /e-ɛ/ in lexical v. morphological tokens, the criteria for determining outliers was reduced so that all tokens presented in the experiment were included. Whereas the maximum possible number of lexical tokens for analysis was 48, the maximum for morphological tokens was 32 (4 verb tokens × 2 carrier phrases × 2 productions × 2 repetitions). A comparison of reaction time difference scores for /e-ɛ/ in lexical v. morphological tokens can be found in Figure 14. In comparing mean reaction time for /e/ and /ɛ/ in morphological tokens compared to baseline (i.e., the mean reaction time of the ipsilateral control vowel) within language group, *t*-tests for paired samples revealed the same pattern as for lexical tokens: the French-dominant group was as fast as baseline in identifying /e/ but not /ɛ/ for both speakers. The English-dominant groups identified both /e/ and /ɛ/ more slowly, compared to baseline. The mean reaction time for identifying /e/ and /ɛ/ in lexical tokens was also paired to the mean reaction time in identifying the same vowel in morphological tokens in order to explore whether there was a difference in processing time that was dependent on token type. The paired samples *t*-tests on these reaction times confirmed that both groups were faster at identifying /ɛ/ in morphological tokens, compared to lexical tokens for both speakers. The English-dominant group was faster at identifying /e/ in morphological tokens, compared to when presented in lexical tokens for Speaker B (Appendix O).

The reaction time difference scores for /e/ v. /ɛ/ in morphological tokens were compared using Wilcoxon Signed-Ranks tests (Appendix P). The results mirrored those of the comparison of /e/ v. /ɛ/ reaction time difference scores in lexical items in all except one instance; the comparatively faster reaction time by the French-dominant group in identifying /ɛ/ in morphological tokens, such there was no difference between the reaction time difference scores in identifying /e/ and /ɛ/ for Speaker A (see Figure 14 for comparison).

In investigating reaction time difference scores across groups, no difference was found between groups in processing time for the morphological tokens of /e/ for Speaker B. The other results were the same as was found for the lexical tokens; no difference between groups in processing time of /ɛ/ in morphological tokens both speakers, and the French group was faster than the English-dominant group in identifying /e/ for Speaker A (Appendix Q).

The proportion of anomalous mouse tracks in correctly identifying /e/ and /ɛ/ in morphological tokens was compared to baseline. The distribution of these proportions relative to baseline and to lexical tokens can be found in Figure 15. Both groups had a larger proportion of anomalous mouse tracks for both /e/ and /ɛ/ compared to baseline for Speaker A, determined by the results of a Wilcoxon-Signed Ranks test. The French-dominant group also had a larger proportion of anomalous tracks for both vowels compared to baseline for Speaker B, but the

English dominant group had a larger proportion for only /e/ in morphological tokens. Comparison of the proportion of anomalous mouse tracks of lexical v. morphological tokens for a given vowel also revealed that both language groups had more anomalous mouse tracks for /e/ in morphological tokens compared to lexical tokens for both speakers, also by means of a Wilcoxon Signed-Ranks Test. In fact, the French-dominant group had more anomalous mouse tracks for both /e/ and /ɛ/ in morphological tokens for Speaker B, compared to lexical tokens (see Appendix R for results of Wilcoxon Signed-Ranks tests). As with the lexical tokens, there was no difference between groups in proportion of anomalous mouse tracks for either /e/ or /ɛ/ in morphological tokens (Appendix S).

An investigation of interesting turning points for morphological tokens showed that the number of participants in the French-dominant group having at least one interesting turning point did not reach significance for either /e/ → /ɛ/ or /ɛ/ → /e/. For the English-dominant group, most participants had at least one interesting turning point for /e/ → /ɛ/ for both speakers, and /ɛ/ → /e/ for only Speaker A. Neither group had an asymmetry in the number of interesting turning points for in /e/ ↔ /ɛ/ in morphological tokens for either speaker, as evidenced by Wilcoxon Sign-Ranks tests on the number of interesting turning points for /e/ → /ɛ/ v. /ɛ/ → /e/, paired by participant, contrary to what was shown for more interesting turning points to /ɛ/ → /e/ in lexical tokens (see Appendix W).

In sum, the French-dominant group was more accurate than the English-dominant group in identifying /ɛ/preceded by labial, coronal, or back stops in lexical and morphological tokens of both speakers. The English-dominant group was faster at correctly identifying both /e/ and /ɛ/ in morphological tokens, relative to lexical tokens. Despite the faster reaction times in identifying morphological tokens, both groups incurred more anomalous mouse tracks in identifying /e/ and /ɛ/ in morphological tokens, relative to lexical tokens.

### 3.5. Comparing French Proficiency with Perceptual Performance

Both PAM-L2 (Best & Tyler, 2007) and ASP (Strange, 2010) would predict that L2 perception of non-native categories will become phonologized with increased experience with the language, depending on their perceptual assimilation patterns. In addition, many studies of cross-language speech perception have shown that a higher degree of L2 use is correlated with better L2 perception and production (see for example a series of studies on an Italian population living in Canada: Flege & MacKay, 2004; MacKay, Meador, & Flege, 2001; Piske, Flege, MacKay, & Meador, 2002; Piske, MacKay, & Flege, 2001). It follows that more L2 experience and extensive L2 usage would lead to a higher L2 proficiency level. Flege and Eefting (1987) indeed showed that higher L2 proficiency was correlated with more native-like L2 perception and production, although the effect was small. Thus, it was an empirical question whether there were correlations between global measures of French proficiency and segmental perceptual performance within the English-dominant group of the present study.

Within the English-dominant group, correlations were investigated between measures of their language proficiency and their performance in the vowel identification task, focusing on performance measures that were shown to be less accurate (i.e., error rates and A' measures) or less automatic (i.e., reaction time difference scores), relative to the French dominant group. Associations between performance and proficiency discovered for measures for which there was a group difference would expand upon the relationship between performance beyond language dominance, showing that within the English-dominant group, participants with higher proficiency in French performed more similarly to the French-dominant group, whereas those with lower proficiency were more dissimilar from the French-dominant group.

### 3.5.1. Measures of Proficiency

Two of the three measures of L2 proficiency used by Flege and Eefting (1987) were employed in the present study. As in Flege and Eefting (1987), language dominance was determined by self-report. Whereas Flege and Eefting (1987) used a 10-point scale to establish language dominance, a binary scale was used in the present study; further elaboration of relative French usage was collected from a detailed self-report of daily French usage from the language background questionnaire. Flege and Eefting (1987) acquired accentedness ratings by native judges of three sentences produced in the L2 by each participant. In the present study, a production sample of each participant was rated in terms of accentedness, as well as fluency. This is described further in Section 3.5.1.1. The third measure used by Flege and Eefting (1987) was based on acoustical analysis of L2 segmental articulation. Although a limited set of productions that would allow for acoustical analysis were recorded for each participant, analysis of their L2 segmental production is beyond the scope of the present study.

Two additional measures of French proficiency were also collected for each participant: performance on a sentence completion test discriminating between the grammatical usage of /e/ and /ε/, and a listening comprehension task.

#### 3.5.1.1. Judgments on Spontaneous Production

Three French-dominant judges were recruited to listen to the recorded narrations of the *City Lights* movie clip by the 32 participants. The judges watched the movie clip once, and then proceeded with the judgment task. The judges listened to a minimum of 60 seconds of the speech sample and were asked to rate the degree of English accent (1 = very strong English accent to 9 = no English accent), as well as the level of French fluency (1 = spoken with effort to 9 = spoken with ease). The judges were encouraged to use the entire scale, and not use only the end points. They were also asked to determine whether each participant was English-dominant bilingual, French-dominant bilingual, or French monolingual. The judges were able to make any additional comments, if they felt it was necessary (full instructions can be found in Appendix Z). The recordings of narrations were presented in random order, each recording normalized with a mean RMS of 70 dB SPL to minimize differences in intensity level among the recordings. The judges completed the experiment in an IAC chamber, using the same headphones and computer as the perception experiment. Judgments were collected using a graphic user interface designed in MATLAB. All judges filled out a language background questionnaire and passed the hearing screening described above. Judging all narrations took approximately 40 to 45 minutes to complete. The judges completed additional tasks and were reimbursed $36CAD for their time.

Regarding interjudge reliability, there was a high degree of concordance among the judges. Twenty-six out of 32 of the participants received the same score in fluency and 25 participants received the same score on accentedness from at least two of the three judges. Overall, the judges' scores were within three points of each other for fluency ratings of 30 participants and for accentedness ratings of 29 participants. In the cases where the judges were more variable, the lowest score from a particular judge was still within three points of the second lowest score. For example, the largest discrepancy was for a participant who received scores of 7, 8, and 4 for fluency and 5, 7, and 2 for accentedness.

In order to rank-order the participants in terms of their perceived accentedness and fluency, their scores from each judge were summed for each participant for a maximum score of 54. The participants were then ranked from highest to lowest, based on this composite score. Fifteen out of 16 French-dominant participants received a rating of 9 (highest score possible) from at least two judges, and one participant received an 8 from two judges, 9 from the third. In comparison, 7 out of 16 English dominant participants received an accentedness rating of 9 from at least two out of three judges and one participant received an 8 from two judges. Fourteen out of 16 French-dominant participants and only 4 of the English-dominant participants received a fluency score of 9 by at least two of the three judges. Thirteen of the sixteen French-Dominant participants were categorized as either French-dominant bilingual or French monolingual and 14 of the 16 English-Dominant bilinguals were classified as English-Dominant bilinguals by at least two of the three judges.

### 3.5.2. Correlations between Performance and French Proficiency

Median tests were used to confirm that The French-dominant group used French in their daily life more than the English dominant group [$\chi^2 = 21.375$, $p < 0.001$]. The French-dominant group was more accurate on the written test than the English-dominant group [$\chi^2 = 7.375$, $p < 0.01$], but there was no difference between groups in performance on the listening comprehension task [$\chi^2 = 0.375$, *n.s.*]. Finally, a Median Test confirmed that the narrations of the French-dominant group were rated as more fluent and less accented than the productions of the English-Dominant group [$\chi^2 = 18.25$, $p < 0.001$]. Thus, as found in previous studies (Flege & Eefting, 1987; MacKain, Best, & Strange, 1981), self-report of language dominance was reliable, in that it correlated with additional subjective measures (i.e., daily French usage), as well as objective measures (i.e., judgments of accentedness/fluency and performance on the sentence completion test) of language dominance.

The scores on the sentence completion and listening comprehension tests were ordered in ascending fashion, such that a higher score meant higher accuracy. The scores of the judged accentedness/fluency in the narration task and the responses of French usage the language background questionnaire, however, were ordered such that a lower score reflected a higher degree of French use in the questionnaire, and the narration judgments were ranked such that a low ranking indicated that the participant was rated as highly fluent, with no English accent. Spearman rho tests were used for analysis. Thus, correlations between performance on the sentence completion and listening comprehension tests were expected to be positively correlated with perceptual accuracy; accented/fluency judgments and self-report of French use were expected to be negatively correlated. Correlations indicating associations between proficiency and perceptual performance are discussed, using the threshold of a correlation coefficient of ±0.3 as a medium effect size; 0.5 as a large effect size (Cohen, 1992). This analysis focused on the total variance accounted for by each language proficiency variable in predicting perception variable. In addition, any correlation greater than ±0.42 was statistically significant ($p < 0.05$, one-tailed) for a sample size of 16.

To restate the measures of perceptual performance in which the English-dominant group performed differently from the French-dominant group, the French-dominant group was more accurate overall than the English-dominant group in French vowel identification. The English-dominant group was not as accurate as the French-dominant group in identifying /e/ and /ɛ/ in lexical or morphological tokens for either speaker. In terms of processing speed of identification, the French dominant group was faster on average than the English-dominant group in identifying /y/ and /e/. No group differences were found regarding mouse tracking analyses; correlations with language proficiency within the English-dominant group were therefore not explored.

The following correlations were found between the measures of French proficiency and accuracy in identification: judgments of having a greater English accent in production were correlated with a higher rate of error in identifying the lexical tokens of both speakers (speaker A: $\rho = 0.40$, Speaker B: $\rho = 0.39$). Poorer performance on the listening comprehension task was also correlated with more overall errors in identification of lexical tokens for Speaker B ($\rho$ = -0.49). Regarding associations with A' scores in identifying /e-ɛ/, better fluency/less accentedness ratings combined in the narration task and higher performance on the listening comprehension task were both associated with a higher A' score for the lexical tokens of Speaker A ($\rho$ = -0.34 and $\rho$ = 0.39, respectively). A higher score on the listening comprehension task was also associated with a higher A' score for the morphological tokens for both speakers (of Speaker A: $\rho$ = 0.51; Speaker B: $\rho$ = 0.32). (See Table 9 for all correlations.)

Correlations were found between French proficiency and speed in correctly identifying vowels as well. A higher self-report of French usage based on responses from the questionnaire was associated with overall faster processing time in identifying the six experimental vowels for Speaker B ($\rho$ = -0.35). Better performance on the listening comprehension test was correlated with faster reaction times in identifying /e/ in both lexical ($\rho$ = 0.54) and morphological tokens ($\rho$ = -0.63) for Speaker A. Better performance in the sentence completion test was also correlated with faster identification of /e/ in lexical ($\rho$ = -0.39) and morphological ($\rho$ = -0.47) tokens for Speaker B. (See Table 10 for all correlations.)

Exploration of the scatter plots revealed that two participants were potential outliers (see Appendix AA for examples of scatter plots with outliers). Reanalysis with these participants removed revealed similar associations to the ones described above. In addition, medium to large correlations were found between higher self-evaluation of French usage and fewer overall errors in identification of lexical tokens for Speaker B ($\rho$ = -0.31 ), higher A' scores on both lexical and morphological tokens for both speakers (lexical: Speaker A: $\rho$ = 0.35, Speaker B: $\rho$ = 0.35; morphological Speaker A: $\rho$ = 0.31, Speaker B: $\rho$ = 0.47), faster overall processing time of experimental vowels for both speakers (Speaker A: $\rho$ = -0.54, Speaker B: $\rho$ = -0.50), as well as faster processing time in identifying /y/ for both speakers (Speaker A: $\rho$ = -0.61, Speaker B: $\rho$ = -0.52). In addition, with these two participants removed, judgments of English accentedess/fluency in the narration task was associated with overall slower reaction time in identifying experimental vowels, as well as identifying /e/ in lexical tokens for Speaker B (both: $\rho$ = -0.40). The differing results with the two participants removed suggest that a larger sample is likely required in order to explore these correlations further. (See Tables 11 & 12 for all correlations with the two participants removed.)

Overall, more accurate performance on the listening comprehension task correlated with better performance in five of the seven perceptual measures for which there was a group difference, including higher A' scores of the morphological tokens for both speakers. Judgments of having more native-like production in the narration task were correlated with higher accuracy in identifying lexical tokens of both speakers. Removing two participants led to correlations of higher self-evaluation of daily French usage of five of the seven perceptual measures as well, including higher A' scores for both lexical and morphological tokens and faster identification of experimental vowels of both speakers. A larger sample size is likely needed in order to understand better the relationship between language proficiency and perceptual performance.

# Chapter 4: Discussion

## 4.1. Summary of Results

In addressing the empirical questions proposed in Section 1.4, the following results were shown:

1. *Are there effects of language dominance and proficiency on perception of vowels in word final position?*

The French-dominant group was more accurate and faster than the English-dominant group overall. The groups did not differ in number of anomalous mouse tracks. Three of the four measures of French proficiency separated the groups in term of French dominance, showing that the self-report of language dominance was reliable. In addition, these measures of proficiency within the English-dominant group correlated with performance measures for which there were group differences. Thus, within the English-dominant group, participants with higher French proficiency tended to have perceptual performance more similar to the French-dominant group. For instance, ratings of more fluent French production in the narration task was associated with higher accuracy in overall identification, and better performance on the listening comprehension and sentence completion tasks was associated with faster processing times in identifying /e/. The analysis of the mouse tracking data provided an interpretation similar to the results of eye tracking experiments, in that quantifying the interesting turning points of the anomalous mouse tracks allowed for a preliminary analysis of possible priming of multiple phonemes during the perceptual process, similar to the eye-tracking studies by Weber and Cutler (2004) and Cutler, et al. (2006).

2. *What is the overall effect of phonetic context on L2 vowel perception?*

Overall, both language groups were very accurate in identifying the eight French vowels, independent of context, whether the vowel was embedded in real or nonsense tokens. Presenting both real and nonsense words randomly within an experimental block minimized any potential differences in processing strategy, as found in Vitevitch and Luce (1999). Thus, any frequency effect of specific lexical tokens was unlikely.

Perception accuracy of French vowels did not differ overall for vowels in different preceding or following consonantal contexts for either group. A separate analysis for possible context effects that included French rounded vowels did reveal a three-way interaction of language dominance × vowel × context. However a non-significant main effect of context made interpretation of this interaction difficult. No explicit prediction was made about the perception of /e-ɛ/ when preceded by /ʁ/ versus other contexts, but both language groups appeared to be faster in identifying /e-ɛ/ when preceded by /ʁ/. This is discussed further in Section 4.4.

The following subsections highlight the performance on specific vowels between and within language groups, focusing first on the control vowels, then French rounded vowels, and finally /e/ and /ɛ/. The theoretical implications of this study are discussed, in terms of PAM-L2 (Best & Tyler, 2007) and ASP (Strange, 2010). A discussion follows on the relative perceptual salience of the distinctive features for French vowels. The discussion concludes with the limitations of the study and future directions of research that would further expand the contribution of this study to the field of cross-language speech perception.

### 4.2. Perception of French /i/ and /a/

All participants were extremely accurate in identifying /a/ for both speakers and /i/ for Speaker B. Although some speakers misidentified /i/ tokens by Speaker A, the incorrect items were not included in either the reaction time or mouse tracking analyses. Also, when the participants did correctly identify /i/ by Speaker A, they were still significantly faster than identifying all other vowel categories, except for /a/.

**4.3. Perception of French Rounded vowels: /y/, /ø/, /u/, and /o/**

The French front-rounded vowel /y/ proved to be the most difficult to identify rapidly and accurately because it could be confused with three other French vowels: back-rounded /u/, front-rounded /ø/, and front unrounded /i/. It was expected that the English-dominant group might exhibit some difficulty in identifying this vowel, given previous findings of Gottfried (1984) and Levy (2009b). This was indeed borne out by the results in terms of all three dependent measures. Regarding overall accuracy of identification, most errors were misidentifying /y/ as /ø/ (English-dominant: 3% for Speaker A, 2% for Speaker B; French Dominant: Speaker A: 1%, Speaker B: < 1%). In terms of speed in correctly identifying /y/, both the French-dominant and English-dominant groups were slowest in identifying /y/ and the English dominant group was even slower on average than the French-dominant group in identifying this vowel. Mouse tracking patterns aligned with the slow reaction times, with a large percentage of anomalous mouse tracks, showing that both groups often did not move the mouse directly to the correct response button, but often moved the mouse toward the response buttons of the other confusable vowels, particularly /u/, but also /ø/.

Both groups were accurate in identifying /u/ for both speakers, but the English-dominant group was slower than baseline for both speakers and had more anomalous mouse tracks than baseline in identifying the /u/ productions of Speaker A. The French-dominant group was slower than baseline in identifying /u/ only for Speaker B and did not have more anomalous mouse tracks for /u/ compared to baseline for either speaker.

Confusions between /y/ and /u/ by both language groups may be due in part to the fact that French front-rounded/y/developed historically from the Latin back-rounded vowel /u:/ (see Fox & Wood, 1968; Picoche & Marchello-Nizia, 1998). The fact that /y/ was historically a back-vowel is evidenced in its preserved orthographic representation as *u*. In addition, there are English/French cognates that would be known to both groups, which could potentially affect perception: e.g., lūcidus (Lat.)> *lucide* /lysid/ (Fre.) and *lucid* /lusɪd/ (Eng.); crūdus (Lat.) > *crude* /kryd/ (Fre.) and *crude* /krud/ (Eng.); nūdus (Lat.) > *nu* /ny/ (Fre.) and *nude* /nud/ (Eng.)[4].

In contrast to the results described for /y/, the other front-rounded vowel /ø/ was identified accurately and relatively quickly by both language groups. Previous research has shown that better perception of French /ø/ is associated with greater language experience (Levy, 2009b; Levy & Law II, 2010), which was borne out in this experiment. All English-dominant participants had extensive language experience. French-dominant and English-dominant groups were both slightly slower than baseline in identifying /ø/, but there was no difference between groups. Neither group had more anomalous mouse tracks for /ø/ than baseline for either speaker. This demonstrates that /ø/ was a robust, stable phonological category for the English-dominant group as a whole, at least for the stimulus materials presented here, which included two speakers and varying phonetic contexts.

Both groups were slower than baseline in identifying /o/, but there was no difference between groups. There may have been possible interference with spectrally higher /u/, as was demonstrated in the mouse tracking patterns of some participants (see Appendix T). This is perhaps due to the fact that /o/ and /u/ are spectrally close to each other, and even the French-dominant participants may have had some difficult in differentiating them rapidly.

To summarize, both groups were slower than baseline in identifying /y/ and /o/ for both speakers, /u/ for Speaker B, but the English-dominant group was particularly slow in identifying /y/. Mouse tracking patterns suggest that both groups considered selecting /u/ before selecting

[4] According to the Oxford English Dictionary, the English words *nude*, *lucid*, and *crude* are borrowed directly from Latin, not indirectly through French.

/y/. Performance on /ø/ showed it was a relatively stable category, in that both groups were accurate and relatively fast in identifying this vowel, with few anomalous mouse tracks.

### 4.4. Perception of French /e/ and /ɛ/

In exploring confusions between /e/ and/ɛ/, which made up most of the errors for these vowels, the French-dominant group was able to identify /e/ and /ɛ/ with relatively high accuracy. Their overall A' for /e-ɛ/ in lexical tokens preceded by a labial, coronal, or back stop consonants was 0.98 for both speakers, 0.97 for morphological tokens for Speaker A, 0.96 for Speaker B. The English-dominant group had relatively lower A' scores: 0.89 for Speaker A in lexical tokens, 0.90 for Speaker B, and for morphological tokens 0.86 for Speaker A, 0.89 for Speaker B. Both groups were faster at correctly identifying /e/ and /ɛ/ in morphological than in lexical tokens. This may be due to the fact that the morphological tokens (or any vowel preceded by /ʁ/) only differed between two vowels, whereas with the lexical tokens preceded by stop consonants, all eight vowels occurred in equal numbers. Thus the participants may have been able to narrow down the selection to choosing between only two vowels, once it was obvious that the target word was a morphological token. The fact that both groups had more anomalous mouse tracks for morphological tokens compared to lexical tokens suggests that participants may have wavered more in their decision, but were able to make the final decision faster. It is possible that this was due to the preceding /ʁ/, which is a slow gesture productively and may have information about the identity of the target vowel in the formant trajectories that could have been used for vowel identification before periodic vowel phonation. In contrast, the lexical tokens were preceded by stops which were voiceless in most cases, resulting in less information regarding the identity of the vowel before phonation.

Unfortunately, the number of trials involving lexical tokens in which /e/ or /ɛ/ was preceded by /ʁ/ was not large enough to tease apart fully the influence of phonetic context.

### 4.5. Interpretations of Results within the PAM-L2 Framework

PAM-L2 (Best & Tyler, 2007) predicts that relative success in acquiring a non-native phonological category is dependent upon the initial perceptual pattern of L2 contrasts involving that phoneme, as well as the relative phonetic similarity of that particular phoneme to other L2 phonemes. For example, an L2 contrast for which both phonemes are heard as similar to a single L1 category would be difficult to learn. An L2 contrast in which one vowel is not consistently assimilated to any one L1 category (i.e., an *uncategorizable* assimilation pattern) will be relatively easy to learn, contingent upon the fact that it is not phonetically similar to other L2 phonemes. As discussed in Section 1.2.1, French front-rounded vowels are perceptually assimilated overwhelmingly to English back-rounded vowels by most English listeners. However, they differ in the consistency with which they are assimilated to particular back vowels. When given sentence materials, naive English listeners tend to assimilate /y/ as a good exemplar of English /u/ or /ʲu/, whereas they tend to assimilate /ø/ as an *uncategorizable* back vowel (Levy, 2009a; Strange et al., 2009). Thus, PAM-L2 would predict that /ø/ would be relatively easier to learn than /y/ because French /u-ø/ is a *categorizable-uncategorizable* contrast, whereas /u-y/ is a single category or close category goodness contrast. Furthermore, Levy (2009a) showed that more experienced late learners of French tended to assimilate /ø/ less often to back vowels, but to the central English vowel /ɝ/, suggesting that /u-ø/ confusions by experienced learners would be less likely. In the present study, the English-dominant group indeed demonstrated relatively stable perception of /ø/ as a phonological category in terms of both accuracy and speed of identification. Regarding /y/ and /u/, both were reliably identified in terms of accuracy, although the mouse tracking data did suggest continued difficulties in distinguishing the two, and reaction times were significantly slower for /y/ by English-dominant listeners.

PAM-L2 would also predict difficulty in discriminating French /y-ø/, given that these vowels are both assimilated to back vowels by naïve listeners (Levy, 2009a; Strange et al., 2009) and they are both front-rounded vowels, and therefore phonetically similar in F1/F2 values, especially for Speaker A (see Figure 2). The results of the present study do indeed show some evidence of confusion in identifying these vowels by the English-dominant group (see Section 4.3 and Table 4) but overall identification was relatively high. The mouse tracking data also suggests some potential confusions, as 10 out of 12 participants had mouse track patterns that implied /y- ø/ confusions (Appendix T). However, this was not a frequent strong pattern for any participant.

As PAM-L2 would predict, /ø/appeared to be encoded as a relatively stable phoneme for the English-dominant group, whereas/y/ was reliably identified, but slow reaction times showed less stable categorization of this phoneme. However the fact that even the French dominant group was slower to identify this vowel suggests that there are factors other than L1/L2 similarities affecting the results.

The perceptual assimilation pattern of French /e-ɛ/ by naïve English listeners is likely to differ as a function of the phonotactic environment in which they are presented. This contrast is phonologically distinguished in English and Strange et al. (2009) suggested that French /e-ɛ/ has a two-category assimilation pattern in word-medial position. However, discriminating this contrast is very difficult for English speakers when presented in an open syllable (Gottfried, 1984). In the present study, the English-dominant group was less accurate than the French-dominant group in identifying these vowels. Moreover, it is not clear whether these vowels were mapped to the English-dominant participants' existing L1 categories, or whether participants had developed separate L2 categories, given the phonetic differences in these vowels across languages. In any case, PAM-L2 would likely predict that /e-ɛ/ would be easily discriminable by L2 learners, given that /e-ɛ/ is contrastive in English and that in Canadian French speakers lower /ɛ/ word-finally, causing /e-ɛ/ to be more dissimilar phonetically. However, it is not clear how discrimination would translate to identification. Given that French /e/ and /ɛ/ are produced with higher tongue positions than English /e/ and /ɛ/, it would be possible for an L2 learner to map French /e-ɛ/ to English /i-e/ and be excellent at discrimination, but poor in identifying these vowels accurately. Also, PAM-L2 does not speak directly to the effects of L1 phonotactic expectations on L2 phoneme processing; recall that the Experienced group had difficulty in discriminating /e-ɛ/ in Gottfried (1984). It would seem reasonable to conclude that the English-dominant participants have assimilated these vowels to two separate categories, but that these categories are not stable and may have overlapping distributions with each other and perhaps with other vowels. There may be many productions for which the English-dominant group is unsure of the vowel's identity. This would explain the longer processing time in identifying both /e/ and /ɛ/.

### 4.6. ASP: Phonetic Mode v. Phonological Mode

That the English-dominant participants were found to be slower overall in identifying French vowels than the French-dominant bilinguals was not particularly surprising. Of interest was whether the pattern of speed in identification is systematic. In terms of the Automatic Selective Perception Model (ASP: Strange, 2010), vowel categories that are identifiable using robust L1 selective perception routines yield rapid responses in tests using sentence materials, which encourages a phonological mode of perception (Strange, 2010). Thus, French-dominant bilinguals were expected to have roughly equivalent mean reaction times across the French experimental vowel categories tested in this study. However, English-dominant bilinguals were predicted to have relatively slower processing times for L2 vowels that could not be processed using L1 routines, /y, ø/ and /e, ɛ/, unless they had established and automated new L2 selective perception routines. Although the English-dominant group did show slower processing times for all four of these vowels (except /ø/ for Speaker A), the French-dominant group was also slower in identifying the experimental vowels /y, o, ɛ/ than control vowels /i, a/ and other experimental vowels /e, ø, u/. This implies that identifying some of the experimental vowels may have been less automatic compared to control vowels, even for the participants for whom these vowels were phonemic in their L1.

The ASP model differentiates between a Phonetic mode and Phonological mode of processing (Strange, 2010). Processing in the phonetic mode requires more attentional resources, is therefore less automatic, and may be less robust when processing complex stimulus materials. This traditionally is used to describe the processing mode in perceiving non-native contrasts by inexperienced listeners. The phonological mode is robust, automatic, overlearned, and requires relatively little attentional resources for successful perception. This is used to describe processing of phonemes in one's native language, in which attentional resources are not needed for phoneme identification and are instead dedicated to such tasks as lexical retrieval and semantic processing. Under this hypothesis, the French-dominant group should have shown no differences in processing time for all French vowels. The fact that reaction times and mouse tracking patterns showed that /y, o, ɛ/ produced by both speakers were processed with more effort suggests that some native contrasts may be intrinsically more difficult than others in continuous speech materials. This is addressed in the next section.

### 4.7. ASP: Auditory Salience v. Perceptual Salience

ASP discusses the notion of contrast salience, in accounting for why some speech sound contrasts are more difficult to differentiate than others. ASP makes a distinction between two types of contrast salience: auditory salience and perceptual salience: Auditory salience refers to the intrinsic amount of auditory differences between contrasting categories, independent of language experience, due to sensitivities of the auditory system to acoustic pattern differences. Perceptual salience is a combination of auditory salience, plus modifications of (higher level) cortical processing, acquired through linguistic experience, that lead to learned distinctiveness (or equivalence) of phonetic categories.

In this manner, salience is usually discussed in terms of specific phonemic contrasts, lending itself to making predictions in phoneme discrimination studies. The present study, however, was an identification study, in that the participant had to choose among eight vowels as potential responses in every trial. Thus, in an identification study, a vowel that is auditorally most distinct from *all seven other* vowels would be fastest to identify with high accuracy, independent of language experience. This definition led to the decision in this study to use /i/ and /a/ as control vowels to establish baseline performance. Using the definition of ASP, an auditorally salient contrast should, among other characteristics, be prevalent in many languages and should be easily discriminable, independent of language experience. The five-vowel system /i, e, a, o, u/ is the most common system in the world (O'Grady, Dobrovolsky, & Aronoff, 1997, p. 350). According to the definition of auditory salience, discrimination among these vowels should be highly accurate with roughly equivalent speeds, independent of language experience. However, in a study that investigated native listeners' performance on vowel discrimination in Spanish, a language with a typical five-vowel system, participants were faster at discriminating some vowel contrasts than others (Rosas et al., 2009). Nor was it the case in the present study that the vowels corresponding to the universal five vowels were perceived with the same speed across groups. Not even the French-dominant group perceived these five vowels with equal speeds; they were slower in identifying /o/ than /u/. Thus, it is likely that not all vowel contrasts are equally salient auditorally. However, in attempting to determine baseline performance, it is necessary either to average across performance measures on vowels or vowel contrasts roughly equivalent in terms of auditory equivalence. In the present study, reaction time scores in identifying /i/ and /a/ were not significantly different, so it is possible to assume, at least in terms of reaction time, that the auditory salience of /i/ and /a/ are roughly equivalent.

It seems plausible that the vowels /i/ and /a/ would qualify as auditorally most salient among vowels given the body of literature that suggests that point vowels have a special status in perception relative to non-point vowels, even for infants (Polka & Bohn, 2010), and the fact that they represent the extremes in articulatory and acoustic vowel space (highest, most front tongue position and highest F2/F3 for /i/, lowest and most back tongue position and highest F1 for /a/). However, given the variability in production of other vowels across languages and the different vowel systems of the world, it seems to be the case that most other vowels are not as auditorally salient, in the sense that they would not be identified in a universal fashion, independent of language experience. Rather non-point vowel categories become *perceptually* salient through language mastery. Furthermore, given that French (and English) has a vowel system larger than the most-common five-vowel inventory, there is likely a greater influence of language experience on perceptual performance. In terms of production, French consistently maintains a four-height vowel distinction, even by speakers as young as four years old (Ménard, Schwartz, & Aubin, 2008) and was demonstrated in the speakers used in this experiment. This more complex vowel system likely affects the perceptual salience of mid vowels.

Perceptual salience in an identification task could be defined as the relative time it takes for a participant to optimize the cues within the speech signal to uniquely identify the target vowel from all other possible vowels (Kluender & Alexander, in press; Kluender, Stilp, & Kiefte, 2011). Thus, in an identification task, the reaction time does not directly reflect confusability between specific contrast pairs, but the relative separability of each vowel from the other seven vowels. In the present study, the experimental vowels did not have equivalent perceptual salience for either group. Relative reaction times for a particular contrast pair can be indirectly interpreted to index perceptual confusions among vowels. For instance, /y/ was not as perceptually salient as the control vowels for either group, given the slower processing time in identification. In fact, the longer reaction time of /y/ compared to all other vowels suggests that /y/ was the least perceptually salient vowel of the eight tested. Also, /y/ was relatively more perceptually salient to the French-dominant group than the English dominant group, given that the processing time for the English-dominant group was significantly longer than that of the French-dominant group, relative to baseline.

In using the notion of relative perceptual salience to interpret possible confusions between vowel categories, consider the results for /e-ɛ/. The distinction between /e/ and /ɛ/ was perceptually salient for the French-dominant group, given that these participants were as fast as baseline in identifying /e/, but not /ɛ/. Given that identification of /e/ was as fast as baseline, it was easily distinguishable from all other eight vowels. Responses to /ɛ/ were slower on average than baseline, suggesting that this vowel was relatively less salient perceptually from all other vowels. Thus, the perceptual salience is asymmetric, in that /e/ was easily and quickly identified, but /ɛ/ was not. This implies, but does not confirm that these two are confusable with each other; however, the mouse tracking data does suggest that there was a potential asymmetry, given the larger number of interesting turning points of /ɛ/ → /e/, but not vice versa.

For the English-dominant group, /e/ and /ɛ/ are presumed to be equal in perceptual salience, in that both vowels were identified slower than baseline and there was no difference in processing time between the two. One can hypothesize that this lack of difference in perceptual salience implies that /e-ɛ/ are confusable, given that the English-dominant group occasionally confused them in identification, and were equally slow when they did correctly identify them. In addition, the fact that many participants had interesting turning points that suggested that they often moved the mouse cursor towards the wrong label before making the correct decision also adds evidence to the fact that the contrast /e-ɛ/ was confusable for the English-dominant group.

In comparing performance on this contrast across groups, it can be concluded that /ɛ/ was equally perceptually salient for both groups but /e/ was comparatively less perceptually salient for the English-dominant group, due to the fact that the French-dominant group was faster than the English-dominant group in identifying /e/, but not /ɛ/.

Given that perception of most vowel categories is influenced by language experience, it is proposed that L1 phonemes are not all perceived as facilely, which was indicated by the perceptual patterns of the French-Dominant group in the present study. For instance, if a phoneme is phonetically dissimilar from most other phonemes, very little information from the speech signal would be necessary to identify that phoneme and the selective perceptual routine (SPR) of the native listener would be relatively fast at identifying such a phoneme. If, however, a phoneme is phonetically similar to one or more other phonemes, the SPR may require more information from the signal to determine distinctiveness, leading to slower processing times. This graded scale of the phonological mode in L1 processing is contemplated in the ASP model. The relationship between automaticity and attentional processing is described as "lying along a continuum" and that "… 'nonsalient' L1 contrasts (in the sense of auditory salience) [might] require more attentional resources even after phonological mastery" (Strange, 2010, p. 6). Whether these slower SPRs are still automatic, requiring no attentional resources is an empirical question.

Empirical support for L1 contrasts having varying degrees of perceptual salience was shown in Hisagi (2010), in which native Japanese listeners were less automatic in processing fricative length contrasts (e.g., /ʃ/ v. /ʃʃ/) relative to vowel length contrasts (e.g., /a/ v. /aa/), indexed by the elicited neurological response. Because length is phonologically contrastive for both fricatives and vowels, one would expect equivalent automatic brain responses for these phonological contrasts. Hiasgi et al. suggested that the difference in neurological response may have been due to the fact that the vowel length contrasts were more auditorally salient (e.g., vowels are periodic sounds with greater intensity), compared to the consonant contrast (aperiodic sound with lower intensity). Shafer, et al. (2004) found a similar difference in perception of native contrasts by Hindi listeners using a neurological correlate; the more perceptually salient contrast /ba-pa/ elicited a mismatch negativity response for native speakers, whereas the less-salient dental-retroflex /d̪a-ɖa/ did not. In a behavioral study, monolingual English participants were significantly faster in discriminating native vowel contrasts that differed in duration and were spectrally non-adjacent, compared to English vowel pairs that were more similar to each other (Ito et al., 2007).

In interpreting the results of the current study, the phoneme /y/ was accurately identified by both language groups, but the SPR of the French-dominant group allowed for a faster response, relative to the less-automatic responding of the English-dominant group. This perhaps suggests that the SPR of the English-dominant group was not as efficient, given their slower response time. However, the fact that both groups were slowest on /y/implies that it is the least salient category in French, given its confusability with three other vowels /i, u, ø/. Similarly, the French-dominant group was also slower than baseline in identifying /ɛ/ and /o/. Perhaps perception of these vowels is slower due to the four-height contrast that is maintained in French, resulting in vowels that are nearer spectrally in the height dimension (F1).

### 4.8. Explaining Vowel Confusability in Terms of Relative Salience of Articulatory Features

In the field of linguistics, the term *markedness* is used to refer to the presence of a feature in a language that is used to distinguish a particular linguistic constituent from other constituents (O'Grady et al., 1997, p. 349). For instance, in French phonology, the difference between the vowel contrast /o-õ/ is the presence/absence of nasality as a distinctive feature; the phoneme /õ/ can be described as being marked for nasality. Marked phonemes are usually described as being harder to produce than unmarked phonemes, given the addition of an articulatory gesture, and the marked features of one language are sometimes rarely found in other languages. For example, all languages have oral vowels, but only some have nasal vowels (O'Grady et al., 1997, p. 349). Optimality Theory is a linguistic theory that can use the relative ranking of production constraints to describe the process by which a child acquires his or her native language (Barlow & Gierut, 1999). When a child first attempts to produce sounds within the language, the child will likely have productions that are unmarked, in favor of greater ease in production. This is defined in Optimality Theory as a Markedness Constraint: don't produce that which is too difficult, even if it sounds different from the correct production. However, the child must learn to produce certain sounds that may be more difficult, but are necessary to differentiate words. This can be thought of as a Faithfulness Constraint: produce the sound exactly right, even if that requires a relatively difficult articulatory constellation. These more difficult, but necessary features can be thought of as marked for that given language. In the case of nasality in French, a typically developing child may first incorrectly produce both words *beau* and *bon* as homophones /bo/, having the markedness constraint as ranked highest in production. The child will eventually reorder the constraints, such that the faithfulness constraint to produce the nasal feature is ranked higher than the markedness features to delete it, leading to the correct production of *bon* as /bõ/. Optimality Theory is also used in examining historical sound change, using the ordering of faithfulness constraints and markedness constraints to explain the relationship between historic pronunciations and present-day productions (see for review: Holt, 2003). Given the importance in producing and perceiving these marked features, experience through learning the language will make the marked distinction perceptually salient. The following section attempts to rank the faithfulness features of the articulatory gestures and their acoustic correlates for French oral vowels in order to explain the varying degrees of perceptual salience that the French-dominant group displayed in the present experiment, when identifying /i, u, ø, y/:

lip rounding > front/back > spectral height

Evidence for this proposed hierarchy is based on the data of this study. Lip rounding has a more global acoustic consequence, in that lip rounding lengthens the vocal track, thereby lowering all formants for a rounded vowel, compared to a spectrally comparable unrounded vowel (Borden, Harris, & Raphael, 2003, p. 93). Rounding of front vowels is considered a marked feature (Fasold & Connor-Linton, p. 27). Front-rounded vowels are rare in the languages of the world but are very important to master for successful French production. High-front vowels /i/ and /y/ were hardly ever confused for each other by the French-dominant group, supporting the hypothesis that lip rounding is ranked highly in French and that /i/ and /y/ are rarely confused with each other, despite the fact that they are both high-front vowels. The hypothesis that the distinction of front v. back is ranked lower than lip rounding is supported by the diachronic sound change of /y/ from a back rounded vowel to a front rounded vowel. Lip rounding was the feature that was maintained, whereas the front/back distinction was more variable. This was seen synchronically in the French-dominant participants in this study who were able to identify /y/ reliably, but whose mouse tracking showed evidence of considering the possibility of labeling /y/ as /u/, which is rounded and high, but differs only in front/back. However, /y/ was hardly ever definitively labeled as /u/ by the French-dominant group, showing that the front/back distinction was reliably perceived, but was ranked lower than lip rounding. Spectral height was decidedly ranked lower than the front/back distinction, given that /y/ and /ø/ are both rounded and fronted, but differ only in height. This similarity was enough to cause occasional mislabeling even by the French-dominant group of one for the other, in addition to influencing the trajectory of the mouse cursor. Moreover, although /y/ and /i/ are close spectrally in F1-F2 vowel space, the productions in this study were taken from a larger dataset, in which measurements of the front-rounded vowels in F1-F2-F3 vowel space formed a separate cluster from front-unrounded vowels and back-founded vowels; /y/ and /ø/ were more similar to each other than to /i/ or /u/ (see Figure 5, based on data from Law II & Strange, 2008). This analysis supports the PAM-L2 predictions of /y-ø/ confusion by L2 learners, due to their phonetic similarity. However, here it shows that phonetic similarity influences L1 perception, as well. By this analysis, /y/ and /ø/ were equidistant from front-unrounded and back-rounded vowels; any bias toward confusing /y/ and /u/ supports the suggestion that lip-rounding is a highly ranked feature. The proposed hierarchy could be further explored and tested using a theoretical framework, such as Optimality Theory, to define the French vowel system, but is beyond the scope of this paper.

### 4.9. Methodological Limitations of study

Although a great effort was made to obtain reaction time measures, using a mouse limits the precision in determining processing speed. For instance, although the mouse always started in the same position, the response buttons were 101 × 56 pixels in dimension; a participant could click anywhere within this area, and a trial termination at the more extreme edge of the response button would have a different reaction time from a click in in the center. Despite this shortcoming, it was still possible to show that there was an overall group difference in processing speed, as well as differences in reaction time difference scores for identifying /y/ and /e/.

In capturing mouse tracking per trial, some participants were inherently more consistent in their use of the mouse than others. Although the participants were instructed not to remove their hand from the mouse during the trial, and not to make extraneous movements with the mouse, this could not be strictly enforced. Although the same equipment set-up was used for all participants, no effort was made to ensure that the screen was equidistant from the sight of view at all times. The distance from the participant to the screen was roughly 60-65 cm.; however, many participants tended to shift their position or move the chair during the course of the experiment.

Choosing response alternatives that corresponded to the eight vowel categories proved to be a formidable task. In piloting this experiment, the response alternative used for /y/ was *eu*, whereas the response alternative for /ø/ was *eux*. Confusions between /y/ and /ø/ were seen in both French-dominant and English-dominant participants. It was hypothesized that this may have been due to the similarities in orthography. Moreover, *eu* pronounced as /y/ is an exception; *-eu-* is often pronounced as /ø/ in most words (e.g., *bleu* /blø/, *feu* /fø/, queue /kø/). Therefore, the response alternative for /y/ was changed to *hue*. Although the pronunciation of the word *eu* as /y/ is an exception, this word is very frequent in French; *eu* is the past participle of "to have", whereas *hue* first-person singular conjugation of the verb "to hoot" or "to boo." The verb *huer* is used in Quebecois, but may not be a word frequently used by an English-dominant bilingual. Any potential effect stemming from unfamiliarity with the word was hopefully eliminated through being acclimated with the response alternatives during familiarization. A further confound is that the orthographic presentation of *hue* has an English orthographic cognate. However, most of the orthographic representations of the target words would be pronounced differently in English and one other word had also an orthographic cognate: *as*. However, there was no apparent effect in reaction time, due to this cross-language homograph.

Accuracy in vowel identification of one speaker was significantly higher than the other, despite the fact that both speakers were Quebecois. Speaker A was born and raised in Montreal, and the Speaker B was born in Jonquière, Quebec and moved to Montreal eight years before the time of recording. Although he was a Quebecois speaker, some participants commented that they did perceive an accent, and that he was harder to understand than Speaker A. He did tend to devoice his high vowels, especially /y/, and /i/, which is common in Quebecois dialect, but may have made identification of his high vowels more difficult. As mentioned, some participants often mislabeled his /ɛ/ productions as /a/, especially in nonsense tokens. Finally, participants had trouble identifying some if his productions of /i/, which was hypothesized to be a relatively easy category to identify. However, Gottfried (1984) reported a similar finding, in that the /i/ productions of one of the speaker was labeled as /e/, even by the French control group.

Finally, the correlational analysis of French proficiency with performance in the modified identification task would have benefitted from a larger sample size. In any case, the fact that any correlations were found suggests that the Joseph Conrad Phenomenon (i.e., poor L2 perception and production at the segmental level, despite a high level of L2 proficiency. See Scovel, 1969, 1988) was not evident in the English-dominant group. This is likely due to the fact that most of the English-dominant group was exposed to French in early childhood.

### 4.10. Summary and Future Directions

In the analysis presented here, reaction time and mouse tracking were treated as separate measures. There is, however, presumably a relationship between the two. Further analyses in mouse tracking may include determining when in time the interesting turning point took place. In addition, some participants may have waited before moving the mouse cursor towards the response; it may be fruitful to look at the point in which the participant decided to execute the motoric movement of advancing the mouse cursor. Also, the analysis presented here investigated only the mouse tracks of correct responses, but it is an empirical question whether the participant considered the correct response before selecting the incorrect choice; an analysis of the mouse tracks to incorrect trials may offer insight into the decision process when the final decision is incorrect. Also, the investigation of mouse tracks in terms of the turning points was a preliminary step in determining whether a participant may have contemplated a confusable vowel before finally making a decision. It may be possible to model the mouse tracking patterns in such a way that captures priming of competing vowels across more trials.

All participants were recorded reading the sentence used in the sentence completion task. It would be possible to obtain acoustic measures of /e-ɛ/ productions for each participant, possibly correlating spectral overlap in their productions with their accuracy and speed in identifying /e/ and /ɛ/.

The participants in this study were divided into two groups, based on self-report. However, some of the participants considered themselves monolingual French; others learned French and English simultaneously, whereas still others learned French during adolescence. Furthermore, many participants had bilingual parents; others had parents who spoke only English, or only French. Given the results of a relationship between language dominance and performance in this study, it would be of interest to include a larger sample in order to explore whether any of these additional factors are correlated with perception of French vowels. Also, the fact that some vowels are more perceptually salient than others even for the French-dominant group leads to the question of whether there is a neurological correlate to the relative auditory/perceptual salience of these vowels.

Two additional participants from British Columbia were tested in this study, but were not included in the final dataset because their results were so disparate from the group data. Although they were fluent in French, they made many more errors overall and were at chance at identifying /e/ and /ɛ/. Including a sample of late learners of French would make it possible to draw further parallels between perception studies based on standard French in different phonotactic environments and the study presented here. In addition, if it is the case that English-dominant participants who learned French in Quebec perform more accurately than participants who learned French outside of Quebec, this may have implications of pedagogical design in broader Canada.

Many studies have focused on perception of Parisian French vowels in word-medial position. The present study adds to the knowledge of English L2 perception of French vowels, examining a different dialect of French, in a different phonotactic position, while investigating various factors that are known to interact with perception. The design of the study allowed a within- as well as across-subject analysis of these factors.

In developing non-native phonological categories, L2 learners must attend to acoustic/articulatory cues that may or may not be important in the learners' native language. This requires attending to differences in the speech signal not utilized in the native language (Levy & Law II, 2010; Yamada & Tohkura, 1992) and may be influenced by phonetic and phonotactic environment. This study endeavored to tease apart these effects, investigating the perceptual performance of English-dominant bilinguals' perception of French vowels. Implications of this study contribute to the understanding of how L2 phonological categories are developed, and will extend traditional methodologies of cross-language perception by incorporating mouse tracking data and through offering a perceptual identification paradigm that will directly test the stability of L2 phonological categories. Implications of the results support an increased awareness of specific perception issues that arise for L2 French learners, which will aid in pedagogical design of second language instruction. [Work supported in part by NIH F31DC008075.]

**Tables**

Table 1: The pure tones generated with the corresponding dB SPL level of intensity to approximate 25 dB HL. Based on RETSPL values obtained from ANSI S3.6-1996 standards.

| Hertz | dB SPL | dB HL |
|---|---|---|
| 500 | 38.5 | 25 |
| 1000 | 32.5 | 25 |
| 2000 | 34 | 25 |
| 4000 | 37 | 25 |

Table 2: List of words that were presented in each trial as response alternatives. The pronunciation of each word corresponds to the pronunciation of each vowel.

| IPA | Response Alternatives | Gloss |
|---|---|---|
| /i/ | y | "there" |
| /y/ | hue | "hoot/boo" (1st per. sing.) |
| /e/ | ai | "have" (1st per. sing.) |
| /ɛ/ | hais | "hate" (2nd per. sing.) |
| /a/ | as | "have" (2nd per. sing.) |
| /ø/ | eux | "them" |
| /o/ | eau | "water" |
| /u/ | ou | "or" |

Table 3: Confusion matrix collapsed across both speakers for French-dominant participants. All context, word types and minimal pair types are included. The target response is indicated by the row labels. Percentage of incorrect responses are highlighted in gray. Based on 2,304 tokens per vowel, 144 per participant, 1152 per speaker.

**Lexical Tokens for French-Dominant Bilinguals**

| | /i/ | /e/ | /ɛ/ | /u/ | /y/ | /ø/ | /o/ | /a/ | Speaker A | Speaker B |
|---|---|---|---|---|---|---|---|---|---|---|
| /i/ | 98% | 2% | | | | | | | 96% | 100% |
| /e/ | | 99% | | | | | | | 99% | 99% |
| /ɛ/ | | | 97% | | | | | 2% | 96% | 99% |
| /u/ | | | | 100% | | | | | 99% | 100% |
| /y/ | | | | | 99% | | | | 99% | 99% |
| /ø/ | | | | | | 99% | | | 98% | 100% |
| /o/ | | | | | | | 99% | | 99% | 99% |
| /a/ | | | | | | | | 100% | 100% | 100% |

Table 4: Confusion matrix collapsed across both speakers for English-dominant participants. All context, word types and minimal pair types are included. The target response is indicated by the row labels. Percentage of incorrect responses are highlighted in gray. Based on 2,304 tokens per vowel, 144 per participant, 1152 per speaker.

**Lexical Tokens for English-Dominant Bilinguals**

| | /i/ | /e/ | /ɛ/ | /u/ | /y/ | /ø/ | /o/ | /a/ | Speaker A | Speaker B |
|---|---|---|---|---|---|---|---|---|---|---|
| /i/ | 95% | 4% | | | | | | | 91% | 99% |
| /e/ | 1% | 95% | 4% | | | | | | 95% | 95% |
| /ɛ/ | | 5% | 94% | | | | | | 94% | 95% |
| /u/ | | | | 99% | | | | | 98% | 99% |
| /y/ | | | | | 97% | 3% | | | 96% | 97% |
| /ø/ | | | | | 1% | 98% | | | 97% | 99% |
| /o/ | | | | | | | 98% | | 99% | 98% |
| /a/ | | | | | | | | 99% | 100% | 99% |

Table 5: Confusion matrix of lexical tokens preceded by /ʁ/ collapsed across both speakers for French-dominant participants. Based on 384 tokens per vowel, 24 per participant, 192 per speaker.

**Lexical Tokens Preceded by /ʁ/ for French-Dominant Bilinguals**

| | /i/ | /e/ | /ɛ/ | /u/ | /y/ | /ø/ | /o/ | /a/ | Speaker A | Speaker B |
|---|---|---|---|---|---|---|---|---|---|---|
| /e/ | | 100% | | | | | | | 100% | 100% |
| /ɛ/ | | | 100% | | | | | | 100% | 100% |

Table 6: Confusion matrix of lexical tokens preceded by /ʁ/ collapsed across both speakers for English-dominant participants. Based on 384 tokens per vowel, 24 per participant, 192 per speaker.

**Lexical Tokens Preceded by /ʁ/ for English-Dominant Bilinguals**

| | /i/ | /e/ | /ɛ/ | /u/ | /y/ | /ø/ | /o/ | /a/ | Speaker A | Speaker B |
|---|---|---|---|---|---|---|---|---|---|---|
| /e/ | | 99% | 1% | | | | | | 99% | 98% |
| /ɛ/ | | 7% | 93% | | | | | | 91% | 95% |

Table 7: Confusion matrix of morphological tokens preceded by /ʁ/ collapsed across both speakers for French-dominant participants.Based on 1,536 tokens per vowel, 96 per participant, 768 per speaker.

**Morphological Tokens for French-Dominant Bilinguals**

| | /i/ | /e/ | /ɛ/ | /u/ | /y/ | /ø/ | /o/ | /a/ | Speaker A | Speaker B |
|---|---|---|---|---|---|---|---|---|---|---|
| /e/ | | 99% | 1% | | | | | | 99% | 99% |
| /ɛ/ | | 2% | 98% | | | | | | 98% | 98% |

Table 8: Confusion matrix of morphological tokens preceded by /ʁ/ collapsed across both speakers for English-dominant participants.Based on 1,536 tokens per vowel, 96 per participant, 768 per speaker.

**Morphological Tokens for English-Dominant Bilinguals**

| | /i/ | /e/ | /ɛ/ | /u/ | /y/ | /ø/ | /o/ | /a/ | Speaker A | Speaker B |
|---|---|---|---|---|---|---|---|---|---|---|
| /e/ | | 94% | 6% | | | | | | 94% | 94% |
| /ɛ/ | | 5% | 94% | | | | | | 93% | 96% |

Table 9: Correlations of French proficiency with accuracy measures of perceptual performance for English-dominant group. Medium and large associations are in bold, correlations significant at $p < 0.05$ are indicated with an asterisk.

| | Overall Errors on Lexical Tokens | A' on Lexical Tokens | A' on Morphological Tokens |
|---|---|---|---|
| Listening Comprehension Task | -0.213 (A)<br>**-0.492 (B)*** | **0.391 (A)**<br>0.198 (B) | **0.512 (A)***<br>**0.316 (B)** |
| Sentence Completion Test | 0.029 (A)<br>-0.019 (B) | 0.111 (A)<br>0.286 (B) | -0.123 (A)<br>0.114 (B) |
| Self-evaluation of daily French usage | 0.057 (A)<br>-0.091 (B) | 0.110 (A)<br>0.161 (B) | 0.078 (A)<br>0.252 (B) |
| Judgments of accentedness and fluency in production | **0.402 (A)**<br>**0.394 (B)** | **-0.341 (A)**<br>-0.275 (B) | -0.119 (A)<br>-0.092 (B) |

Table 10: Correlations of French proficiency with reaction time measures of perceptual performance for English-dominant group. Medium and large associations are in bold, correlations significant at $p < 0.05$ are indicated with an asterisk.

| | Overall RT Diff Scores Across All Experimental Vowels | Speed in Identifying /y/ Tokens | Speed in identifying /e/ Lexical Tokens | Speed in Identifying /e/ Morphological Tokens |
|---|---|---|---|---|
| Listening Comprehension Task | -0.181 (A)<br>0.046 (B) | -0.269 (A)<br>0.000 (B) | **-0.54 (A)***<br>-0.287 (B) | **-0.631 (A)***<br>-0.223 (B) |
| Sentence Completion Test | -0.149 (A)<br>-0.097 (B) | -0.057 (A)<br>-0.083 (B) | -0.085 (A)<br>**-0.393 (B)** | -0.042 (A)<br>**-0.472 (B)*** |
| Self-evaluation of daily French usage | -0.259 (A)<br>**-0.353 (B)** | -0.287 (A)<br>-0.277 (B) | -0.053 (A)<br>0.046 (B) | 0.024 (A)<br>0.096 (B) |
| Judgments of accentedness and fluency in production | 0.013 (A)<br>-0.242 (B) | 0.106 (A)<br>-0.025 (B) | 0.177 (A)<br>-0.224 (B) | 0.111 (A)<br>0.168 (B) |

Table 11: Correlations of French proficiency with accuracy measures of perceptual performance for English-dominant group, outliers removed. Medium and large associations are in bold, correlations significant at $p < 0.05$ are indicated with an asterisk.

| | Overall Errors on Lexical Tokens | A' on Lexical Tokens | A' on Morphological Tokens |
|---|---|---|---|
| Listening Comprehension Task | -0.103 (A)<br>**-0.524 (B)*** | **0.375 (A)**<br>0.145 (B) | **0.505 (A)***<br>0.275 (B) |
| Sentence Completion Test | 0.066 (A)<br>-0.007 (B) | 0.275 (A)<br>0.115 (B) | -0.184 (A)<br>0.082 (B) |
| Self-evaluation of daily French usage | -0.166 (A)<br>**-0.313 (B)** | **0.346 (A)**<br>**0.346 (B)** | **0.311 (A)**<br>**0.466 (B)*** |
| Judgments of accentedness and fluency in production | **0.303 (A)**<br>**0.347 (B)** | -0.220 (A)<br>-0.153 (B) | 0.059 (A)<br>0.003 (B) |

Table 12: Correlations of French proficiency with reaction time measures of perceptual performance for English-dominant group, outliers removed. Medium and large associations are in bold, correlations significant at $p < 0.05$ are indicated with an asterisk.

| | Overall RT Diff Scores Across All Experimental Vowels | Speed in Identifying /y/ Tokens | Speed in identifying /e/ Lexical Tokens | Speed in Identifying /e/ Morphological Tokens |
|---|---|---|---|---|
| Listening Comprehension Task | -0.099 (A)<br>0.072 (B) | -0.173 (A)<br>0.142 (B) | **-0.543 (A)***<br>-0.173 (B) | **-0.647 (A)***<br>-0.056 (B) |
| Sentence Completion Test | -0.181 (A)<br>-0.076 (B) | -0.060 (A)<br>-0.114 (B) | -0.076 (A)<br>**-0.413 (B)** | -0.002 (A)<br>**-0.515 (B)*** |
| Self-evaluation of daily French usage | **-0.543 (A)***<br>**-0.503 (B)*** | **-0.611 (A)***<br>**-0.523 (B)*** | -0.295 (A)<br>-0.131 (B) | -0.186 (A)<br>-0.064 (B) |
| Judgments of accentedness and fluency in production | -0.168 (A)<br>**-0.399 (B)** | -0.055 (A)<br>-0.216 (B) | 0.037 (A)<br>**-0.415 (B)** | -0.071 (A)<br>-0.042 (B) |

**Figures**

Figure 1: A spectral comparison of French vowel tokens (shapes indicated by legend) to English vowel categories (vowel productions of English vowel categories by 3 male speakers, encompassed by the ellipses), all produced in citation (/Vb(ə)/) form. Adapted from Strange, Levy and Law (2009). The ordinate plots F1 values from high to low, which correlates most with tongue/jaw position of from low to high.

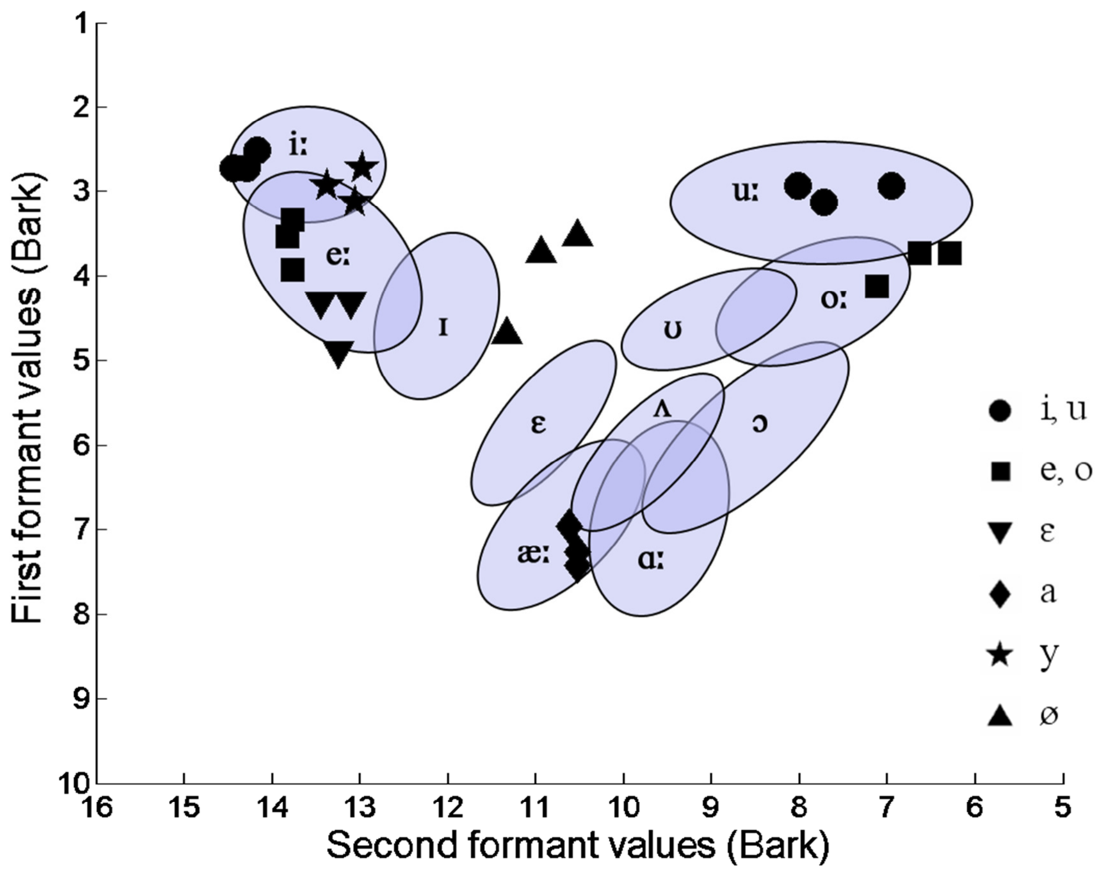


Figure 2: Average F1-F2 formant values for the 8 French vowels by speaker separated by context, collapsed across real and nonsense tokens.

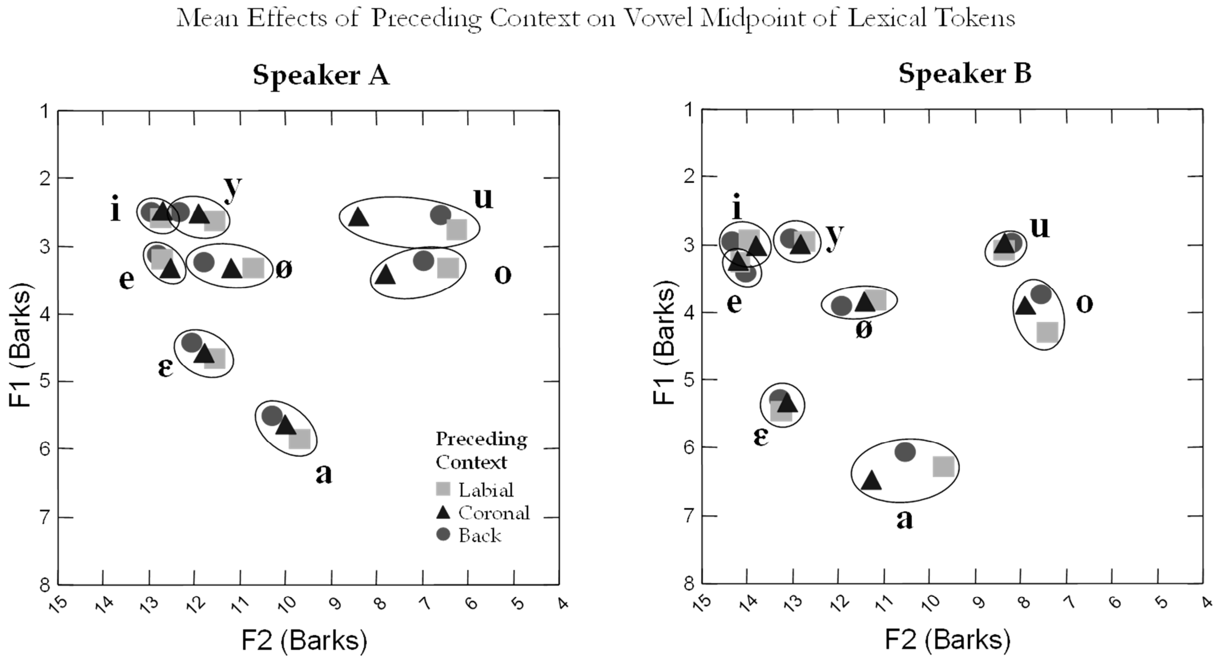



Figure 3: Variation in production of /e/ and /ɛ/ in lexical tokens by speaker. Ellipses encompass 2 standard deviations of tokens. Filled ellipses include production of vowels preceded by labial, coronal, or back consonant. Open circles represent productions of /e/ and /ɛ/ preceded by /ʁ/.

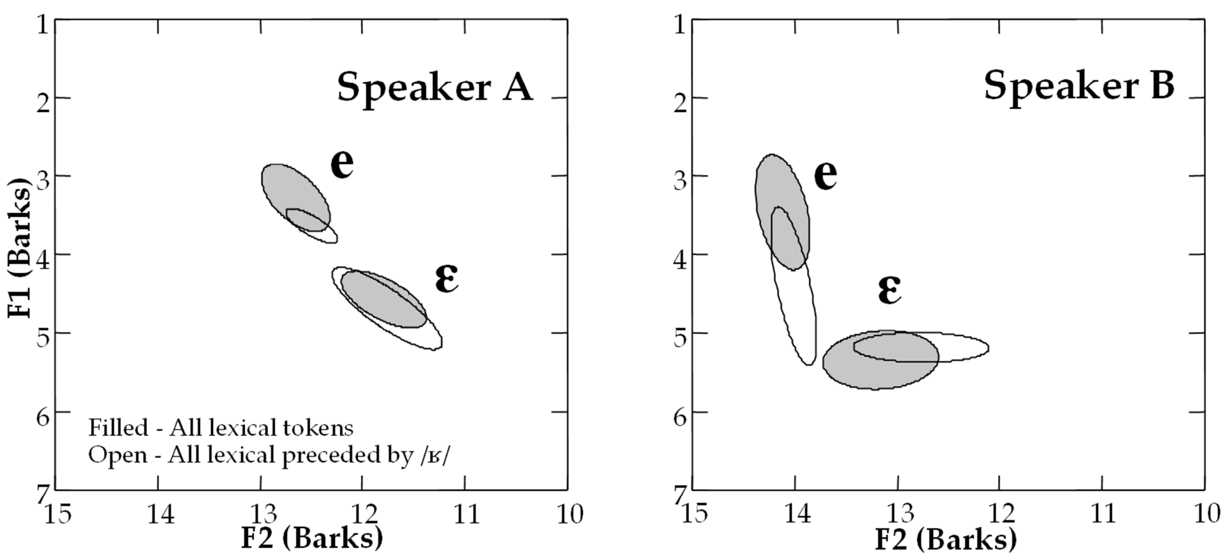


Figure 4: Variation in production of /e/ and /ɛ/ in morphological tokens by speaker. Ellipses encompass 2 standard deviations of tokens.

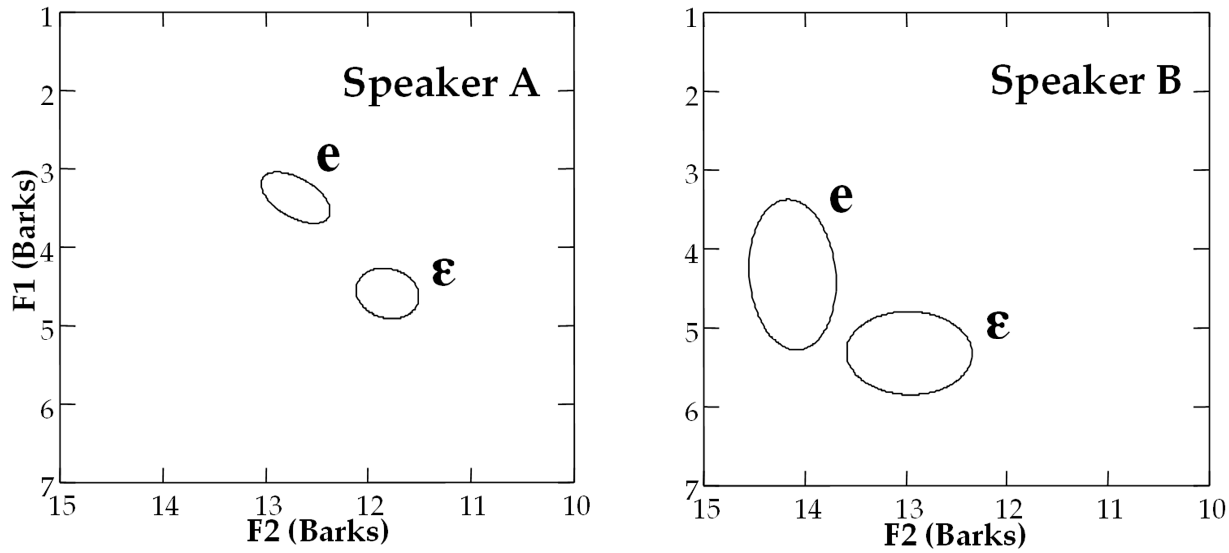



Figure 5: Comparison of front-rounded, back-rounded and in F1-F2-F3 space. Data adapted from Law & Strange (2008). In F1-F2-F3 space, the following clusters of vowels can be seen: Front-unrounded vowels have a high F2 and high F3. Back-rounded vowels have a relatively lower F2, but high F3. Front-rounded vowels have an F3 lower than both back-rounded and front-unrounded vowels, with an F2 value between the back-rounded and front-unrounded vowels.

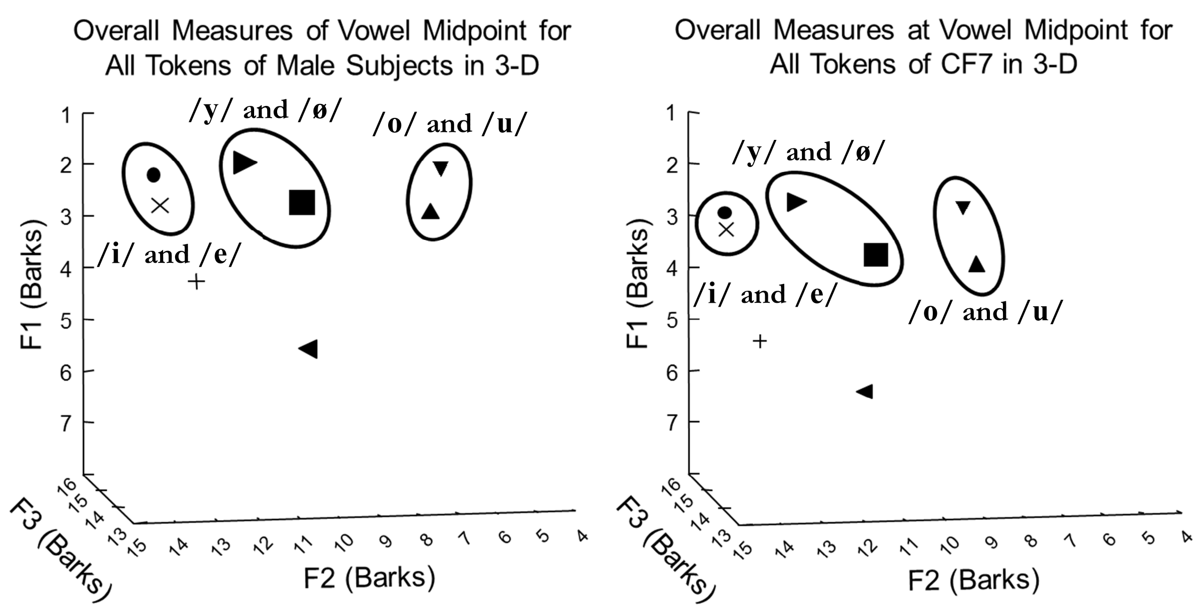


Figure 6: Layout of an experimental trial.  The mouse cursor was at the apex of the semicircle at the beginning of the trial.

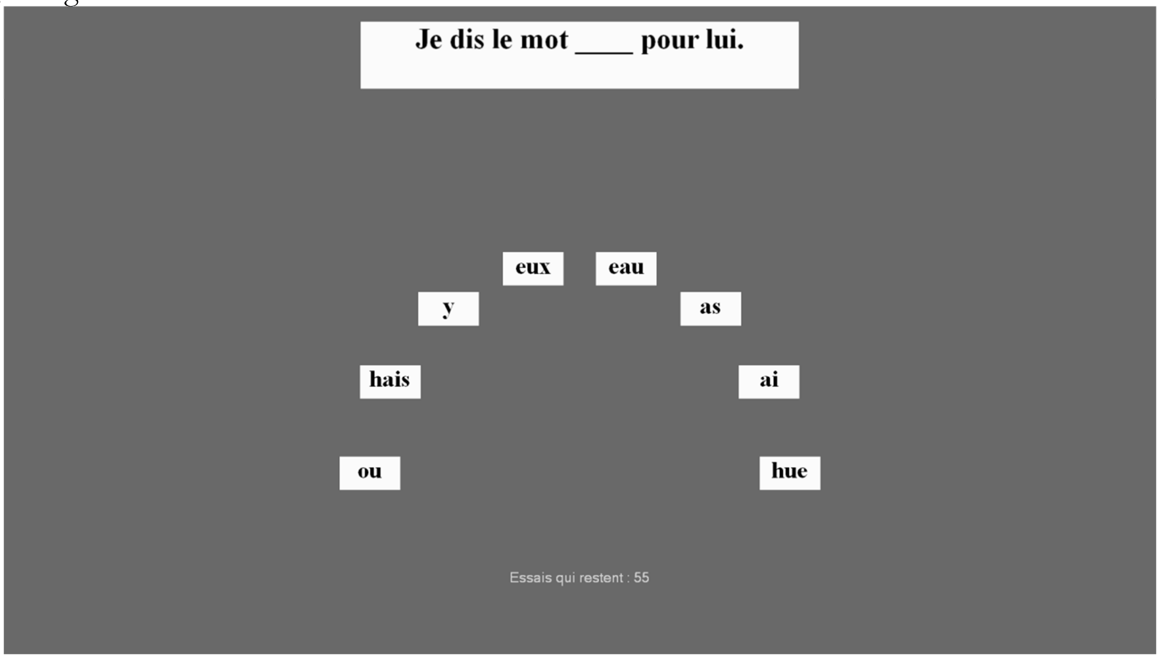
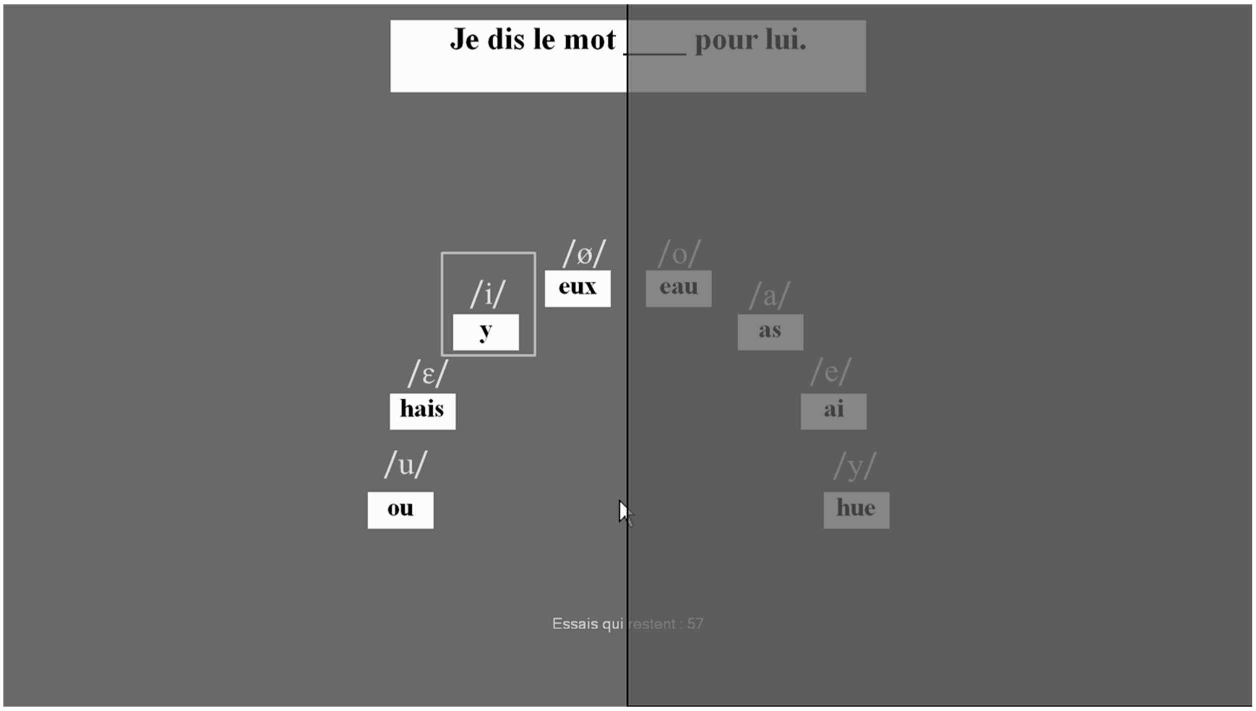


Figure 7: Illusration of the proximity of experimental vowels to their corresponding control vowel.

a) Experimental vowels that were compared to control vowel /i/.




b) Experimental vowels that were compared to control vowel /a/.

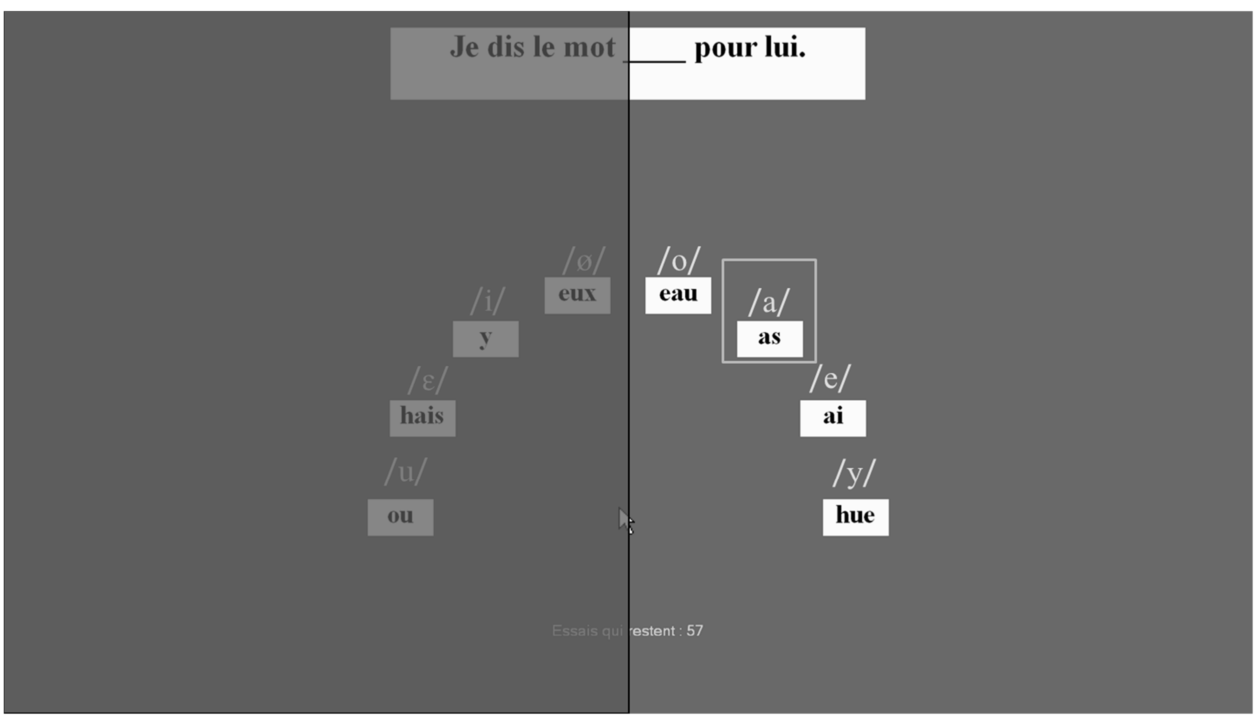


Figure 8: Within-group reaction time difference scores (in ms.) for all 6 experimental vowels, by speaker. The dotted line represents baseline performance. The asterisk * represents a significant difference from baseline (see Appendix O for *p*-values). The asterisk ⁎ represents a pairwise difference (see Appendix O for *p*-values).

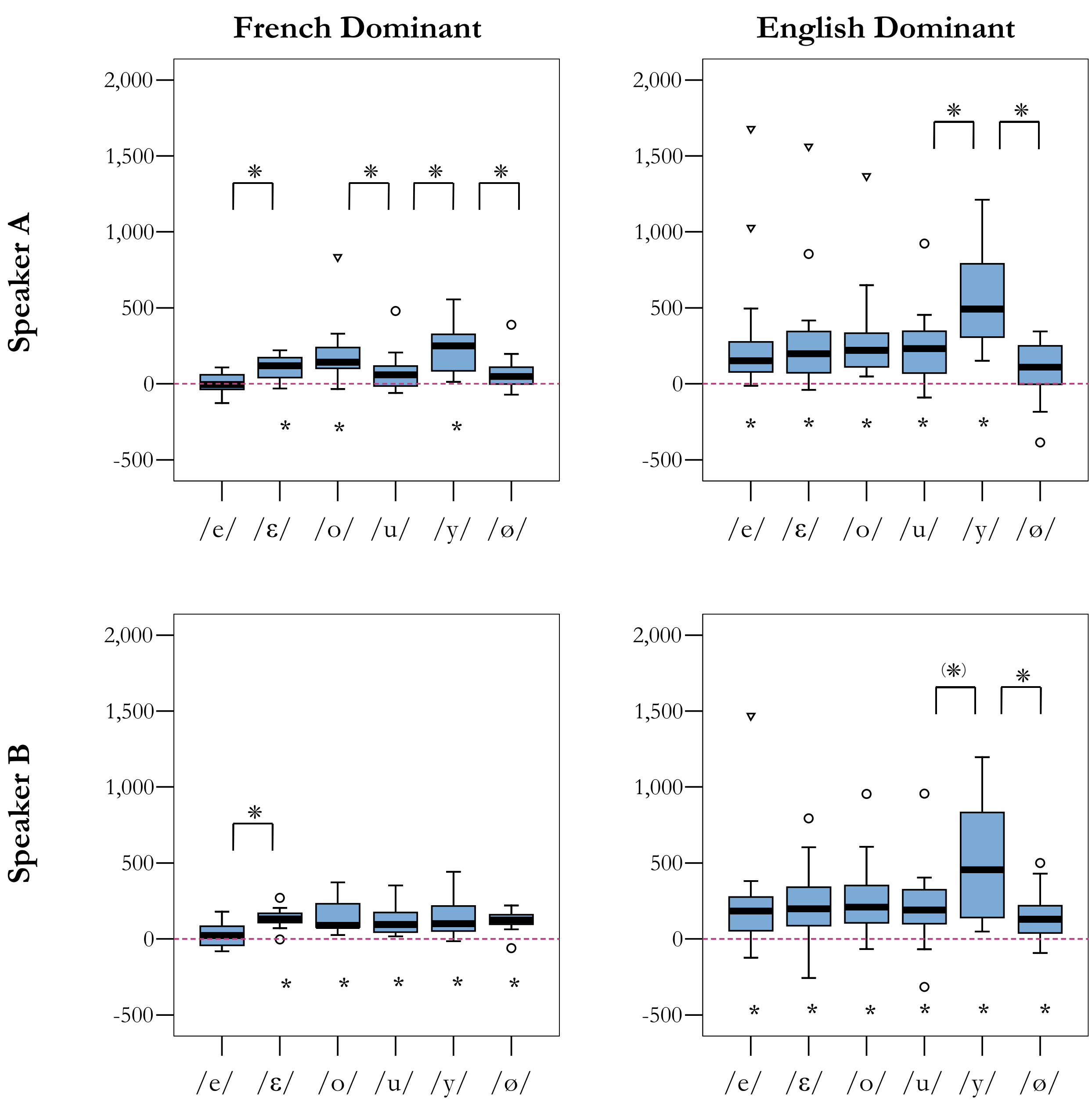


Figure 9: Within group anomalous mouse track difference scores (in proportion) for all 6 experimental vowels, by speaker. The dotted line represents baseline performance. The asterisk * represents a significant difference from baseline (see Appendix R for *p*-values).

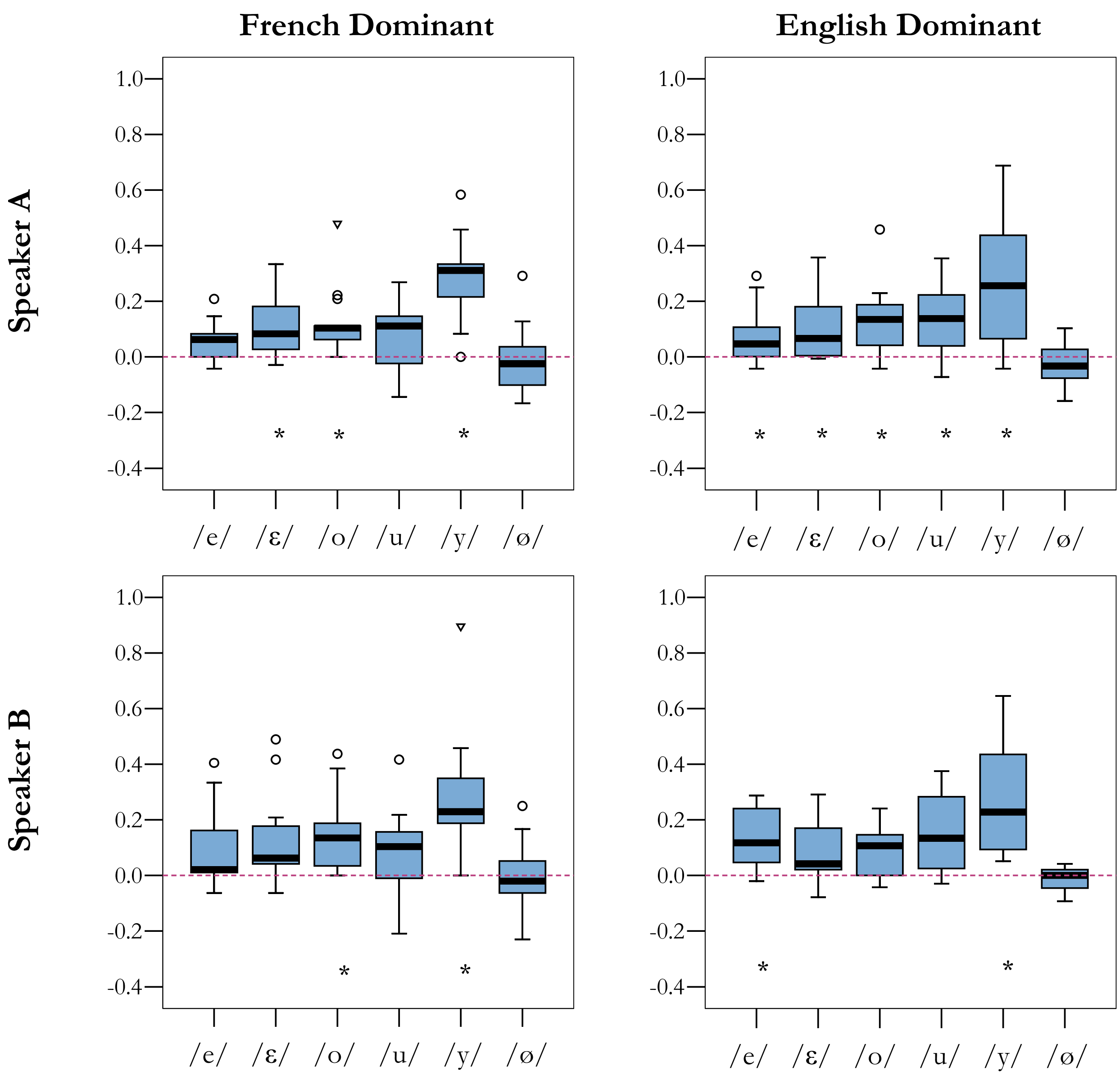


Figure 10: Interesting turning points of mouse tracks for front-rounded vowels.

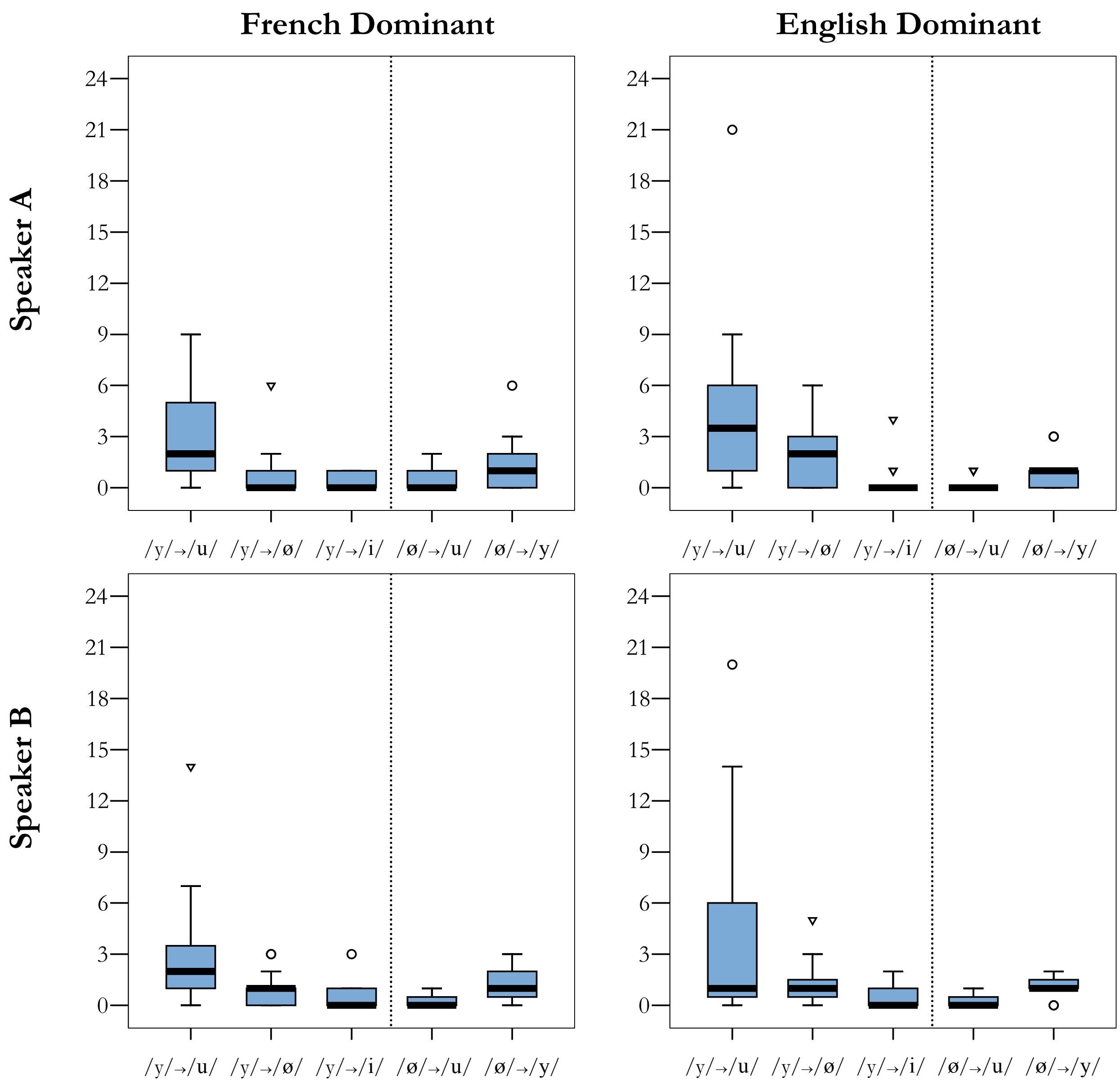


Figure 11: Turning points of mouse tracks to spectrally higher vowels.

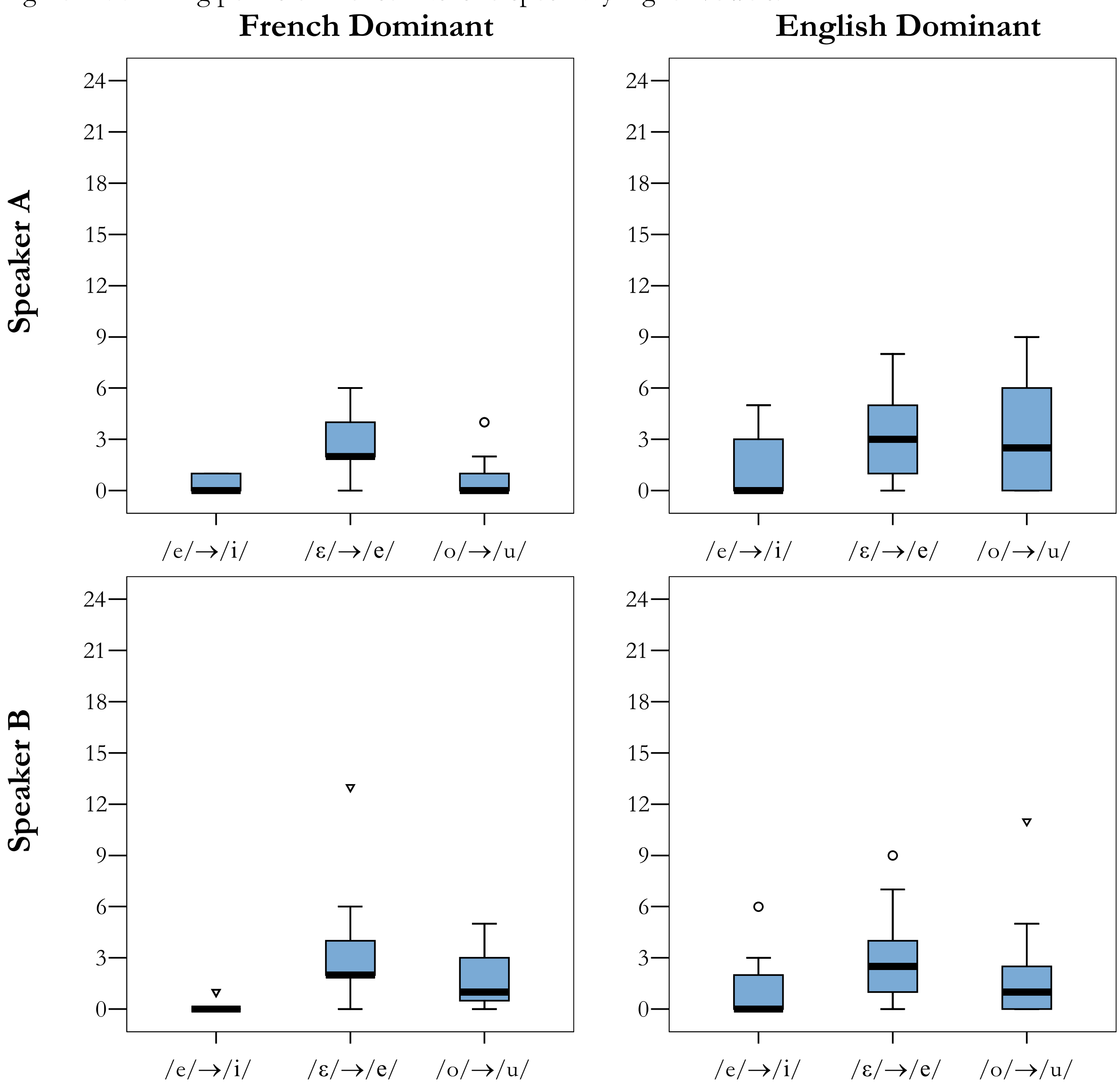


Figure 12: Mouse track turning points: Possible asymmetries of vowel pairs that may be confused with each other.

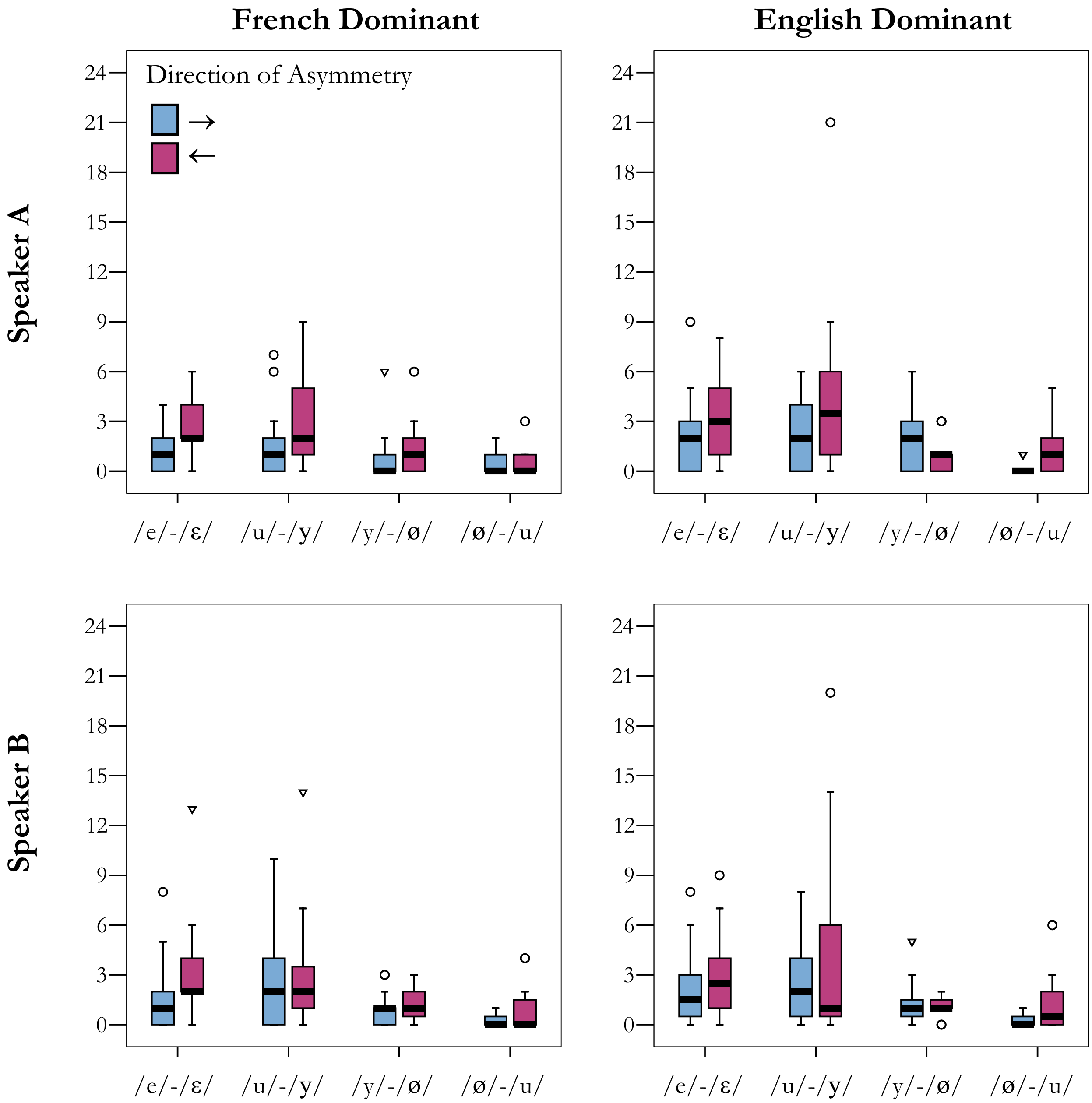


Figure 13: Comparison of A' scores between groups in identification of /e/-/ɛ/ in lexical and morphological tokens.

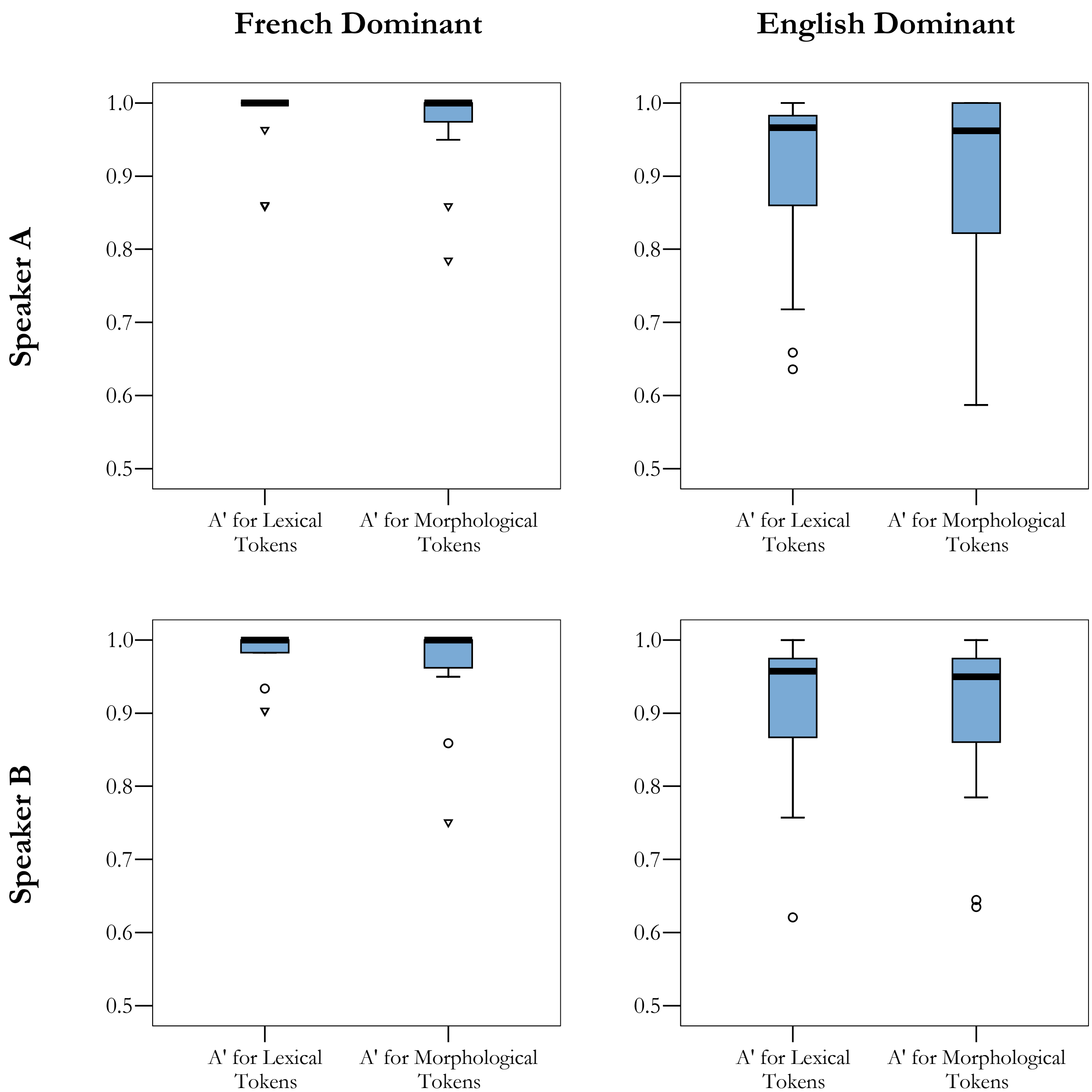


Figure 14: Comparison of the reaction time difference scores of /e/-/ɛ/ in lexical v. morphological tokens. The asterisk * represents a significant difference from baseline (see Appendix O for *p*-values). The asterisk ⁕ represents a pairwise difference (see Appendix O for *p*-values).

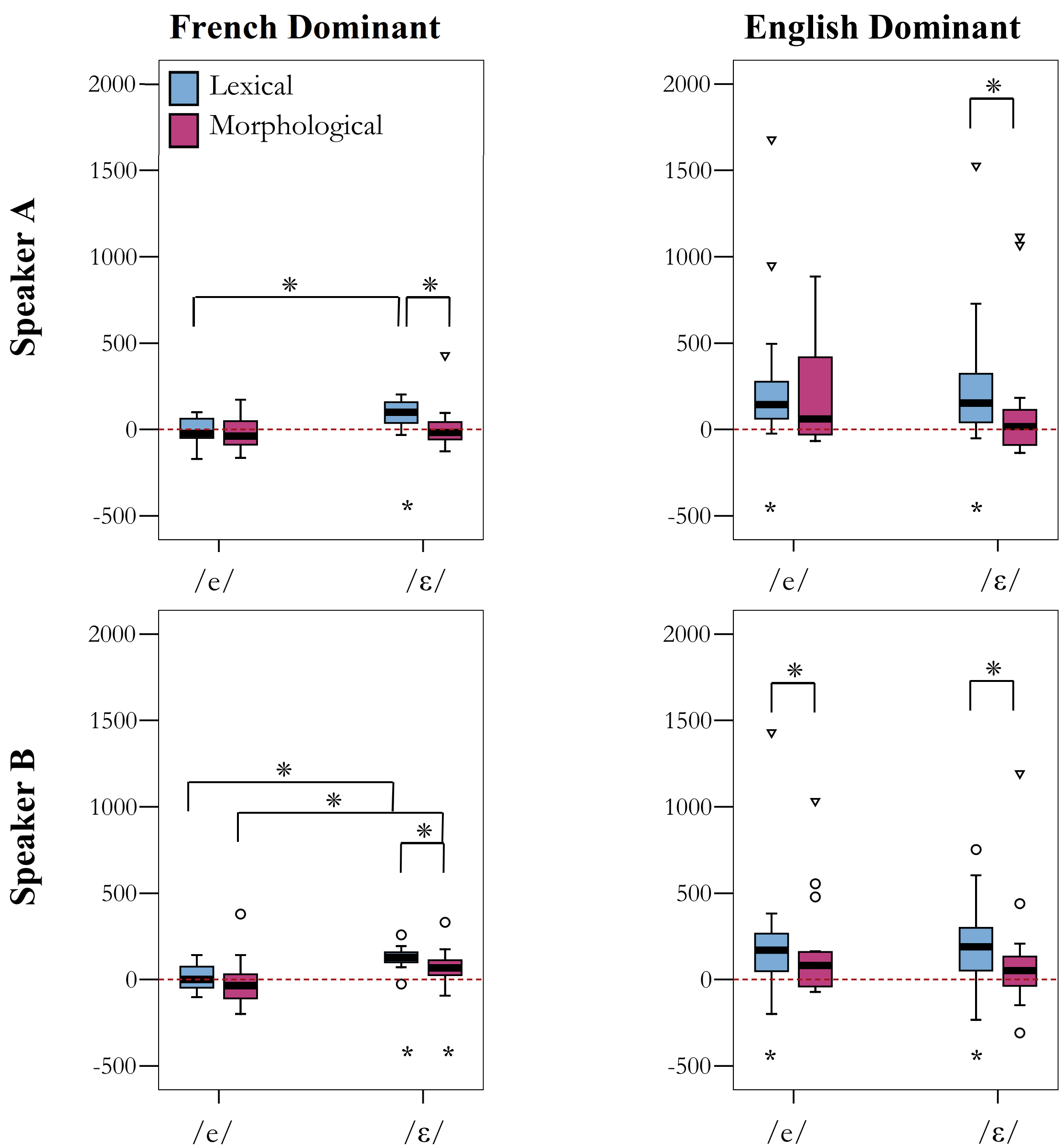
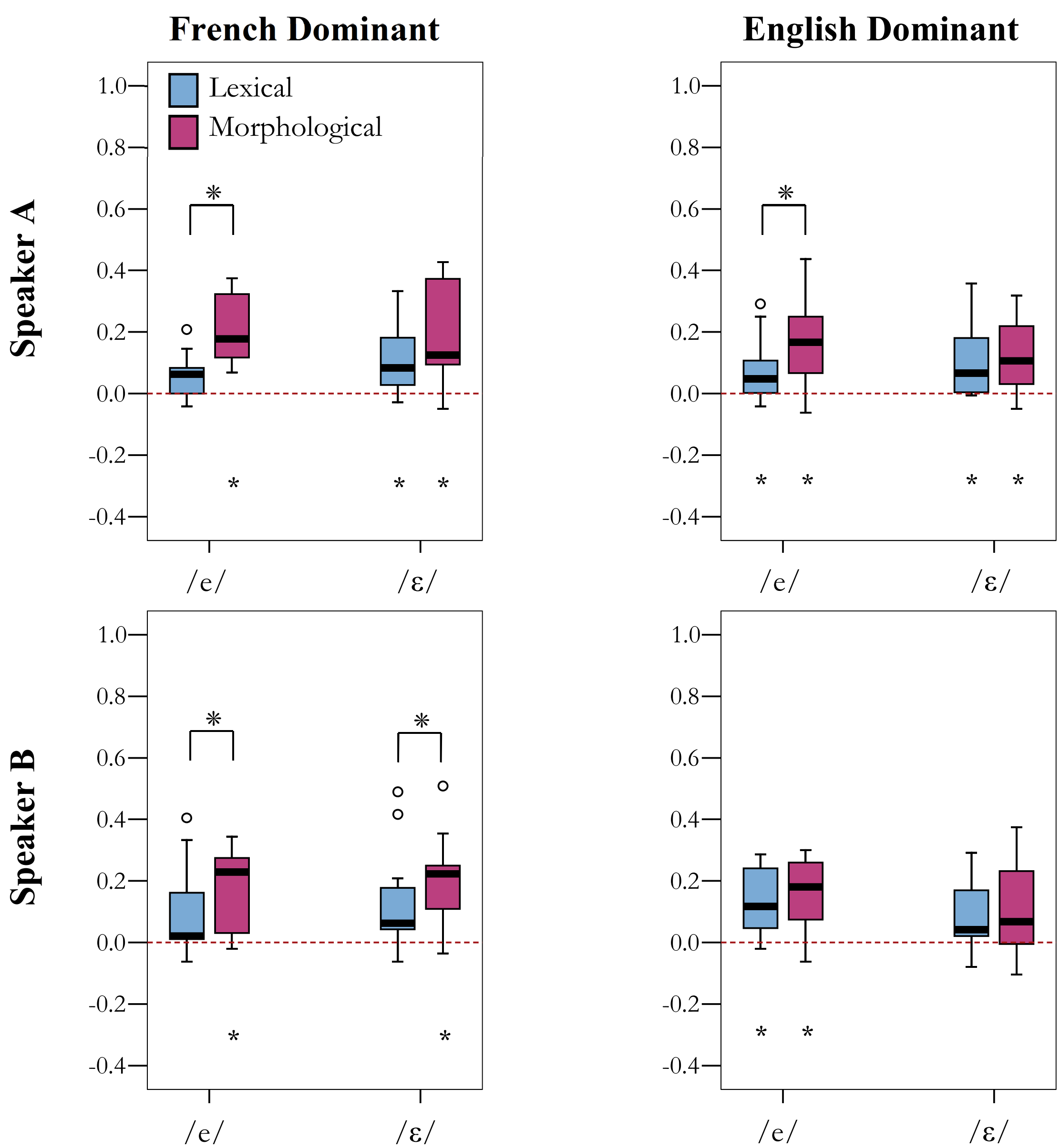


Figure 15: Within group anomalous mouse track difference scores (in proportion) for /e/-/ɛ/ in lexical v. morphological tokens, by speaker. The dotted line represents baseline performance. The asterisk * represents a significant difference from baseline and the asterisk ✻ represents a pairwise difference (see Appendix R for *p*-values).



## Appendices

Appendix A: Participant Characteristics

| | Participant | Speaker Order | Button Order | Gender | Age | Dominant Language | First Language | Birthplace |
|---|---|---|---|---|---|---|---|---|
| French-Dominant Bilinguals | Bil_13 | B | | F | 29 | French | French | Quebec City, QC |
| | Bil_22 | A | counter | M | 34 | French | English | Montreal, QC |
| | Bil_25 | A | counter | F | 22 | French | French | Lasalle, QC |
| | Bil_29 | B | counter | F | 20 | French | French | Montreal, QC |
| | M_03 | B | | F | 53 | French | French | Abitibi, QC |
| | M_04 | A | | F | 19 | French | French | Longueuil, QC |
| | M_05 | B | | F | 54 | French | French | Malartic, QC |
| | M_06 | A | | M | 26 | French | French | Quebec City, QC |
| | M_07 | B | | F | 46 | French | French | Quebec City, QC |
| | M_08 | A | counter | F | 32 | French | French | Montreal, QC |
| | M_10 | B | counter | F | 25 | French | French | Longueuil, QC |
| | M_11 | A | counter | F | 21 | French | French | Hull, QC |
| | M_12 | A | | M | 29 | French | French | Montreal, QC |
| | M_13 | B | counter | M | 26 | French | French | Drummondville, QC |
| | M_14 | B | counter | M | 43 | French | French | Montreal, QC |
| | M_15 | A | | M | 33 | French | French | Lasalle, QC |
| English-Dominant Bilinguals | Bil_09 | A | | F | 21 | English | English | Ottawa, ON |
| | Bil_10 | B | | F | 31 | English | English | Montreal, QC |
| | Bil_14 | A | | M | 23 | English | French | Montreal, QC |
| | Bil_15 | B | | M | 43 | English | English | Montreal, QC |
| | Bil_16 | A | | M | 24 | English | French/English | Montreal, QC |
| | Bil_17 | B | | F | 40 | English | English | Montreal, QC |
| | Bil_18 | A | counter | M | 34 | English | English | Montreal, QC |
| | Bil_19 | B | counter | M | 43 | English | French | Montreal, QC |
| | Bil_20 | A | counter | F | 27 | English | French/English | Montreal, QC |
| | Bil_26 | B | counter | F | 25 | English | English | Ottawa, ON |
| | Bil_28 | A | counter | F | 24 | English | English | Montreal, QC |
| | Bil_31 | B | | F | 24 | English | English | Montreal, QC |
| | Bil_32 | A | | F | 25 | English | English | Ottawa, ON |
| | Bil_34 | B | counter | M | 23 | English | English | Montreal, QC |
| | Bil_35 | B | counter | F | 29 | English | English | Montreal, QC |
| | Bil_36 | A | counter | F | 33 | English | English | Bancroft, ON |
| Judges | J_03 | A | judge | F | 23 | French | English/French | Montreal, QC |
| | J_04 | B | judge | M | 27 | French | French | Laval, QC |
| | J_05 | A | judge | M | 30 | French | French | Montreal, QC |

Appendix B: Language Background Questionnaire

# Questionnaire de formation linguistique

**Veuillez compléter ce questionnaire au mieux de vos connaissances, et ajouter toute information qui vous semble pertinente.**

Date : _____/_____/______ Date de naissance : _____/______/______Âge :_____ No. de participant______

Prénom :___________________________Nom :______________________Situation maritale :_________

Adresse :_________________________________________Ville :_______________Province :_________

Téléphone (Domicile) : ____________________(Professionnel/Cellulaire) :_________________________

Adresse de courriel : ______________________Emploi :__________________________________________

Sexe : _________Manualité :_________ Race/Origine ethnique (facultatif) :__________________________

Lieu de naissance :_______________________________________________

Langue maternelle :____________________

Quelles autres langues parlez-vous couramment et comprenez sans effort ?

1.____________________2.__________________3.____________________4.____________________

Lieux où vous avez vécu plus de trois ans :

| Ville/Province/Pays | | Années | | |
|---|---|---|---|---|
| __________________________________ | de | _________________ | à | _________________ |
| __________________________________ | de | _________________ | à | _________________ |
| __________________________________ | de | _________________ | à | _________________ |
| __________________________________ | de | _________________ | à | _________________ |

Voyagez-vous régulièrement dans des pays non anglophones ou non francophones?

❑ OUI ❑ NON

Si OUI, indiquez le lieu, la fréquence et la longueur des séjours____________

**Milieu familial**

Lieu de naissance de la mère/du tuteur :________________________Langue(s) parlée(s) :________________

Lieu de naissance de la grand-mère maternelle :__________________Langue(s) parlée(s) :________________

Lieu de naissance du grand-père maternel : _____________________Langue(s) parlée(s) :________________

Lieu de naissance du père :___________________________________Langue(s) parlée(s) :________________

Lieu de naissance de la grand-mère paternelle :__________________Langue(s) parlée(s) :________________

Lieu de naissance du grand-père paternel : ______________________Langue(s) parlée(s) :________________

(le cas échéant)
Lieu de naissance de la gouvernante/nounou :___________________Langue(s) parlée(s) :________________

Lorsque vous étiez enfant, une personne autre que vos parents (par exemple, un grand-parent, une nounou) jouait-elle avec vous en parlant une langue différente de votre langue maternelle?

Si oui, qui (lien de parenté)__________________Dans quelle langue?____________________

qui (lien de parenté)__________________Dans quelle langue?____________________

**Formation scolaire**

Veuillez sélectionner toutes les réponses pertinentes et répertorier les langues, le cas échéant, sur la droite :

| | | | |
|---|---|---|---|
| A. Jardin d'enfants : | ❑ en français | ❑ en anglais | ❑ Autre __________________ |
| B. École primaire : | ❑ en français | ❑ en anglais | ❑ Autre __________________ |
| C. École intermédiaire : | ❑ en français | ❑ en anglais | ❑ Autre __________________ |
| D. École secondaire : | ❑ en français | ❑ en anglais | ❑ Autre __________________ |
| E. Collège : | ❑ en français | ❑ en anglais | ❑ Autre __________________ |
| F. École d'études supérieures/ École professionnelle : | ❑ en français | ❑ en anglais | ❑ Autre __________________ |

Veuillez mentionner les cours de langues spéciaux ou autres : (par exemple, cours de linguistique et de conversation, classes bilingues et anglais deuxième langue, cours de littérature dans des langues autres que l'anglais ou le français)______________________________________________

Avez-vous étudié la phonétique (étude des sons du langage) au lycée ou à l'université.

❑ OUI ❑ NON

Si vous avez répondu OUI à la question précédente, avez vous fait de la transcription phonétique :

❑ OUI ❑ NON Si OUI, combien d'années : ____

**Cursus linguistique**

Quel âge aviez-vous lorsque vous avez commencé à parler français? ____L'anglais? ___Une autre langue?___

Quel âge aviez-vous lorsque vous avez commencé à lire le français?____L'anglais? ____Une autre langue?____

Quel âge aviez-vous lorsque vous avez commencé à écrire le français? ___L'anglais? ___Une autre langue?___

Veuillez indiquer les autres langues apprises non mentionnées plus haut et l'âge de leur acquisition :

Langue : ____________________ Âge d'acquisition :___________________

Langue : ____________________Âge d'acquisition :___________________

Langue : ____________________ Âge d'acquisition :___________________

Dans quelle langue communiquez-vous le mieux selon vous?______________________

Combien de temps au cours d'une journée entendez-vous l'un des éléments qui suivent (veuillez entourer une réponse) :

1. Francophones sans accent :
❑ Toute la journée ❑ 1/2 de la journée ❑ 1/4 de la journée ❑ 1/8 de la journée

2. Français avec accent :
❑ Toute la journée ❑ 1/2 de la journée ❑ 1/4 de la journée ❑ 1/8 de la journée

3. Français avec accent parlé par des personnes chez vous :
❑ Toute la journée ❑ 1/2 de la journée ❑ 1/4 de la journée ❑ 1/8 de la journée

4. Anglophones sans accent :
❑ Toute la journée ❑ 1/2 de la journée ❑ 1/4 de la journée ❑ 1/8 de la journée

5. Anglais avec accent :
❑ Toute la journée ❑ 1/2 de la journée ❑ 1/4 de la journée ❑ 1/8 de la journée

6. Anglais avec accent parlé par des personnes chez vous :
❑ Toute la journée ❑ 1/2 de la journée ❑ 1/4 de la journée ❑ 1/8 de la journée

Avez-vous une audition normale : ❑ OUI ❑ NON

Avez vous jamais suivi une thérapie orthophonique dans le passé ou actuellement : ❑ OUI ❑ NON

Pour les questions suivantes, cochez le chiffre qui correspond aux proportions dans lesquelles vous utilisez votre langue maternelle et l'anglais.

**« 1 »** si vous utilisez le français quasiment tout le temps (90 à 100 % français)

**« 2 »** si vous utilisez le français et un tout petit peu d'anglais (75 à 90 % français / 10 à 25 % anglais)

**« 3 »** si vous utilisez le français et un peu d'anglais (60 à 74 % français / 26 à 40 % anglais)

**« 4 »** si vous utilisez le français et l'anglais à parts égales (50 % français / 50 % anglais)

**« 5 »** si vous utilisez l'anglais et un peu de français (60 à 74 % anglais / 26 à 40 % français)

**« 6 »** si vous utilisez l'anglais et un tout petit peu de français (75 à 90 % anglais / 10 à 25 % français)

**« 7 »** si vous utilisez l'anglais quasiment tout le temps (90 à 100 % anglais)

Veuillez cocher le chiffre qui correspond aux proportions dans lesquelles vous **utilisez généralement** les différentes langues dans les **situations** suivantes. Essayez de baser vos estimations sur l'utilisation de votre langue maternelle ou de l'anglais lors de la période pendant laquelle vous avez vécu au Canada. Suivez le barème ci-dessus :

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | S/O |
|---|---|---|---|---|---|---|---|---|
| **Utilisation :** | **Français quasiment tout le temps** | **Français en général avec très peu d'anglais** | **Français en général avec un peu d'anglais** | **Français à parts égales avec l'anglais** | **Anglais en général, avec un peu de** | **Anglais en général, avec très peu de français** | **Anglais quasiment tout le temps** | |
| Entendu et parlé au travail, à l'école | | | | | | | | |
| Entendu et parlé à l'école, dans les magasins, dans les soirées | | | | | | | | |
| Entendu, parlé à la maison et dans le voisinage | | | | | | | | |
| Entendu à la télé, à la radio, sur Internet, dans les films, les vidéos, les jeux vidéo, etc. | | | | | | | | |
| Lu/écrit à la maison, au travail, à l'école | | | | | | | | |
| Lu/écrit pour le plaisir | | | | | | | | |

Souhaitez-vous participer à des enquêtes futures? ❑ OUI ❑ NON

*Trans.*

# Language Background Questionnaire

**Please complete this questionnaire to the best of your knowledge and add any information you feel might be relevant.**

Date: ______/______/______D.O.B.: ______/____/_______Age:_______ Participant number_______

Name (First):________________________(Last):______________________Marital Status:____________

Address:__________________________________________City:________________Province:_________

Telephone (Home): _______________________(Work/Cell):____________________________________

E-mail address: _________________________Occupation:_______________________________________

Gender: ____________Handedness:_________ Race/Ethnic Background (optional):_________________

Birthplace:______________________________________________________

Native Language:_____________________

What other languages do you speak fluently and understand without effort?

1.____________________2.__________________3.____________________4.___________________

Places in which you have lived for more than 3 years:

| City/Province/Country | Years | |
|---|---|---|
| __________________________________________ | from ____________ | to ____________ |
| __________________________________________ | from ____________ | to ____________ |
| __________________________________________ | from ____________ | to ____________ |
| __________________________________________ | from ____________ | to ____________ |

Do you travel to any other non-English or non-French speaking country regularly?

❑ OUI ❑ NON

If YES, specify place, frequency and length of stay_________________________________________

**Family Background**

Mother's/Guardian's birthplace:__________________________Language(s) spoken:_____________________

Maternal Grandmother's birthplace:_______________________Language(s) spoken:_____________________

Maternal Grandfather's birthplace: _______________________Language(s) spoken:_____________________

Father's birthplace:_____________________________________Language(s) spoken:_____________________

Paternal Grandmother's birthplace:_______________________Language(s) spoken:_____________________

Paternal Grandfather's birthplace: _______________________Language(s) spoken:_____________________

(If applicable)
Caretaker's/Nanny's birthplace:__________________________Language(s) spoken:_____________________

When you were a child, did anyone other than your parents (e.g., grandparent, nanny) play games with you in a language other than your first language?

If yes, who (relationship)____________________In what language?_____________________

who (relationship)____________________ In what language?_____________________

**Educational Background**

Please check all that applies and list the languages, if applicable on the right:

| | | | |
|---|---|---|---|
| A. Pre-school: | ❑ in French | ❑ in English | ❑ Other __________________ |
| B. Elementary: | ❑ in French | ❑ in English | ❑ Other __________________ |
| C. Middle School: | ❑ in French | ❑ in English | ❑ Other __________________ |
| D. High School: | ❑ in French | ❑ in English | ❑ Other __________________ |
| E. College: | ❑ in French | ❑ in English | ❑ Other __________________ |
| F. Graduate/professional school: | ❑ in French | ❑ in English | ❑ Other __________________ |

Specify special language classes or other: (e.g., linguistics, speech, bilingual, ESL classes, literature classes in languages other than English or French)_______________________________________

Have you studied phonetics (study of language sounds) in high school or in college?

❑ YES ❑ NO

If you responses YES to the preceding question, have you done any phonetic transcription:

❑ YES ❑ NO If YES, how many years: ______

**Language History**

How old were you when you started to speak French? __________ English? _____ Other language?______

How old were you when you started to read French? ___________ English? _____ Other language?______

How old were you when you started to write in French? ________ English? _____ Other language?______

Please specify other languages learned not mention above and age of acquisition below:

Language: ____________________ Age of acquisition:____________________

Language: ____________________ Age of acquisition:____________________

Language: ____________________ Age of acquisition:____________________

In what language do you feel you communicate best?______________________________

About what portion of the day do you listen to the following (please circle one):

| | | | | |
|---|---|---|---|---|
| 1. French speakers with no accent: | ❑ Whole day | ❑ 1/2 day | ❑ 1/4 day | ❑ 1/8 day |
| 2. Accented French: | ❑ Whole day | ❑ 1/2 day | ❑ 1/4 day | ❑ 1/8 day |
| 3. Accented French with speakers in your home: | ❑ Whole day | ❑ 1/2 day | ❑ 1/4 day | ❑ 1/8 day |
| 4. English speakers with no accent: | ❑ Whole day | ❑ 1/2 day | ❑ 1/4 day | ❑ 1/8 day |
| 5. Accented English: | ❑ Whole day | ❑ 1/2 day | ❑ 1/4 day | ❑ 1/8 day |
| 6. Accented English with speakers in your home: | ❑ Whole day | ❑ 1/2 day | ❑ 1/4 day | ❑ 1/8 day |

Do you have normal hearing: ❑ YES ❑ NO

Have you ever had speech therapy in the past or presently: ❑ YES ❑ NO

For the following questions, check the number that corresponds with the amount that you use your native language and English.

**"1"** if you use French almost all the time (90-100% French)

**"2"** if you use French with a little English (75-90% French / 10-25% English)

**"3"** if you use French with some English (60-74% French / 26-40% English)

**"4"** if you use French about equally with English (50% French / 50% English)

**"5"** if you use English with some French (60-74% English / 26-40% French)

**"6"** if you use English usually with a little French (75-90% English / 10-25% French)

**"7"** If you use English almost all of the time (90-100% English)

Please check the number that corresponds with the amount that you **generally use** in the following **situations**. Try to base your estimate on your use of your native language or English during the time that you have lived in Canada. Follow the scale above:

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | n/a |
|---|---|---|---|---|---|---|---|---|
| **Use:** | **French almost all the time** | **French usually with a little English** | **French with some English** | **French as much as English** | **English usually with some French** | **English usually with a little French** | **English almost all the time** | |
| Listening/talking at work/school | | | | | | | | |
| Listening/talking at church, shopping, parties | | | | | | | | |
| Listening/talking at home and in the neighborhood | | | | | | | | |
| Listening to TV, radio, internet, movies, videos, video games, etc | | | | | | | | |
| Reading/writing at work/school | | | | | | | | |
| Reading/writing for pleasure | | | | | | | | |

Would you like to participate in future studies? ❑ YES ❑ NO

Appendix C: Measures of language proficiency: results of questionnaire, judgments on narration task, resuls of listening comprehension task, and written task.

| Group | Participant | work/ school | stores | home | television/ radio | reading at home | reading at work | Judgment Scores | Judgment Ranking | Audio Test | Written Test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| French-Dominant Bilinguals | Bil_13 | 5 | 5 | 3 | 4 | 4 | 4 | 44 | 23.5 | 84% | 100% |
| | Bil_22 | 4 | 3 | 3 | 4 | 2 | 3 | 48 | 20.5 | 76% | 96% |
| | Bil_25 | 5 | 3 | 2 | 6 | 6 | 3 | 54 | 6 | 96% | 92% |
| | Bil_29 | 7 | 6 | 1 | 3 | 3 | 1 | 53 | 14 | 88% | 100% |
| | M_03 | 1 | 1 | 1 | 3 | 1 | 1 | 54 | 6 | 96% | 96% |
| | M_04 | 1 | 3 | 1 | 3 | 1 | 2 | 54 | 6 | 80% | 92% |
| | M_05 | 1 | 4 | 3 | 4 | 2 | 1 | 54 | 6 | 84% | 75% |
| | M_06 | 3 | 3 | 3 | 4 | 4 | 3 | 54 | 6 | 96% | 83% |
| | M_07 | 1 | 1 | 1 | 3 | 1 | 1 | 54 | 6 | 80% | 92% |
| | M_08 | 1 | 3 | 1 | 5 | 3 | 4 | 54 | 6 | 76% | 96% |
| | M_10 | 1 | 3 | 1 | 7 | 1 | 3 | 53 | 14 | 92% | 79% |
| | M_11 | 1 | 2 | 1 | 3 | 2 | 1 | 54 | 6 | 96% | 100% |
| | M_12 | 1 | 1 | 2 | 7 | 1 | 4 | 53 | 14 | 80% | 100% |
| | M_13 | 3 | 3 | 1 | 4 | 4 | 4 | 54 | 6 | 92% | 100% |
| | M_14 | 3 | 3 | 1 | 4 | 3 | 3 | 54 | 6 | 96% | 100% |
| | M_15 | 6 | 3 | 2 | 6 | 4 | 2 | 54 | 6 | 84% | 100% |
| English-Dominant Bilinguals | Bil_09 | 7 | 4 | 5 | 5 | 4 | 4 | 42 | 25.5 | 80% | 92% |
| | Bil_10 | 4 | 5 | 7 | 2 | 3 | 6 | 51 | 18.5 | 100% | 71% |
| | Bil_14 | 7 | 5 | 1 | 7 | 6 | 7 | 38 | 28 | 80% | 92% |
| | Bil_15 | 3 | 4 | 3 | 5 | 5 | 5 | 42 | 25.5 | 92% | 92% |
| | Bil_16 | 6 | 5 | 4 | 7 | 6 | 6 | 52 | 17 | 96% | 100% |
| | Bil_17 | 5 | 4 | 5 | 6 | 5 | 6 | 53 | 14 | 84% | 96% |
| | Bil_18 | 1 | 3 | 4 | 5 | 4 | 7 | 46 | 22 | 80% | 83% |
| | Bil_19 | 5 | 5 | 4 | 4 | 4 | 5 | 51 | 18.5 | 80% | 92% |
| | Bil_20 | 5 | 5 | 4 | 7 | 5 | 4 | 41 | 27 | 88% | 88% |
| | Bil_26 | 3 | 5 | 5 | 6 | 6 | 7 | 17 | 32 | 84% | 75% |
| | Bil_28 | 3 | 5 | 7 | 7 | 6 | 6 | 34 | 29 | 76% | 88% |
| | Bil_31 | 3 | 4 | 3 | 6 | 6 | 6 | 53 | 14 | 84% | 79% |
| | Bil_32 | 4 | 3 | 4 | 7 | 4 | 6 | 48 | 20.5 | 84% | 100% |
| | Bil_34 | 7 | 5 | 5 | 6 | 6 | 5 | 33 | 30 | 92% | 88% |
| | Bil_35 | 5 | 5 | 6 | 6 | 6 | 5 | 44 | 23.5 | 88% | 83% |
| | Bil_36 | 5 | 4 | 6 | 6 | 5 | 7 | 23 | 31 | 100% | 79% |
| Judges | J_03 | 2 | 4 | 2 | 6 | 2 | 6 | N/A | N/A | 88% | 92% |
| | J_04 | 3 | 3 | 1 | 5 | 6 | 2 | N/A | N/A | 84% | 63% |
| | J_05 | 4 | 3 | 1 | 4 | 4 | 3 | N/A | N/A | 100% | 92% |

Appendix D: Age of Acquisition for Each Participant

| | Participant | Age for Speaking French | Age for Reading French | Age for Writing French |
|---|---|---|---|---|
| French-Dominant Bilinguals | Bil_13 | 0 | 5 | 5 |
| | Bil_22 | 13 | 12 | 13 |
| | Bil_25 | 0 | 4-5 | 4-5 |
| | Bil_29 | 1.5 | 6 | 6 |
| | M_03 | 2 | 5 | 6 |
| | M_04 | 2.5 | 6 | 6 |
| | M_05 | 3 | 5 | 5 |
| | M_06 | 0-1 | 6 | 6 |
| | M_07 | 0 | 6 | 6 |
| | M_08 | 2 | 5 | 5 |
| | M_10 | 2 | 6 | 6 |
| | M_11 | 1 | 6 | 6 |
| | M_12 | 2 | 5 | 5 |
| | M_13 | 1 | 6 | 6 |
| | M_14 | 1 | 3.5 | 5.5 |
| | M_15 | 1 | 6 | 6 |
| English-Dominant Bilinguals | Bil_09 | 4 | 4 | 4.5 |
| | Bil_10 | 5 | 5 | 5 |
| | Bil_14 | 2 | 5 | 5 |
| | Bil_15 | 18 | 18 | 18 |
| | Bil_16 | 2 | 5 | 6 |
| | Bil_17 | 5 | 5 | 6 |
| | Bil_18 | 10 | 10 | 10 |
| | Bil_19 | 2 | 4 | 4 |
| | Bil_20 | 3 | 5 | 5 |
| | Bil_26 | 5 | 5 | 5 |
| | Bil_28 | 4-5 | 5-6 | 5-6 |
| | Bil_31 | 2 | 5 | 5 |
| | Bil_32 | 4 | 5 | 6 |
| | Bil_34 | 2 | 5 | 5 |
| | Bil_35 | 10 | 10 | 10 |
| | Bil_36 | 6 | 6 | 8 |
| Judges | J_01 | 0 | 4 | 5 |
| | J_02 | 1 | 5 | 5 |
| | J_03 | 1 | 4 | 5 |

Appendix E: List of all 58 target words. The target words are grouped by preceding phonetic context. For the tokens preceded by /ʁ/, the lexical minimal pair is listed first, followed by the morphosyntactic minimal pairs for each vowel.

| | IPA | Real | Gloss | Nonsense |
|---|---|---|---|---|
| **Labial** | /i/ | pis | "worse" | gispit |
| | /y/ | pu | past. part of "to be able" | gispu |
| | /e/ | épée | "sword" | gispé |
| | /ɛ/ | paix | "peace" | gispais |
| | /a/ | pas | "step" | gispas |
| | /ø/ | peux | 1st per. sing. pres. of "to be able" | gispeux |
| | /o/ | peau | "skin" | gispôt |
| | /u/ | poux | "lice" | gispou |
| **Coronal** | /i/ | dis | 1st per. sing. pres. of "to say" | gistit |
| | /y/ | tu | "you" (sing.) | gistu |
| | /e/ | thé | "tea" | gisté |
| | /ɛ/ | tais | 1st per. sing. pres. of "to hush" | gistais |
| | /a/ | ta | "your" (fem. sing. poss.) | gistas |
| | /ø/ | deux | "two" | gisteux |
| | /o/ | tôt | "soon" | gistôt |
| | /u/ | doux | "sweet" | gistou |
| **Back** | /i/ | qui | "who" | gisquit |
| | /y/ | écu | "shield" | giscut |
| | /e/ | quai | "platform" | gisqué |
| | /ɛ/ | guet | "lookout, patrol" | gisquais |
| | /a/ | cas | "case" | gisquas |
| | /ø/ | queue | "tail" | gisqueux |
| | /o/ | écho | "echo" | gisquôt |
| | /u/ | cou | "back" | gisquou |
| **/ʁ/** | /e/ | ré | "re" | gisterai |
| | | finirai | "will finish" | |
| | | parlerai | "will talk" | |
| | | vendrai | "will sell" | |
| | /ɛ/ | craie | "chalk" | gisterais |
| | | parlerais | "would talk" | |
| | | finirais | "would finish" | |
| | | vendrais | "would sell" | |

Appendix F: Instructions for experimental task.

*Trans.*

Bonjour !

Hello!

Merci d'avoir accepté de participer à cette expérience. Vous serez amené à écouter plusieurs phrases au moyen de vos écouteurs. Un mot cible sera placé au milieu de chaque phrase. Votre tâche sera de vous concentrer sur ce mot cible et de sélectionner parmi les huit propositions offertes celle qui rime avec le mot cible.

Thank you for participating in this study. You will be listening to various sentences over headphones. There is a target word in the middle of each sentence. Your task is to focus on the target word and to pick which one of eight possible response options rhymes with the target word.

Vous devrez donc choisir le mot qui possède un son-voyelle final identique au son-voyelle final du mot cible (par exemple « pis » rime avec « y »).

That is, you will pick the response option that has the same vowel sound as the final vowel sound of the target word (for example, "pis" rhymes with "y").

Cliquer sur la souris pour continuer…

Click the mouse to continue...

Les huit propositions de réponse s'afficheront sur l'écran de votre ordinateur sous la forme de boutons :

eux eau<br>
y as<br>
hais ai<br>
ou hue

The eight response options will be displayed as buttons on the computer screen:

/ø/ /o/<br>
/i/ /a/<br>
/ɛ/ /e/<br>
/u/ /y/

Vous devrez sélectionner la bonne réponse en cliquant sur le bouton à l'aide de la souris. Certains mots cibles possèdent une signification, d'autres mots cibles ne signifient rien (mots inventés).

You will pick your response by clicking on the button, using the mouse. Some of the target words are real words. Others are nonsense words.

Cliquer sur la souris pour continuer…

Click the mouse to continue...

Par exemple, si vous entendez le mot cible « pis » dans la phrase :

« Je dis le mot pis pour lui. »

Vous devrez choisir « y » parce que ce mot possède le même son-voyelle final que le mot cible « pis ».

eux eau
***y*** as
hais ai
ou hue

Remarque : le son-voyelle final s'écrit différemment dans « y » et « pis », pourtant il s'agit de *sons* identiques.

Cliquer sur la souris pour continuer…

So, for example, if you heard the target word "pis" in the sentence:

"Je dis le mot pis pour lui."

You would pick "y" because it has the same vowel sound as the final vowel sound in "pis".

/ø/ /o/
**/i/** /a/
/ɛ/ /e/
/u/ /y/

Note that the same vowel sound is spelled differently in "y" and "pis" but that they *sound* the same.

Click the mouse to continue...

De la même manière, si vous entendez :

« Je dis le mot gispôt tout le temps. »

Vous devrez choisir « **eau** » parce que ce mot possède **le même son-voyelle final** que le mot cible « gispôt ».

eux ***eau***
y as
hais ai
ou hue

Cliquer sur la souris pour continuer…

Similarly, if you heard:

"Je dis le mot gispôt tout le temps."

You would pick "eau" because it has **the same vowel sound** as in "gispôt".

/ø/ **/o/**
/i/ /a/
/ɛ/ /e/
/u/ /y/

Click the mouse to continue...

Cette étude mesure à la fois vitesse et précision. Veuillez avancer aussi vite que vous le pouvez, tout en répondant de manière aussi précise que possible.

Pour commencer un test expérimental, il vous faudra appuyer sur le bouton vert portant la flèche que vous verrez sur l'écran.

Lorsque vous aurez appuyé sur ce bouton, veuillez garder la main sur la souris en essayant d'éviter tout mouvement superflu de la souris, sauf bien sûr pour sélectionner vos réponses. Les mouvements de souris superflus auront un impact sur vos résultats.

Si vous devez faire une petite pause ou retirer votre main de la souris, veuillez le faire *avant* d'appuyer sur le bouton vert pour commencer le test suivant, ou bien entre deux blocs expérimentaux.

Cliquer sur la souris pour continuer…

In this study, both speed and accuracy will be measured. Please go as fast as you can, while being as accurate as possible.

You will need to press the green button with the arrow on the screen in order to begin an experimental trial.

Once you have pressed this button, please keep your hand on the mouse and try not to make any extraneous moves with the mouse, except to select your answer. Extra mouse movement will negatively affect your results.

If you need to take a small break or to move your hand from the mouse, please wait to do so either during the time *before* you press the green button to begin the next trial, or between experimental blocks.

Click the mouse to continue…

Deux exercices de familiarisation vous permettront de vous entraîner, ils seront suivis par une série de douze exercices.

Pendant les exercices de familiarisation, si vous voudriez réécouter une phrase en particulier, vous devrez appuyer sur le bouton

Les exercices de familiarisation vous permettront de vous préparer. Si vous sélectionnez la bonne réponse, votre écran deviendra vert. Si vous sélectionnez la mauvaise réponse, votre écran deviendra rouge et la bonne réponse s'affichera. Aucune remarque ne sera faite au cours de l'expérience en elle-même (pendant les douze exercices).

En moyenne, chaque exercice comporte 58 questions et il faut compter entre 5 et 7 minutes par exercice. Si vous en ressentez le besoin, vous avez la possibilité de faire une pause entre les exercices.

Avez-vous des questions ?

Cliquer sur la souris lorsque vous êtes prêt à démarrer l'expérience.

There will be 2 practice blocks to familiarize you with the task, followed by 12 test blocks.

During the familiarization blocks, if you would like to hear a particular sentence again, you may press the "Replay" button once to hear it again.

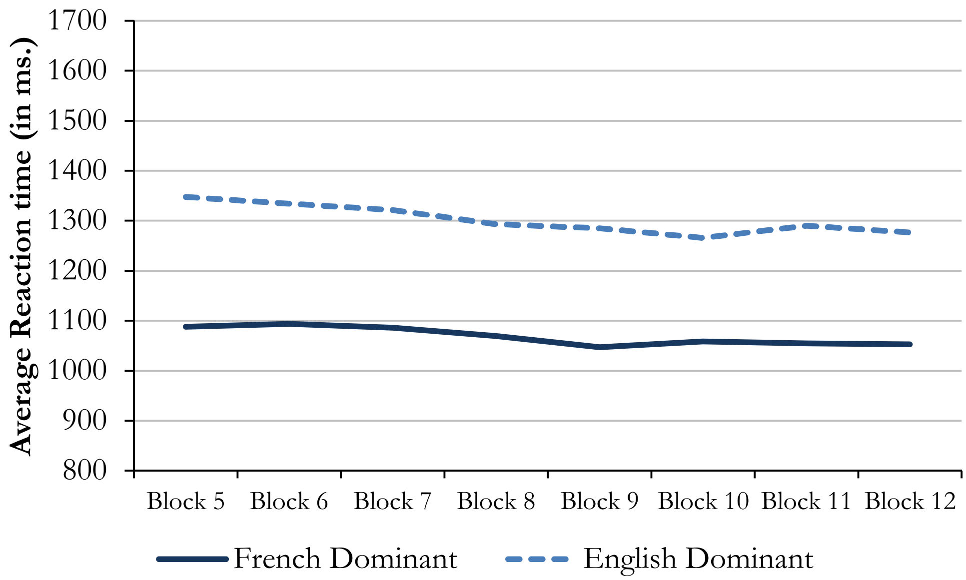
The familiarization blocks will give you a chance to practice. If you get the correct answer, the screen will turn green. If you give an incorrect answer, the screen will turn red and the correct answer will be displayed. There will be no feedback during the actual experiment (12 test blocks).

Each test block contains approximately 58 trials and each block takes approximately 5-7 minutes per block. You may take a break between blocks if you need to.

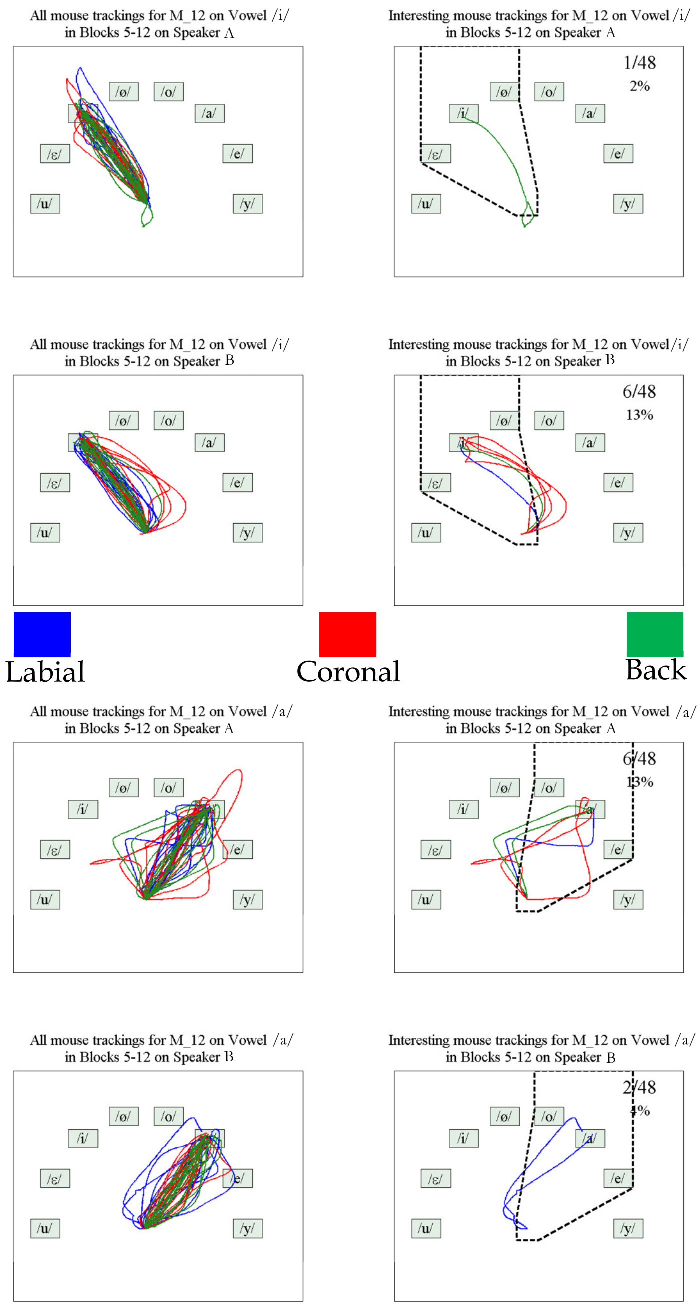
Any questions?

Click the mouse when you are ready to begin the experiment.

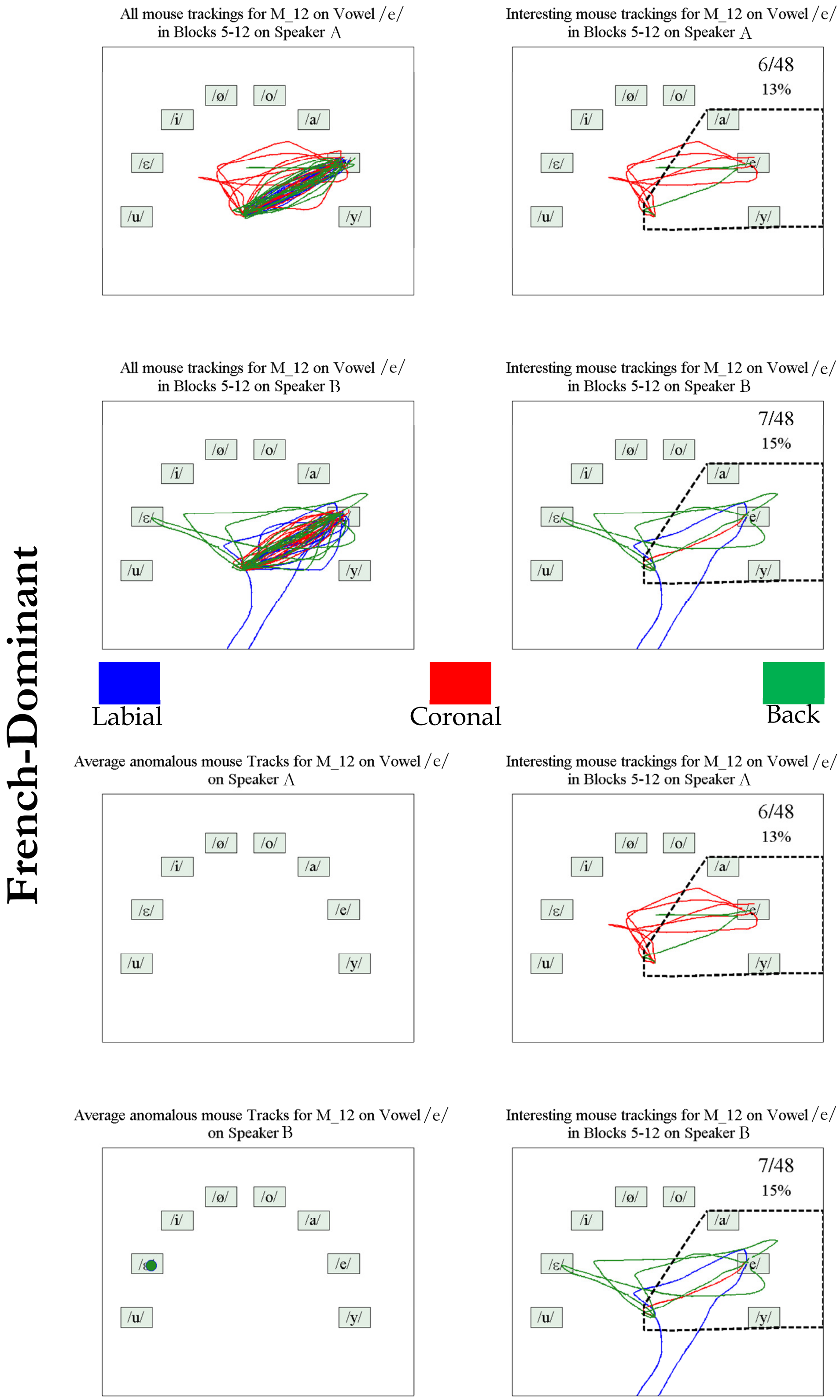
Appendix G: Average reaction time by block.

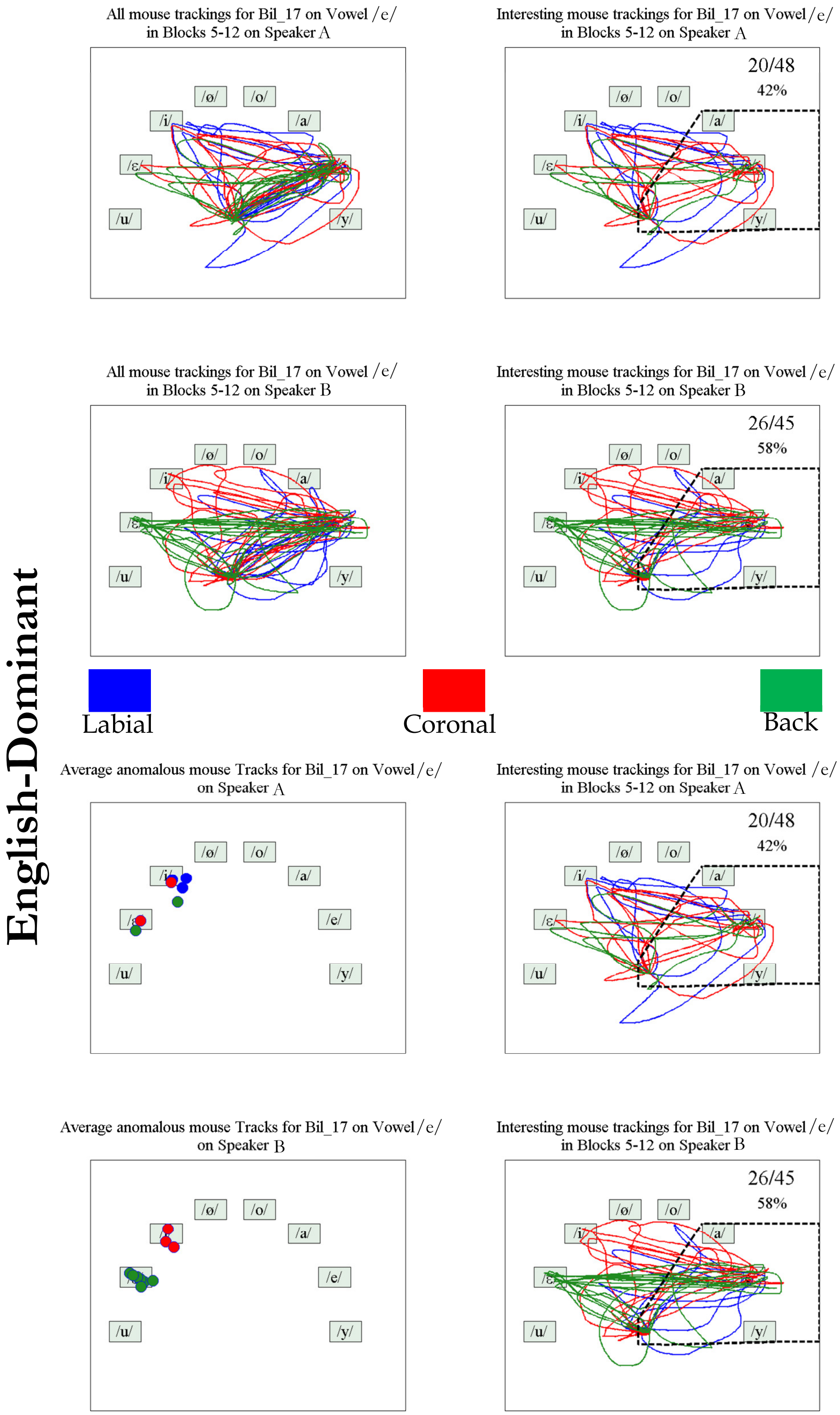


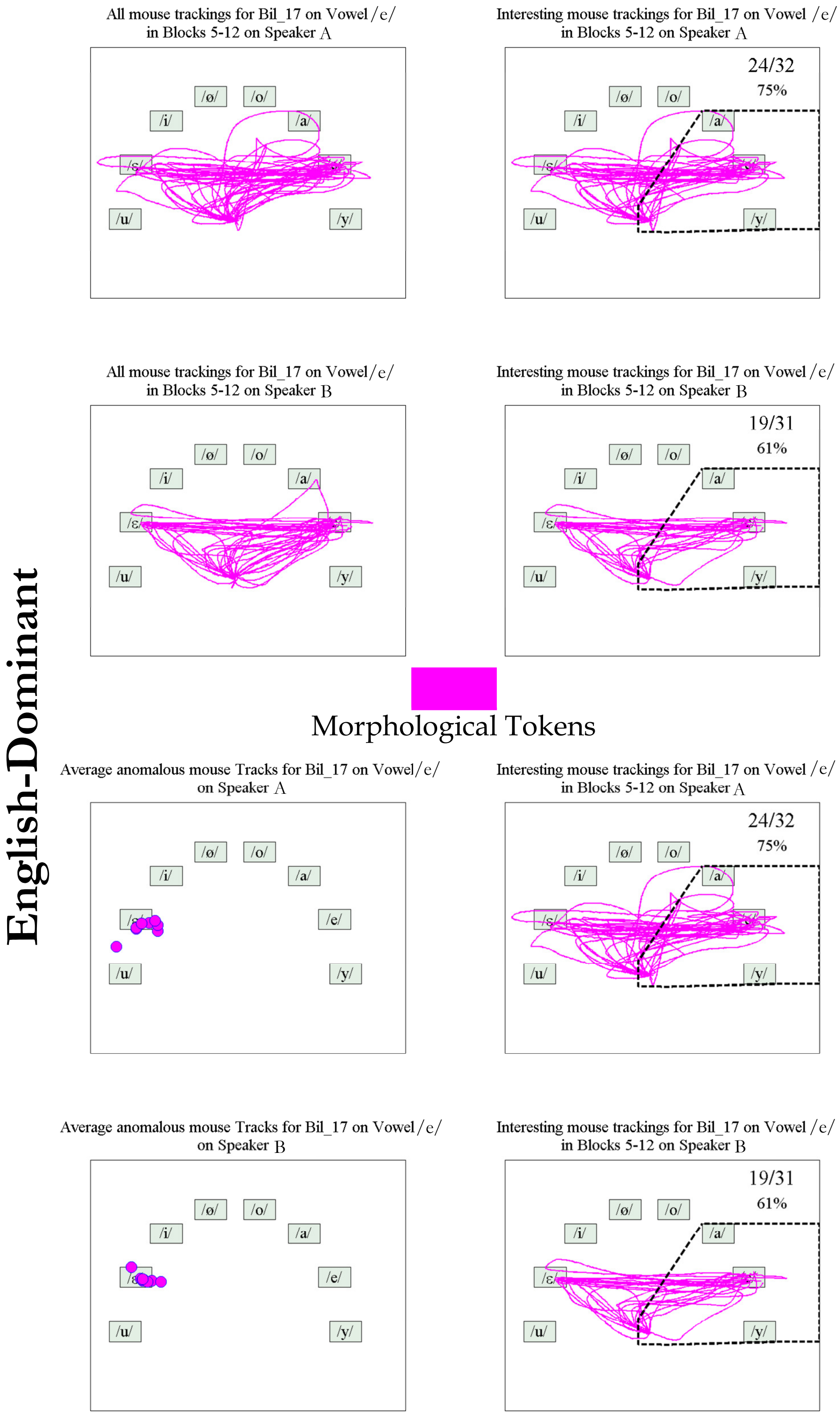
Appendix H: This figure shows mouse tracking patterns for control vowels /i/(top two rows) and /a/bottom two rows). The first row are the mouse tracking for Speaker A, the second row are the mouse tracks for speaker B. The left panels of these rows are all mouse tracks of correct trials from Blocks 5-12. The right panel are the mouse tracks in thee left panel that traveled outside of the area defined by the dotted line. This area encompasses the dock button and the left-adjacent to the correct response, as well as the right adjacent button. The ratio in the right panels correspond to the proportion of mouse tracks that were considered anomalous.

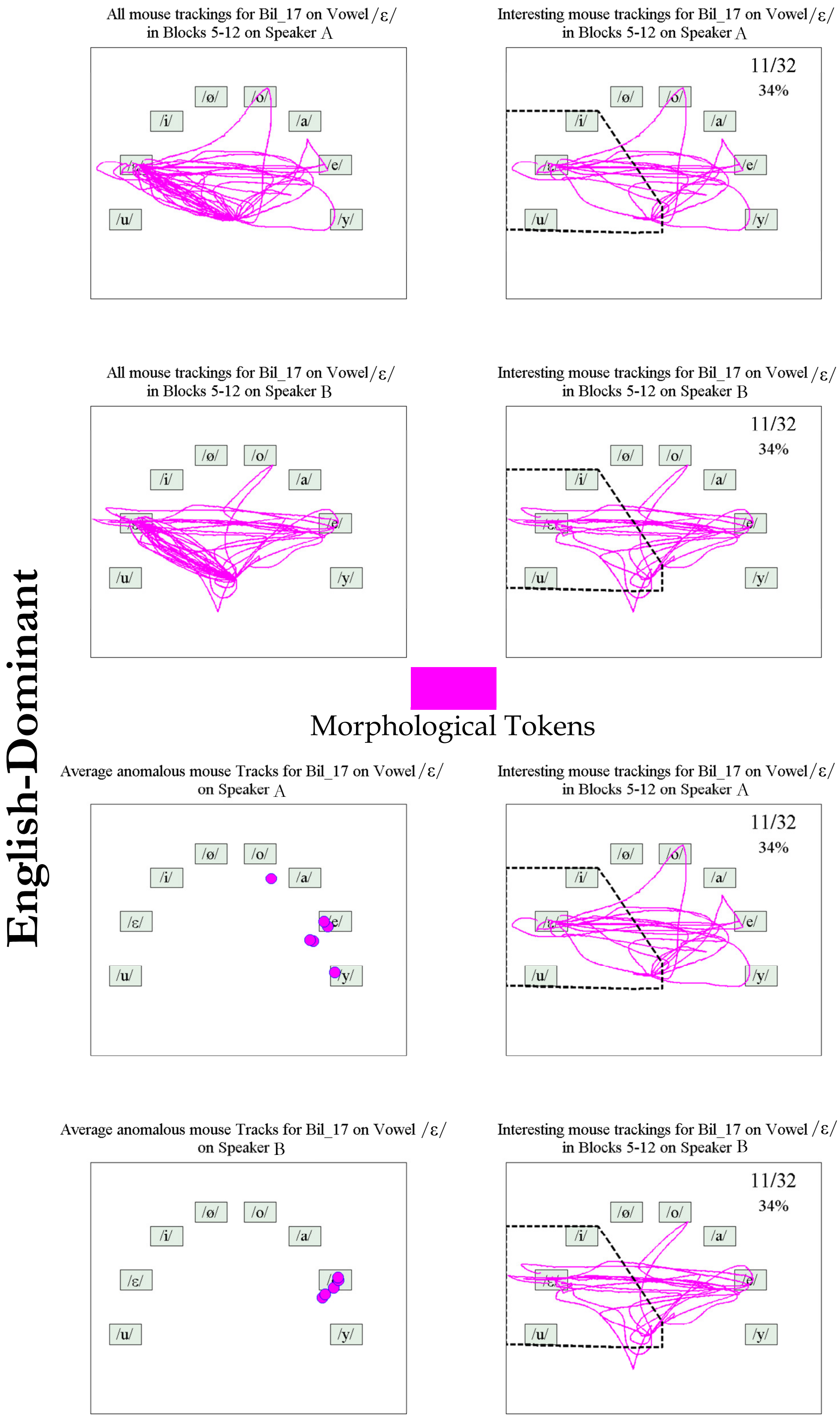


Appendix I: The figures on the next pages are samples of the mouse tracking data. The first row are the mouse tracking for Speaker A, the second row are the mouse tracks for speaker B. The left panels of these rows are all mouse tracks of correct trials from Blocks 5-12. The right panel are the mouse tracks in thee left panel that traveled outside of the area defined by the dotted line. This area encoumpasses the dock button and the left-adjacent to the correct response, as well as the right adjacent button. In the bottom two panels, again one row corresponds to the mouse tracks for speaker A, and the bottom row correspond to Speaker B. The right panels are the same as the top right panels: all anomalous mouse tracks for a given speaker. The left panels correspond to the mouse tracks whose turning point was within an inch of a confusable vowel. The ratio in the right panels corresponds to the proportion of mouse tracks that were considered anomalous.

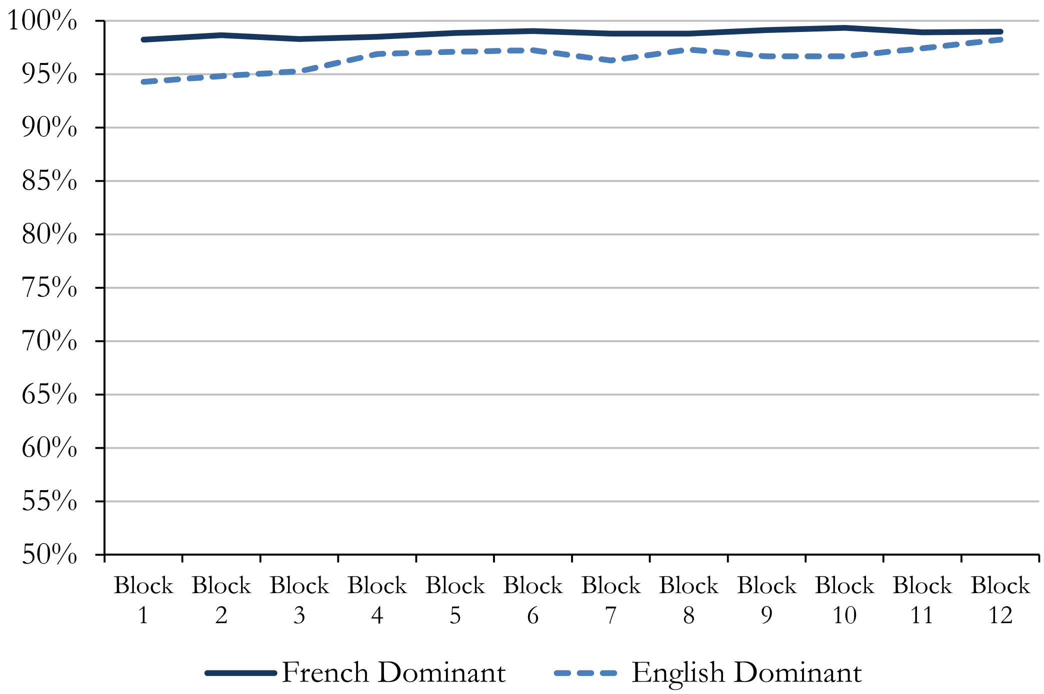

French-Dominant
All mouse trackings for M_12 on Vowel /e/ in Blocks 5-12 on Speaker A
Interesting mouse trackings for M_12 on Vowel /e/ in Blocks 5-12 on Speaker A
6/48
13%
All mouse trackings for M_12 on Vowel /e/ in Blocks 5-12 on Speaker B
Interesting mouse trackings for M_12 on Vowel /e/ in Blocks 5-12 on Speaker B
7/48
15%
Labial
Coronal
Back
Average anomalous mouse Tracks for M_12 on Vowel /e/ on Speaker A
Interesting mouse trackings for M_12 on Vowel /e/ in Blocks 5-12 on Speaker A
6/48
13%
Average anomalous mouse Tracks for M_12 on Vowel /e/ on Speaker B
Interesting mouse trackings for M_12 on Vowel /e/ in Blocks 5-12 on Speaker B
7/48
15%
/ø/
/o/
/i/
/a/
/ɛ/
/e/
/u/
/y/


English-Dominant
All mouse trackings for Bil_17 on Vowel /e/ in Blocks 5-12 on Speaker A
Interesting mouse trackings for Bil_17 on Vowel /e/ in Blocks 5-12 on Speaker A
20/48
42%
All mouse trackings for Bil_17 on Vowel /e/ in Blocks 5-12 on Speaker B
Interesting mouse trackings for Bil_17 on Vowel /e/ in Blocks 5-12 on Speaker B
26/45
58%
Labial
Coronal
Back
Average anomalous mouse Tracks for Bil_17 on Vowel /e/ on Speaker A
Interesting mouse trackings for Bil_17 on Vowel /e/ in Blocks 5-12 on Speaker A
20/48
42%
Average anomalous mouse Tracks for Bil_17 on Vowel /e/ on Speaker B
Interesting mouse trackings for Bil_17 on Vowel /e/ in Blocks 5-12 on Speaker B
26/45
58%
/ø/
/o/
/i/
/a/
/ɛ/
/e/
/u/
/y/


English-Dominant
All mouse trackings for Bil_17 on Vowel /e/ in Blocks 5-12 on Speaker A
Interesting mouse trackings for Bil_17 on Vowel /e/ in Blocks 5-12 on Speaker A
24/32
75%
All mouse trackings for Bil_17 on Vowel /e/ in Blocks 5-12 on Speaker B
Interesting mouse trackings for Bil_17 on Vowel /e/ in Blocks 5-12 on Speaker B
19/31
61%
Morphological Tokens
Average anomalous mouse Tracks for Bil_17 on Vowel /e/ on Speaker A
Interesting mouse trackings for Bil_17 on Vowel /e/ in Blocks 5-12 on Speaker A
24/32
75%
Average anomalous mouse Tracks for Bil_17 on Vowel /e/ on Speaker B
Interesting mouse trackings for Bil_17 on Vowel /e/ in Blocks 5-12 on Speaker B
19/31
61%
/ø/
/o/
/i/
/a/
/ɛ/
/e/
/u/
/y/


English-Dominant
All mouse trackings for Bil_17 on Vowel /ε/ in Blocks 5-12 on Speaker A
Interesting mouse trackings for Bil_17 on Vowel /ε/ in Blocks 5-12 on Speaker A
11/32
34%
All mouse trackings for Bil_17 on Vowel /ε/ in Blocks 5-12 on Speaker B
Interesting mouse trackings for Bil_17 on Vowel /ε/ in Blocks 5-12 on Speaker B
11/32
34%
Morphological Tokens
Average anomalous mouse Tracks for Bil_17 on Vowel /ε/ on Speaker A
Interesting mouse trackings for Bil_17 on Vowel /ε/ in Blocks 5-12 on Speaker A
11/32
34%
Average anomalous mouse Tracks for Bil_17 on Vowel /ε/ on Speaker B
Interesting mouse trackings for Bil_17 on Vowel /ε/ in Blocks 5-12 on Speaker B
11/32
34%
/ø/
/o/
/i/
/a/
/ε/
/e/
/u/
/y/

Appendix J: Average percent correct by block.



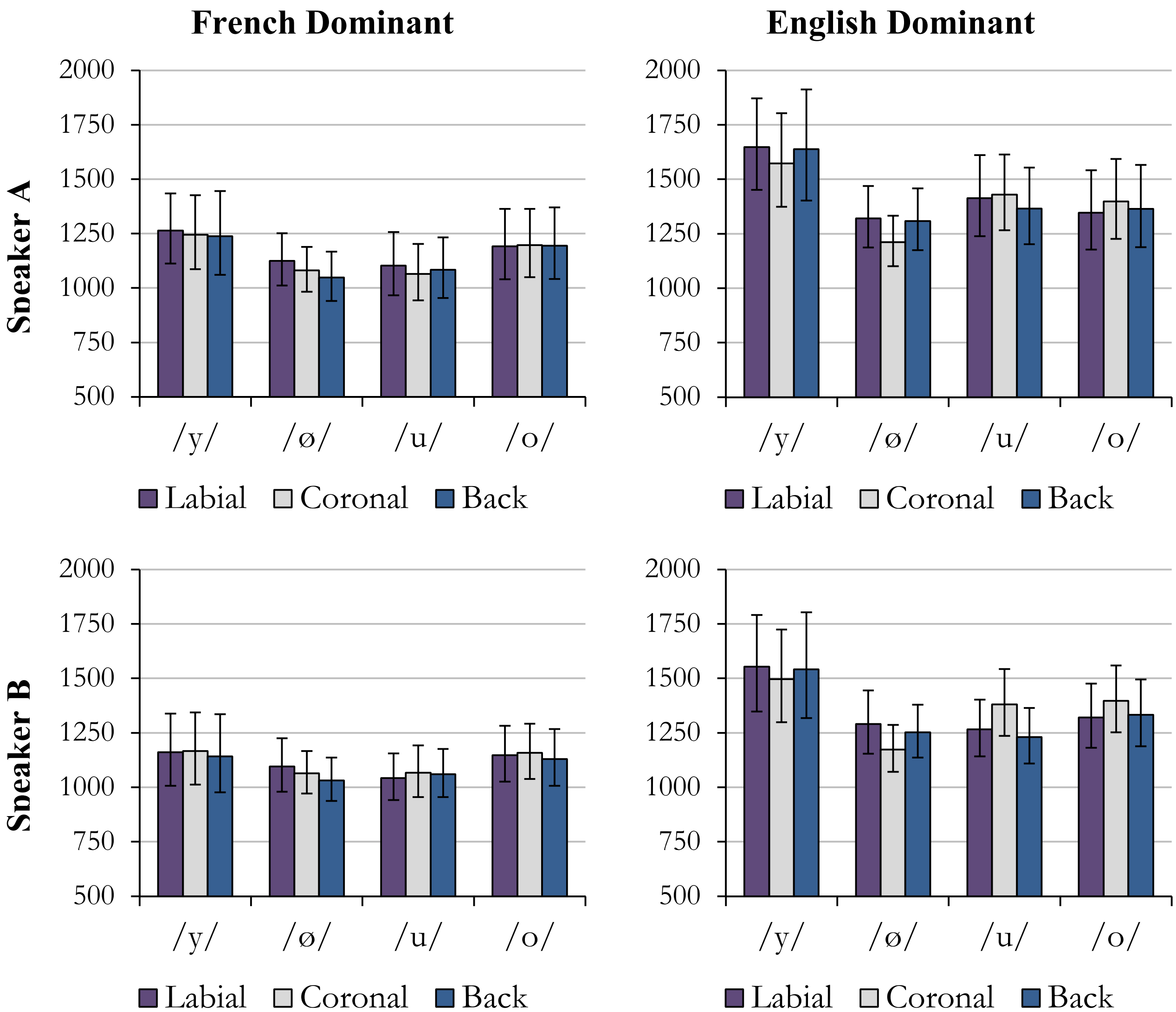
Appendix K: Mann-Whitney *U* tests between language groups on number of errors by vowel category. All *p*-vales are one-tailed, and Bonferroni corrected, requiring an uncorrected *p*-value of 0.00625 to meet the 0.05 criterion.

| | Vowel | Lexical | Morphological |
|---|---|---|---|
| **Speaker A** | /i/ | $U = 64.5$, $z = -2.411$, $p = 0.064$ | |
| | /a/ | $U = 104.0$, $z = -1.789$, $p = 1.000$ | |
| | /e/ | $U = 76.5$, $z = -2.087$, $p = 0.208$ | $U = 88.5$, $z = -1.716$, $p = 0.552$ |
| | /ɛ/ | $U = 120.0$, $z = -0.308$, $p = 1.000$ | $U = 83.5$, $z = -1.825$, $p = 0.376$ |
| | /y/ | $U = 83.0$, $z = -1.768$, $p = 0.376$ | |
| | /ø/ | $U = 75.5$, $z = -2.049$, $p = 0.184$ | |
| | /o/ | $U = 120.5$, $z = -0.299$, $p = 1.000$ | |
| | /u/ | $U = 97.0$, $z = -1.386$, $p = 1.000$ | |
| **Speaker B** | /i/ | $U = 80.5$, $z = -2.359$, $p = 0.296$ | |
| | /a/ | $U = 119.0$, $z = -0.671$, $p = 1.000$ | |
| | /e/ | $U = 48.5$, $z = -3.168$, $p = 0.008$ | $U = 67.5$, $z = -2.568$, $p = 0.088$ |
| | /ɛ/ | $U = 75.0$, $z = -2.180$, $p = 0.184$ | $U = 122.5$, $z = -0.239$, $p = 1.000$ |
| | /y/ | $U = 76.5$, $z = -2.127$, $p = 0.208$ | |
| | /ø/ | $U = 102.0$, $z = -1.238$, $p = 1.000$ | |
| | /o/ | $U = 116.0$, $z = -0.490$, $p = 1.000$ | |
| | /u/ | $U = 102.5$, $z = -1.215$, $p = 1.000$ | |

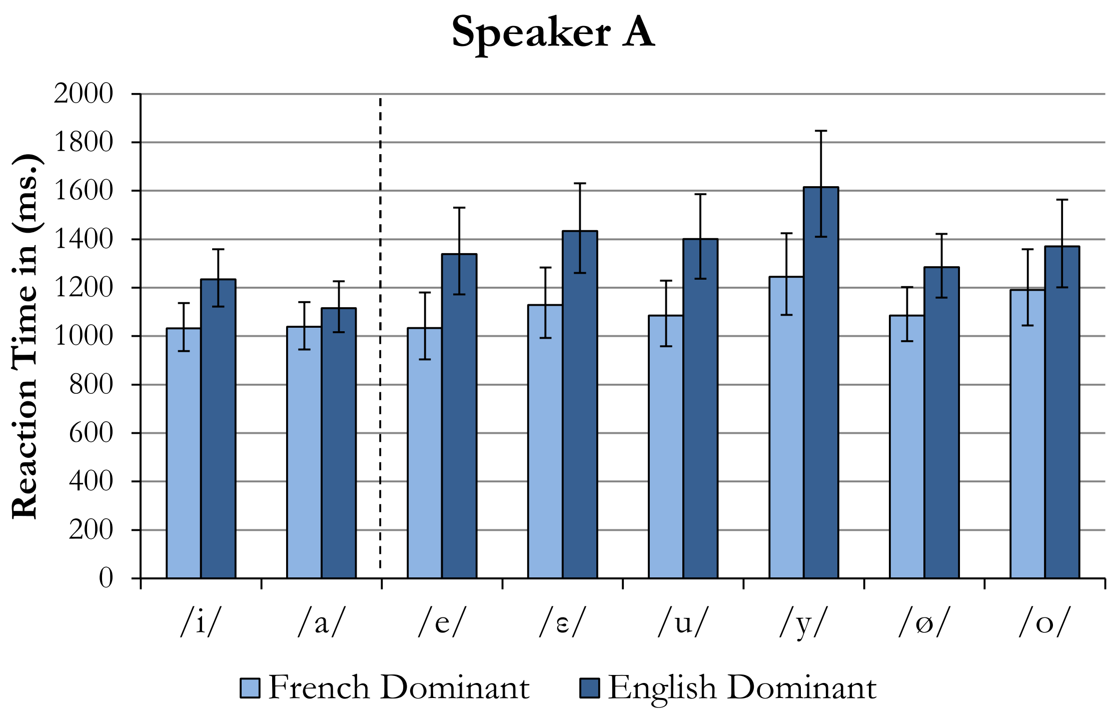
Appendix L: Planned comparison tests of mean reaction times in identifying each French vowel(*p*-values are Sidak-corrected). Collapsed across speaker, language group word type

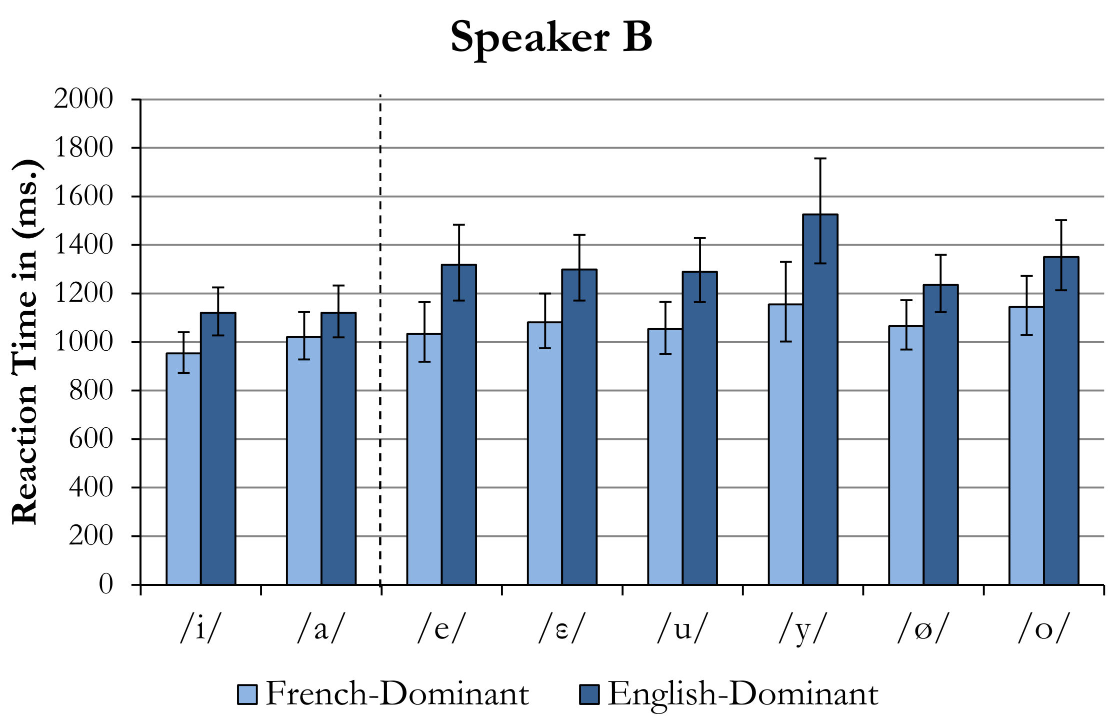
| Vowel (I) | Vowel (J) | Mean Difference (I-J) | Std. Error | *p*-value | Vowel (I) | Vowel (J) | Mean Difference (I-J) | Std. Error | *p*-value |
|---|---|---|---|---|---|---|---|---|---|
| | /e/ | -0.081 | 0.020 | 0.011* | | /i/ | -0.007 | 0.016 | 1 |
| | /ɛ/ | -0.128 | 0.018 | < 0.001* | | /e/ | -0.088 | 0.023 | 0.014* |
| | /u/ | -0.104 | 0.022 | 0.001* | | /ɛ/ | -0.135 | 0.024 | < 0.001* |
| /i/ | /y/ | -0.239 | 0.024 | < 0.001* | /a/ | /u/ | -0.111 | 0.020 | < 0.001* |
| | /ø/ | -0.075 | 0.016 | 0.002* | | /y/ | -0.245 | 0.025 | < 0.001* |
| | /o/ | -0.154 | 0.024 | < 0.001* | | /ø/ | -0.081 | 0.015 | < 0.001* |
| | /a/ | 0.007 | 0.016 | 1 | | /o/ | -0.161 | 0.021 | < 0.001* |
| | /i/ | 0.081 | 0.020 | 0.011* | | /i/ | 0.128 | 0.018 | < 0.001* |
| | /ɛ/ | -0.047 | 0.019 | 0.390 | | /e/ | 0.047 | 0.019 | 0.390 |
| | /u/ | -0.023 | 0.028 | 1 | | /u/ | 0.024 | 0.027 | 1 |
| /e/ | /y/ | -0.157 | 0.027 | < 0.001* | /ɛ/ | /y/ | -0.111 | 0.024 | 0.002* |
| | /ø/ | 0.007 | 0.022 | 1 | | /ø/ | 0.054 | 0.022 | 0.489 |
| | /o/ | -0.073 | 0.030 | 0.473 | | /o/ | -0.026 | 0.026 | 1 |
| | /a/ | 0.088 | 0.023 | 0.014* | | /a/ | 0.135 | 0.024 | < 0.001* |
| | /i/ | 0.104 | 0.022 | 0.001* | | /i/ | 0.239 | 0.024 | < 0.001* |
| | /e/ | 0.023 | 0.028 | 1 | | /e/ | 0.157 | 0.027 | < 0.001* |
| | /ɛ/ | -0.024 | 0.027 | 1 | | /ɛ/ | 0.111 | 0.024 | 0.002* |
| /u/ | /y/ | -0.135 | 0.021 | < 0.001* | /y/ | /u/ | 0.135 | 0.021 | < 0.001* |
| | /ø/ | 0.029 | 0.020 | 0.988 | | /ø/ | 0.164 | 0.023 | < 0.001* |
| | /o/ | -0.050 | 0.018 | 0.212 | | /o/ | 0.085 | 0.023 | < 0.021* |
| | /a/ | 0.111 | 0.020 | < 0.001* | | /a/ | 0.245 | 0.025 | < 0.001* |
| | /i/ | 0.154 | 0.024 | < 0.001* | | /i/ | 0.075 | 0.016 | 0.002* |
| | /e/ | 0.073 | 0.030 | 0.473 | | /e/ | -0.007 | 0.022 | 1 |
| | /ɛ/ | 0.026 | 0.026 | 1 | | /ɛ/ | -0.054 | 0.022 | 0.489 |
| /o/ | /u/ | 0.050 | 0.018 | 0.212 | /ø/ | /u/ | -0.029 | 0.020 | 0.988 |
| | /y/ | -0.085 | 0.023 | 0.021* | | /y/ | -0.164 | 0.023 | < 0.001* |
| | /ø/ | 0.079 | 0.024 | 0.057 | | /o/ | -0.079 | 0.024 | 0.057 |
| | /a/ | 0.161 | 0.021 | < 0.001* | | /a/ | 0.081 | 0.015 | < 0.001* |

Appendix M: rounded vowel mean reaction time (in ms.) by context.Bars = 95% confidence interval



Appendix N: Average reaction time for each vowel category, collapsed across context, real/nonsense, by language group and speaker.Bars = 95% Confidence intervals.



Appendix O: Comparison of mean reaction time of experimental vowels to baseline using *t*-tests for Matched Samples.The *t*-tests for lexical and morphological vowels are Bonferroni corrected, requiring an uncorrected *p*-value of 0.00625 to meet the 0.05 criterion.

## French-Dominant

| | | | Lexical | Morphological | Lexical v. Morphological |
|---|---|---|---|---|---|
| **Speaker A** | **/i/** | **/ɛ/** | $t(15) = -5.234, p < 0.008^*$ | $t(15) = -0.241, p = 1.000$ | $t(15) = -4.249, p = 0.001$ |
| | | **/ø/** | $t(15) = -2.175, p = 0.368$ | | |
| | | **/u/** | $t(15) = -1.722, p = 0.848$ | | |
| | **/a/** | **/e/** | $t(15) = 0.095, p = 1.000$ | $t(15) = 0.973, p = 0.346$ | $t(15) = 0.986, p = 0.34$ |
| | | **/y/** | $t(15) = -5.813, p < 0.008^*$ | | |
| | | **/o/** | $t(15) = -4.842, p < 0.008^*$ | | |
| **Speaker B** | **/i/** | **/ɛ/** | $t(15) = -8.181, p < 0.008^*$ | $t(15) = -3.785, p = 0.016$ | $t(15) = 3.013, p = 0.009$ |
| | | **/ø/** | $t(15) = -6.606, p < 0.008^*$ | | |
| | | **/u/** | $t(15) = -4.884, p < 0.008^*$ | | |
| | **/a/** | **/e/** | $t(15) = -0.741, p = 1.000$ | $t(15) = 0.525, p = 1.000$ | $t(15) = 1.161, p = 0.264$ |
| | | **/y/** | $t(15) = -3.804, p = 0.016^*$ | | |
| | | **/o/** | $t(15) = -5.198, p < 0.008^*$ | | |

## English-Dominant

| | | | Lexical | Morphological | Lexical v. Morphological |
|---|---|---|---|---|---|
| **Speaker A** | **/i/** | **/ɛ/** | $t(15) = -3.904, p = 0.008^*$ | $t(15) = -1.033, p = 1.000$ | $t(15) = 3.902, p = 0.001$ |
| | | **/ø/** | $t(15) = -1.112, p = 1.000$ | | |
| | | **/u/** | $t(15) = -3.317, p = 0.048^*$ | | |
| | **/a/** | **/e/** | $t(15) = 3.906, p = 0.008^*$ | $t(15) = -2.854, p = 0.016$ | $t(15) = 1.494, p = 0.156$ |
| | | **/y/** | $t(15) = -9.801, p < 0.008^*$ | | |
| | | **/o/** | $t(15) = -5.835, p < 0.008^*$ | | |
| **Speaker B** | **/i/** | **/ɛ/** | $t(15) = -4.278, p = 0.008^*$ | $t(15) = -1.422, p = 1.000$ | $t(15) = 3.379, p = 0.004$ |
| | | **/ø/** | $t(15) = -3.455, p = 0.032^*$ | | |
| | | **/u/** | $t(15) = -3.413, p = 0.032^*$ | | |
| | **/a/** | **/e/** | $t(15) = -3.827, p = 0.016^*$ | $t(15) = -1.486, p = 1.000$ | $t(15) = 2.469, p = 0.026$ |
| | | **/y/** | $t(15) = -7.174, p < 0.008^*$ | | |
| | | **/o/** | $t(15) = -4.525, p < 0.008^*$ | | |

Appendix P: Pairwise comparison of reaction time difference sores by phonological contrasts of interest.All reported values are Bonferroni corrected, requiring an uncorrected *p*-value of 0.008 to meet the 0.05 criterion.

**French-Dominant**

| | | Lexical | Morphological |
|---|---|---|---|
| **Speaker A** | **/ɛ/ v. /e/** | $N = 16$, $T+ = 15$, $z = -3.154$, $p = 0.012$* | $N = 16$, $T+ = 10$, $z = -1.086$, $p = 1.000$ |
| | **/y/ v. /u/** | $N = 16$, $T+ = 15$, $z = -3.413$, $p = 0.006$* | |
| | **/ø/ v. /u/** | $N = 16$, $T+ = 9$, $z = -0.259$, $p = 1.000$ | |
| | **/y/ v. /ø/** | $N = 16$, $T+ = 13$, $z = -2.844$, $p = 0.024$* | |
| | **/o/ v. /u/** | $N = 16$, $T+ = 14$, $z = -2.947$, $p = 0.018$* | |
| **Speaker B** | **/ɛ/ v. /e/** | $N = 16$, $T+ = 15$, $z = -3.464$, $p = 0.006$* | $N = 16$, $T+ = 12$, $z = -2.741$, $p = 0.036$ |
| | **/y/ v. /u/** | $N = 16$, $T+ = 10$, $z = -0.724$, $p = 1.000$ | |
| | **/ø/ v. /u/** | $N = 16$, $T+ = 9$, $z = -0.103$, $p = 1.000$ | |
| | **/y/ v. /ø/** | $N = 16$, $T+ = 9$, $z = -0.465$, $p = 1.000$ | |
| | **/o/ v. /u/** | $N = 16$, $T+ = 10$, $z = -0.827$, $p = 1.000$ | |

**English-Dominant**

| | | Lexical | Morphological |
|---|---|---|---|
| **Speaker A** | **/ɛ/ v. /e/** | $N = 16$, $T+ = 7$, $z = -0.103$, $p = 1.000$ | $N = 16$, $T+ = 5$, $z = -1.396$, $p = 0.978$ |
| | **/y/ v. /u/** | $N = 16$, $T+ = 13$, $z = -3.051$, $p = 0.012$* | |
| | **/ø/ v. /u/** | $N = 16$, $T+ = 12$, $z = -2.120$, $p = 0.204$ | |
| | **/y/ v. /ø/** | $N = 16$, $T+ = 16$, $z = -3.516$, $p = 0.006$* | |
| | **/o/ v. /u/** | $N = 16$, $T+ = 10$, $z = -1.448$, $p = 0.888$ | |
| **Speaker B** | **/ɛ/ v. /e/** | $N = 16$, $T+ = 8$, $z = -0.155$, $p = 1.000$ | $N = 16$, $T+ = 10$, $z = -0.052$, $p = 1.000$ |
| | **/y/ v. /u/** | $N = 16$, $T+ = 12$, $z = -2.534$, $p = 0.066$ | |
| | **/ø/ v. /u/** | $N = 16$, $T+ = 11$, $z = -1.551$, $p = 0.726$ | |
| | **/y/ v. /ø/** | $N = 16$, $T+ = 13$, $z = -3.154$, $p = 0.012$* | |
| | **/o/ v. /u/** | $N = 16$, $T+ = 10$, $z = -0.879$, $p = 1.000$ | |

Appendix Q: Mann-Whitney *U* tests between language groups on reaction time difference scores of experimental vowels.One-tailed, Bonferroni corrected, requiring an uncorrected *p*-value of 0.0125 to meet the 0.05 criterion.

| | Vowel | Lexical | Morphological |
|---|---|---|---|
| Speaker A | /e/ | *U* = 21, *z* = -4.0327, *p* < 0.001* | *U* = 59,*z* = -2.601, *p* = 0 .032 |
| | /ɛ/ | *U* = 85, *z* = -1.6206, *p* = 0.44 | *U* = 121, *z* = -0.264, *p* = 1.000 |
| | /u/ | *U* = 67, *z* = -2.2990, *p* = 0.084 | |
| | /y/ | *U* = 47, *z* = -3.0528, *p* = 0.004* | |
| | /ø/ | *U* = 108, *z* = -0.7538, *p* = 1.000 | |
| | /o/ | *U* = 91, *z* = -1.3945,*p* = 0.684 | |
| Speaker B | /e/ | *U* = 50, *z* = -2.9397, *p* = 0.012* | *U* = 88, *z* = -1.508, *p* = 0 .552 |
| | /ɛ/ | *U* = 95, *z* = -1.2437, *p* = 0.896 | *U* = 109, *z* = -0.716, *p* = 1.000 |
| | /u/ | *U* = 82, *z* = -1.7337, *p* = 0.344 | |
| | /y/ | *U* = 53, *z* = -2.8267, *p* = 0.016* | |
| | /ø/ | *U* = 127, *z* = -0.0377, *p* = 1.000 | |
| | /o/ | *U* = 88, *z* = -1.5076, *p* = 0.552 | |

Appendix R: Friedman tests of overall difference among vowels and pairwise comparison of proportion of anomalous mouse tracks to baseline.The pairwise comparisons for lexical and morphological vowels are Bonferroni corrected, requiring an uncorrected *p*-value of 0.00625 to meet the 0.05 criterion.

| | **French-Dominant** | **English-Dominant** |
|---|---|---|
| **Speaker A** | $N = 13$, $\chi^2 = 39.880$, $df = 7$, $p < 0.001$ | $N = 14$, $\chi^2 = 53.067$, $df = 7$, $p < 0.001$ |
| **Speaker B** | $N = 15$, $\chi^2 = 45.117$, $df = 7$, $p < 0.001$ | $N = 12$, $\chi^2 = 42.338$, $df = 7$ $p < 0.001$ |

## French-Dominant

| | | | **Lexical** | **Morphological** | **Lexical v. Morphological** |
|---|---|---|---|---|---|
| **Speaker A, *N* = 13** | /i/ | /ɛ/ | $T+ = 12$, $z = -2.900$, $p = 0.032^*$ | $T+ = 10$, $z = -2.760$, $p = 0.048^*$ | $T+ = 9$, $z = -1.503$, $p = 0.133$ |
| | | /ø/ | $T+ = 4$, $z = -0.549$, $p = 1.000$ | | |
| | | /u/ | $T+ = 9$, $z = -1.818$, $p = 0.552$ | | |
| | /a/ | /e/ | $T+ = 9$, $z = -2.624$, $p = 0.072$ | $T+ = 13$, $z = -3.180$, $p = 0.008^*$ | $T+ = 12$, $z = -3.11$, $p = 0.002^*$ |
| | | /y/ | $T+ = 12$, $z = -3.061$, $p = 0.016^*$ | | |
| | | /o/ | $T+ = 12$, $z = -3.065$, $p = 0.016^*$ | | |
| **Speaker B, *N* = 15** | /i/ | /ɛ/ | $T+ = 12$, $z = -2.612$, $p = 0.072$ | $T+ = 14$, $z = -3.351$, $p = 0.008^*$ | $T+ = 11$, $z = -2.104$, $p = 0.035^*$ |
| | | /ø/ | $T+ = 5$, $z = -0.472$, $p = 1.000$ | | |
| | | /u/ | $T+ = 11$, $z = -2.046$, $p = 0.328$ | | |
| | /a/ | /e/ | $T+ = 11$, $z = -2.419$, $p = 0.128$ | $T+ = 13$, $z = -3.012$, $p = 0.024^*$ | $T+ = 10$, $z = -1.960$, $p = 0.05^*$ |
| | | /y/ | $T+ = 14$, $z = -3.297$, $p = 0.008^*$ | | |
| | | /o/ | $T+ = 14$, $z = -3.297$, $p = 0.008^*$ | | |

## English-Dominant

| | | | **Lexical** | **Morphological** | **Lexical v. Morphological** |
|---|---|---|---|---|---|
| **Speaker A, *N* = 14** | /i/ | /ɛ/ | $T+ = 12$, $z = -2.970$, $p = 0.024$ | $T+ = 11$, $z = -2.794$, $p = 0.04^*$ | $T+ = 8$, $z = -0.245$, $p = 0.807$ |
| | | /ø/ | $T+ = 5$, $z = -1.412$, $p = 1.000$ | | |
| | | /u/ | $T+ = 13$, $z = -3.045$, $p = 0.016^*$ | | |
| | /a/ | /e/ | $T+ = 11$, $z = -2.746$, $p = 0.048^*$ | $T+ = 12$, $z = -3.045$, $p = 0.016^*$ | $T+ = 11$, $z = -2.271$, $p = 0.023$ |
| | | /y/ | $T+ = 13$, $z = -3.202$, $p = 0.008^*$ | | |
| | | /o/ | $T+ = 13$, $z = -3.107$, $p = 0.016^*$ | | |
| **Speaker B, *N* = 12** | /i/ | /ɛ/ | $T+ = 10$, $z = -2.040$, $p = 0.328$ | $T+ = 9$, $z = -1.883$, $p = 1.000$ | $T+ = 6$, $z = -0.432$, $p = 0.666$ |
| | | /ø/ | $T+ = 3$, $z = -0.844$, $p = 1.000$ | | |
| | | /u/ | $T+ = 10$, $z = -2.629$, $p = 0.072$ | | |
| | /a/ | /e/ | $T+ = 10$, $z = -2.825$, $p = 0.04^*$ | $T+ = 11$, $z = -2.903$, $p = 0.032^*$ | $T+ = 6$, z= $-0.628$, $p = 0.53$ |
| | | /y/ | $T+ = 12$, $z = -3.059$, $p = 0.016^*$ | | |
| | | /o/ | $T+ = 10$, $z = -2.512$, $p = 0.012$ | | |

Appendix S: Mann-Whitney *U* tests between language groups on anomalous mouse track difference scores of experimental vowels.One-tailed, all non-significant without Bonferroni correction.

| | Vowel | Lexical | Morphological |
|---|---|---|---|
| **Speaker A** | /e/ | $U = 82.5$, $z = -0.413$, $p = 0.343$ | $U = 69.0$, $z = -1.068$, $p = 0.151$ |
| | /ɛ/ | $U = 83.0$, $z = -0.388$, $p = 0.360$ | $U = 74.0$, $z = -0.825$, $p = 0.215$ |
| | /u/ | $U = 68.0$, $z = -1.116$, $p = 0.140$ | |
| | /y/ | $U = 89.0$, $z = -0.097$, $p = 0.472$ | |
| | /ø/ | $U = 86.0$, $z = -0.243$, $p = 0.415$ | |
| | /o/ | $U = 81.5$, $z = -0.461$, $p = 0.325$ | |
| **Speaker B** | /e/ | $U = 70.0$, $z = -0.977$, $p = 0.174$ | $U = 88.0$, $z = -0.098$, $p = 0.472$ |
| | /ɛ/ | $U = 74.0$, $z = -0.781$, $p = 0.228$ | $U = 59.5$, $z = -1.488$, $p = 0.070$ |
| | /u/ | $U = 71.0$, $z = -0.928$, $p = 0.187$ | |
| | /y/ | $U = 89.5$, $z = -0.024$, $p = 0.491$ | |
| | /ø/ | $U = 86.5$, $z = -0.172$, $p = 0.434$ | |
| | /o/ | $U = 69.0$, $z = -1.026$, $p = 0.162$ | |

Appendix T: Descriptive statistics and Binomial tests for interesting returning points for trials involving lexical tokens.

| | | French Dominant | | | | | English Dominant | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **Median** | **Range** | **# of participants with at least 1** | **Binomial Test** | | **Median** | **Range** | **# of participants with at least 1** | **Binomial Test** |
| **Speaker A, *N* = 13** | /e/ → /i/ | 0 | 0-1 | 4 | $p = 0.27$ | **Speaker A, *N* = 14** | 0 | 0-5 | 5 | $p = 0.42$ |
| | /o/ → /u/ | 0 | 0-4 | 5 | $p = 0.58$ | | 2.5 | 0-9 | 9 | $p = 0.42$ |
| | /y/ → /i/ | 0 | 0-1 | 5 | $p = 0.58$ | | 0 | 0-4 | 3 | $p = 0.06$ |
| | /e/ → /ɛ/ | 1 | 0-4 | 8 | $p = 0.58$ | | 2 | 0-9 | 9 | $p = 0.42$ |
| | /ɛ/ → /e/ | 2 | 0-6 | 12 | $p < 0.01$ | | 3 | 0-8 | 11 | $p = 0.06$ |
| | /y/ → /u/ | 2 | 0-9 | 10 | $p = 0.09$ | | 3.5 | 0-21 | 12 | $p = 0.01$ |
| | /u/ → /y/ | 1 | 0-7 | 7 | $p = 1$ | | 2 | 0-6 | 10 | $p = 0.18$ |
| | /y/ → /ø/ | 0 | 0-6 | 4 | $p = 0.27$ | | 2 | 0-6 | 9 | $p = 0.42$ |
| | /ø/ →/y/ | 1 | 0-6 | 7 | $p = 1$ | | 1 | 0-3 | 8 | $p = 0.79$ |
| | /u/ → /ø/ | 0 | 0-3 | 6 | $p = 1$ | | 1 | 0-5 | 9 | $p = 0.42$ |
| | /ø/ → /u/ | 0 | 0-2 | 4 | $p = 0.27$ | | 0 | 0-1 | 3 | $p = 0.06$ |
| **Speaker B, *N* = 15** | /e/ → /i/ | 0 | 0-1 | 3 | $p = 0.04$ | **Speaker B, *N* = 12** | 0 | 0-6 | 5 | $p = 0.39$ |
| | /o/ → /u/ | 1 | 0-5 | 11 | $p = 0.12$ | | 1 | 0-11 | 7 | $p = 0.77$ |
| | /y/ → /i/ | 0 | 0-3 | 5 | $p = 0.30$ | | 0 | 0-2 | 4 | $p = 0.39$ |
| | /e/ → /ɛ/ | 1 | 0-8 | 9 | $p = 0.61$ | | 1.5 | 0-8 | 9 | $p = 0.15$ |
| | /ɛ/ → /e/ | 2 | 0-13 | 13 | $p = 0.01$ | | 2.5 | 0-9 | 10 | $p = 0.04$ |
| | /y/ → /u/ | 2 | 0-14 | 12 | $p = 0.04$ | | 1 | 0-20 | 9 | $p = 0.15$ |
| | /u/ → /y/ | 2 | 0-10 | 10 | $p = 0.30$ | | 2 | 0-8 | 9 | $p = 0.15$ |
| | /y/ → /ø/ | 1 | 0-3 | 8 | $p = 1$ | | 1 | 0-5 | 9 | $p = 0.15$ |
| | /ø/ → /y/ | 1 | 0-3 | 11 | $p = 0.12$ | | 1 | 0-2 | 10 | $p = 0.04$ |
| | /u/ → /ø/ | 0 | 0-4 | 7 | $p = 1$ | | 0.5 | 0-6 | 6 | $p = 1$ |
| | /ø/ → /u/ | 0 | 0-1 | 4 | $p = 0.12$ | | 0 | 0-1 | 3 | $p = 0.15$ |

Appendix U: Descriptive statistics and Binomial tests for interesting turning points for /y/ collapsing across /y/ →/i/, /y/ →/u/ and /y/ →/ø/.

| | **French Dominant** | | | **English Dominant** | | |
|---|---|---|---|---|---|---|
| | **Median** | **Range** | **Binomial Test** | **Median** | **Range** | **Binomial Test** |
| **Speaker A** | 6 | 0-20 | 11 out of 13, $p = 0.0225$ | 8.5 | 0-46 | 13 out of 14, $p = 0.0018$ |
| **Speaker B** | 4 | 0-28 | 14 out of 15, $p = 0.0225$ | 4 | 0-42 | 11 out of 12, $p = 0.0063$ |

Appendix V: Wilcoxon tests of asymmetry in interesting turning points.

| | | **French-dominant** | **English Dominant** |
|---|---|---|---|
| **Speaker A** | /y/ ↔ /u/ | $N = 13$, $T\!+ = 7$, $z = -1.79$<br>$p = 0.073$ | $N = 14$, $T\!+ = 7$, $z = -1.12$<br>$p = 0.263$ |
| | /y/ ↔ /ø/ | $N = 13$, $T\!+ = 5$, $z = -0.781$<br>$p = 0.435$ | $N = 14$, $T\!+ = 2$, $z = -1.698$<br>$p = 0.089$ |
| | /ø/ ↔ /u/ | $N = 13$, $T\!+ = 3$, $z = -0.632$<br>$p = 0.527$ | $N = 14$, $T\!+ = 2$, $z = -2.14$<br>$p = 0.032$ |
| | /e/ ↔ /ɛ/<br>(Lexical) | $N = 13$, $T\!+ = 9$, $z = -2.714$<br>$p = 0.007$ | $N = 14$, $T\!+ = 7$, $z = -1.12$<br>$p = 0.263$ |
| | /e/ ↔ /ɛ/<br>(Morphological) | $N = 13$, $T\!+ = 4$, $z = -0.826$<br>$p = 0.408$ | $N = 14$, $T\!+ = 6$, $z = -0.181$<br>$p = 0.857$ |
| **Speaker B** | /y/ ↔ /u/ | $N = 15$, $T\!+ = 7$, $z = -0.079$<br>$p = 0.937$ | $N = 12$, $T\!+ = 5$, $z = -0.357$<br>$p = 0.721$ |
| | /y/ ↔ /ø/ | $N = 15$, $T\!+ = 9$, $z = -0.644$<br>$p = 0.519$ | $N = 12$, $T\!+ = 1$, $z = -0.535$<br>$p = 0.593$ |
| | /ø/ ↔ /u/ | $N = 15$, $T\!+ = 2$, $z = -1.725$<br>$p = 0.084$ | $N = 12$, $T\!+ = 2$, $z = -1.845$<br>$p = 0.065$ |
| | /e/ ↔ /ɛ/<br>(Lexical) | $N = 15$, $T\!+ = 10$, $z = -2.571$<br>$p = 0.01$ | $N = 12$, $T\!+ = 6$, $z = -0.617$<br>$p = 0.537$ |
| | /e/ ↔ /ɛ/<br>(Morphological) | $N = 15$, $T\!+ = 5$, $z = -0.634$<br>$p = 0.526$ | $N = 12$, $T\!+ = 3$, $z = -1.568$<br>$p = 0.117$ |

Appendix W: Comparison of reaction time difference scores for lexical tokens preceded by /ʁ/ with mean reaction time difference scores of lexical tokens in other contexts and morphological tokens.Bonferroni corrected, requiring an uncorrected *p*-value of 0.0125 to meet the 0.05 criterion.

| | | |
|---|---|---|
| | | **French Dominant** |
| **Speaker A** | /ʁe/ v. lexical | $N = 16$, $T+= 6$, $z = -0.724$, $p = 1.000$ |
| | /ʁe/ v. morphological | $N = 16$, $T+= 7$, $z = -0.827$, $p = 1.000$ |
| | /ʁɛ/ v. lexical | $N = 16$, $T+= 14$, $z = -3.309$, $p = 0.004^{*}$ |
| | /ʁɛ/ v. morphological | $N = 16$, $T+= 10$, $z = -1.138$, $p = 1.000$ |
| **Speaker B** | /ʁe/ v. lexical | $N = 16$, $T+= 6$, $z = -0.621$, $p = 1.000$ |
| | /ʁe/ v. morphological | $N = 16$, $T+= 4$, $z = -1.396$, $p = 0.652$ |
| | /ʁɛ/ v. lexical | $N = 16$, $T+= 14$, $z = -3.258$, $p = 0.004^{*}$ |
| | /ʁɛ/ v. morphological | $N = 16$, $T+= 11$, $z = -1.810$, $p = 0.28$ |
| | | **English Dominant** |
| **Speaker A** | /ʁe/ v. lexical | $N = 16$, $T+= 9$, $z = -0.569$, $p = 1.000$ |
| | /ʁe/ v. morphological | $N = 16$, $T+= 6$, $z = -0.517$, $p = 1.000$ |
| | /ʁɛ/ v. lexical | $N = 16$, $T+= 13$, $z = -2.534$, $p = 0.044^{*}$ |
| | /ʁɛ/ v. morphological | $N = 16$, $T+= 8$, $z = -0.103$, $p = 1.000$ |
| **Speaker B** | /ʁe/ v. lexical | $N = 16$, $T+= 10$, $z = -1.138$, $p = 1.000$ |
| | /ʁe/ v. morphological | $N = 16$, $T+= 5$, $z = -0.724$, $p = 1.000$ |
| | /ʁɛ/ v. lexical | $N = 16$, $T+= 12$, $z = -2.689$, $p = 0.028^{*}$ |
| | /ʁɛ/ v. morphological | $N = 16$, $T+= 11$, $z = -0.724$, $p = 1.000$ |

Appendix X: Comparison of reaction time difference scores for /ʁɛ/ lexical tokens with lexical tokens preceded by a labial, coronal, and back stops.Bonferroni corrected, requiring an uncorrected *p*-value of 0.017 to meet the 0.05 criterion.

| | | |
|---|---|---|
| | | **French Dominant** |
| **Speaker A** | /ʁɛ/ v. labial | $N = 16$, $T+= 13$, $z = -3.103$, $p = 0.006^{*}$ |
| | /ʁɛ/ v. coronal | $N = 16$, $T+= 13$, $z = -2.999$, $p = 0.009^{*}$ |
| | /ʁɛ/ v. back | $N = 16$, $T+= 14$, $z = -3.206$, $p = 0.003^{*}$ |
| **Speaker B** | /ʁɛ/ v. labial | $N = 16$, $T+= 13$, $z = -2.947$, $p = 0.009^{*}$ |
| | /ʁɛ/ v. coronal | $N = 16$, $T+= 13$, $z = -3.206$, $p = 0.003^{*}$ |
| | /ʁɛ/ v. back | $N = 16$, $T+= 12$, $z = -2.741$, $p = 0.018^{*}$ |
| | | **English Dominant** |
| **Speaker A** | /ʁɛ/ v. labial | $N = 16$, $T+= 13$, $z = -1.965$, $p = 0.147$ |
| | /ʁɛ/ v. coronal | $N = 16$, $T+= 11$, $z = -1.913$, $p = 0.168$ |
| | /ʁɛ/ v. back | $N = 16$, $T+= 13$, $z = -3.051$, $p = 0.006^{*}$ |
| **Speaker B** | /ʁɛ/ v. labial | $N = 16$, $T+= 12$, $z = -2.430$, $p = 0.045^{*}$ |
| | /ʁɛ/ v. coronal | $N = 16$, $T+= 13$, $z = -2.792$, $p = 0.015^{*}$ |
| | /ʁɛ/ v. back | $N = 16$, $T+= 12$, $z = -2.637$, $p = 0.024^{*}$ |

Appendix Y: Descriptive statistics and Binomial test for interesting returning points for trials involving morphological tokens.

**French Dominant**

| | | Median | Range | # of participants with at least 1 | Binomial Test |
|---|---|---|---|---|---|
| **Speaker A** | /e/→/ɛ/ | 2 | 0-9 | 9 | $p = 0.27$ |
| ***N* = 13** | /ɛ/→/e/ | 2 | 0-8 | 9 | $p = 0.27$ |
| **Speaker B** | /e/ →/ɛ/ | 1 | 0-7 | 10 | $p = 0.09$ |
| ***N* = 15** | /ɛ/→/e/ | 1 | 0-12 | 10 | $p = 0.09$ |

**English Dominant**

| | | Median | Range | # of participants with at least 1 | Binomial Test |
|---|---|---|---|---|---|
| **Speaker A** | /e/→/ɛ/ | 2.5 | 0-7 | 11 | $p = 0.06$ |
| ***N* = 14** | /ɛ/→/e/ | 2 | 1-6 | 14 | $p = 0.0001$ |
| **Speaker B** | /e/ →/ɛ/ | 3 | 0-8 | 11 | $p = 0.01$ |
| ***N* = 12** | /ɛ/→/e/ | 1 | 0-8 | 9 | $p = 0.15$ |

Appendix Z: Instructions for judgments of narration task.

*Trans.*

Évaluation des narrations

Vous allez voir un extrait du film *Les Lumières de la ville*. Ensuite, vous allez écouter des enregistrements de 36 locuteurs, en racontant cet extrait en français. Votre tâche sera d'évaluer le degré de leur accent anglais sur une échelle de 1 (très fort accent anglais) à 9 (sans accent anglais) ainsi que leur maîtrise du français: 1 (parlé avec difficulté) à 9 (parlé (sans accent anglais) ainsi que leur maîtrise du français: 1 (parlé avec difficulté) à 9 (parlé avec aisance).

Lorsque vous choisissez une réponse, utilisez les échelles entières, en considérant les niveaux intermédiaires, de même que les niveaux extrêmes. Vous aurez aussi la tâche de déterminer si le(la) locuteur(rice) est francophone monolingue, francophone bilingue, ou anglophone bilingue. Vous aurez aussi la possibilité d'ajouter des commentaires additionnels.

Chaque enregistrement durera environ 2 minutes. Le bouton « Le prochain » apparaîtra après un délai de 60 secondes et il sera possible d'avancer au prochain enregistrement. Il sera possible de jouer ou d'arrêter chaque enregistrement en appuyant sur le bouton « Jouer/Pause ». De plus, vous ne pourrez pas revenir en arrière ou réécouter l'enregistrement.

Vous pouvez continuer au locuteur(trice) suivant(e) lorsque le bouton « Le Prochain » se montre et vous êtes sûr de vos réponses, même si l'enregistrement n'a pas terminé. Appuyez sur le bouton pour avancer.

Avez-vous des questions?

Evaluation of the Narrations

You will watch an excerpt from the film *City Lights*. Then you will hear recordings of 36 speakers, narrating this clip in French. Your task will be to rate their English accent on a scale from 1(very strong English accent) to 9 (no English accent) as well as their fluency in French: 1(spoken with difficulty) to 9 (spoken with ease).

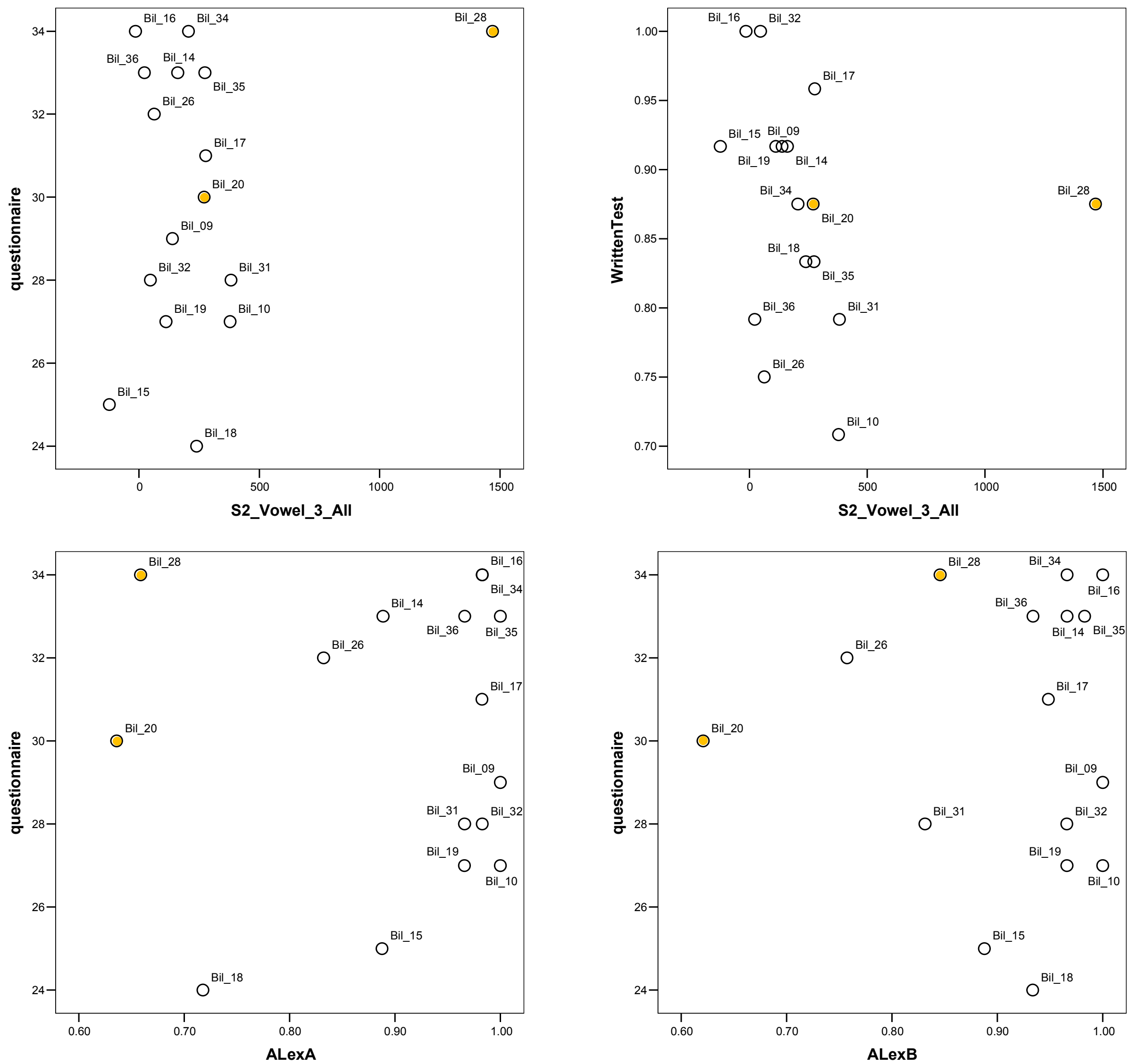
When you are making a choice, use the entire scale, considering the intermediate levels, as well as the extreme levels. You also have the task of determining whether the speaker is either French monolingual, French-dominant bilingual, or English-dominant bilingual. You may also make any additional comments.

Each recording is approximately 2 minutes long. The button "Le prochain" will appear after a delay of 60 seconds and it will then be possible to advance to the next recording. It will be possible to play or stop each recording by pressing the button "Jouer/Pause." You will not be able to go back or relisten to the recording.

You may continue to the next speaker when the button "Le Prochain" appears and you are sure of your responses, even if the recording has not finished. Press the button to advance.

Any questions?

# Appendix AA: Correlations with language proficiency.



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