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STOP IDENTITY CUE AS A CUE TO LANGUAGE IDENTITY

by

PAULA LISA CASTONGUAY

DISSERTATION

Submitted to the Graduate School

of Wayne State University

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for the degree of

DOCTOR OF PHILOSOPHY

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DISORDERS (Cognitive Linguistics)

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Advisor Date

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION / BACKGROUND

I. Introduction

In models of Bilingual Lexical Access, language membership typically comes into play at the semantic, lexical and/or phonetic level (e.g., Bilingual Interactive Activation Plus Model; Bilingual Model of Lexical Access). Furthermore, it is generally assumed that language membership does not affect the relative activation of words within a given language, implying that language membership is not involved in the early stages of lexical access (Schwartz & Arêas Da Luz Fontes, 2008). Although it is generally assumed that language membership is not established until later stages of lexical access, it is not clear whether language membership could potentially be cued by the acoustic-phonetic detail of the speech waveform and retained all the way through the process of lexical access.

II. Background

Research on monolingual speakers has shown that low-level acoustic differences can affect lexical access (Andruski, Blumstein, & Burton, 1994). For example, voice onset time (VOT) is an acoustic cue that differentiates stop consonant pairs such as /p/-/b/ and /t/-/d/. For monolingual speakers, prior research has shown that when VOT is reduced in /p/, /t/ and /k/, lexical activation is reduced, even though the modified sounds are still reliably identified as /p/, /t/ and /k/ (Andruski et al., 1994). For monolingual English speakers, these small changes in VOT are perceived as differences in the ‘goodness’ of the sound. A /p/ with a reduced VOT, for example, is heard as a ‘not very good’ example of /p/. For English-French bilinguals, however, these small acoustic differences potentially indicate whether the word is English or French. For example, English and French word-initial voiceless stops such as the /k/s in *coo* and *cou* ‘neck’ differ acoustically in that English voiceless stops have longer VOT’s and are more highly aspirated than French voiceless stops. If two words that are pronounced similarly across languages (e.g., *coo* /ku/ vs. *cou* /ku/) are presented to a bilingual listener, that listener should be able to discriminate between the English and French words based on the acoustic differences in the initial /k/. A long VOT with aspiration may be expected to signal that it is an English word while a short VOT with little aspiration may be expected to signal that it is a French word. In addition to VOT, relative burst intensity and burst spectral standard deviation have also been shown to cue stop identity and to vary with language (Sundara, 2005). If these acoustical differences are present across speakers, bilingual listeners may show different levels of word activation that, in effect, establish language identity, in addition, to stop identity. As a result, these fine-grained acoustic differences may speed the recognition of which language is being spoken and play a role in bilingual lexical access.

Studies in bilingual speech perception have shown that listeners are, indeed, sensitive to theses fine-grained acoustic differences. In a gating study, Grosjean (1988) showed that listeners are able to determine which language a word belongs to, simply by hearing the initial phoneme of a word. Grosjean (1988) showed that bilingual French-English speakers were able to judge language membership of so-called guest words, which were pronounced as either code-switches or borrowings, solely based on the word's initial phoneme. Code-switches are words from the guest language (e.g., English), which have retained their phonetic cue as to which language it belongs to. For example, *Il faudrait qu'on PICK les bons chiffres* ‘We should pick the right numbers’.

Here the VOT strongly favors an English /p/, and hence indicates an English word (i.e., pick [pʰɪk]). In contrast, borrowings are words that are borrowed from the guest language (e.g., English) but pronounced in the base language (e.g., French). In this case, the borrowed word no longer contains the phonetic cue of the language of origin (i.e., English). For example, *Il faudrait qu'on PIQUE les bons chiffres* 'We should pick the right numbers'. Here the VOT suggests a French /p/ and thus a French word (i.e., *pique* /pik/ - notice the vowel changed too). Interestingly, Grosjean (1988) found that code-switch homophones (e.g., *pick* [pʰɪk]) were identified sooner, as to which language they belonged to, than borrowed homophones (e.g., *pique* [pik]). Code-switches still contain the phonetic cue indicating the language of origin, whereas borrowings do not. Grosjean (1988) found that listeners processed borrowings with difficulty since the cross-language word (e.g. *pique*) is preferred (the actual French word *pique* means 'to prick' in English) when in actuality the word that is required is the English candidate (e.g. *pick*). In the preceding example, *pick* strongly competes with *pique* since *pick* has a higher frequency of occurrence than *pique*. Eventually, the French word *pique* is erroneously selected since the acoustic input suggests a French VOT and hence a French word (Grosjean, 1988). This indicates that even though there was a semantic mismatch between the lexical candidate selected (*pique* 'prick' was selected over *pick*) and the sentence context, the listener still selected the French word *pique* over the English word *pick* due to the acoustic information found in the input. This suggests that subphonemic, acoustic information can restrict lexical candidates to the language in use.

Schulpen, Dijkstra, Schriefers, and Hasper (2003) showed that Dutch-English bilingual speakers used subphonemic differences in order to discriminate between interlingual homophones of different languages. In a cross-modal priming task, in which primes were presented auditorily and in which targets were presented visually, subjects were asked to indicate whether the target word presented represented an English word or not. Dutch-English bilinguals responded more quickly to targets that were preceded by the English pronunciation of the interlingual homophone than by the Dutch pronunciation of the interlingual homophone. For example, the participants responded more quickly to the pair /liːf/ – *leaf*, when the acoustic input /liːf/ was pronounced as the English word *leaf*, than when it was pronounced as the Dutch word *lief*, meaning 'nice' in English. Furthermore, the authors demonstrated that bilingual speakers might at times be able to determine language membership even before they have identified the acoustic input as a word. After hearing approximately 60% of the acoustic input (usually, this included the initial phoneme and part of the vowel), the participants were able to determine which language the fragment belonged to with a 100% level of confidence and accuracy. This indicates that bilingual speakers are sensitive to the presence of language-specific cues and may make their language decisions to some extent prelexically, based on subtle language-specific cues in the signal.

In an eye-tracking experiment, Ju and Luce (2004) presented Spanish-English bilinguals with spoken Spanish words that contained either an English- or Spanish-appropriate voice onset time. They found that participants fixated on interlingual distracters, images of English words (e.g., *pliers*), which were phonologically similar to the Spanish target word (e.g., *playa* 'beach') more frequently than control distracters (e.g., the image of an eye and ruler), but only when the Spanish target word had been modified to contain an English appropriate voice onset time. When the Spanish target word contained a Spanish appropriate VOT, the bilingual speakers fixated on both the control and interlingual distracters equally. In the Spanish appropriate VOT condition, the target *playa* did not compete with the interlingual distracter *pliers* since the acoustic input indicated that the target word was a Spanish candidate. This was reflected by equal eye fixation time for both the control and interlingual distracters, indicating that listeners were able to restrict language access to Spanish candidates only based on the acoustic input. However, in the English appropriate VOT condition, the interlingual distracter *pliers* competed for selection with the target word *playa* since the acoustic input indicated that the target word was possibly an English candidate due to the English VOT. This was reflected by longer fixation times on the interlingual distracters than control distracters. It would appear that bilingual listeners used fine-grained, sub-phonemic, acoustic information to constrain language selection, thereby refining their lexical search and reducing the number of possible lexical candidates.

III. Purpose of the Study

The purpose of the proposed study is to investigate whether the acoustic-phonetic detail of the speech waveform can provide language cues that are used at the lexical level to aid in language identification. Language cues may be especially important for bilingual word recognition since bilingual speakers could use these cues to restrict lexical access to the language in use or enhance activation of words in the appropriate language. Furthermore, a language selection mechanism could considerably reduce the number of lexical candidates available, thereby speeding the process of word recognition.

The first question to be addressed in this study is whether stop identity cues such as voice onset time can cue language identity in Canadian bilingual French-English speakers. It seems plausible that bilingual speakers could use such cues, given that Grosjean (1988) showed that bilingual speakers could accurately determine language membership simply by listening to the initial phoneme of words, and given that Ju and Luce (2004) found that fine-grained acoustic information such as voice onset time affected cross-lingual lexical activation.

The first question is concerned with whether bilingual speakers can use stop consonant cues as cues to language membership. The second question is concerned with the effects of subphonetic differences on bilingual lexical access. Previous work has demonstrated that bilingual speakers use fine-grained (sub-phonemic), acoustic information to determine language membership; however, it is not clear whether cues to language membership are retained all the way through the process of lexical access. Furthermore, to date no models of bilingual lexical access exist that incorporate a role for language membership at the acoustic level, nor do existing lexical access models stipulate how language membership might be represented at the acoustic level. Therefore, the second question to be addressed here is: Does language membership play a role at the feature level in bilingual lexical access and if so, how is it represented?

IV. Organization of the Present Study

In order to address these two research questions, the literature review in Chapter 2 is organized into two parts, 1) literature pertaining to possible cues to language identity in CE and CF word-initial stops, and 2) the role of language membership in bilingual lexical access.

To determine whether the acoustic-phonetic details of stop consonants can cue language identity, it is first necessary to determine which acoustic features in stop consonants vary across Canadian French (CF) and Canadian English (CE) in bilingual speech production. From there, it is necessary to ensure that bilingual CF-CE listeners perceive these acoustic feature(s) as being significantly different in CE and CF. Two preliminary studies were conducted to provide this information.

The first preliminary study consisted of an interlingual homophone production study. The purpose of this study was to examine how word-initial stop consonants of Canadian English (CE) and Canadian French (CF) interlingual homophones differ in terms of their acoustic properties. Canadian bilingual speakers of English and French were asked to produce interlingual homophones (e.g., English *coo* [k^{h}u] and French *cou* 'neck' [ku]) presented in carrier phrases and in isolation. Voice onset time (VOT), relative burst intensity, and four spectral moments (i.e., mean, SD, kurtosis, and skewness of burst frequency) were measured and compared across languages. Using interlingual homophones ensured that the phonetic environment in which the word-initial stops was produced was nearly identical across languages.

The second preliminary study consisted of a language and phoneme categorization task. The purpose of this study was to ensure that the participants showed a perceptual sensitivity to the acoustic–phonetic manipulations while maintaining the percept of the intended phonetic category. The results of the preliminary language and phoneme categorization task were used to select a set of stimuli which participants identified as beginning with a voiceless stop and which the participants perceived across language VOT differences. The selected stimuli were used in the main perceptual experiment.

The main perceptual experiment consisted of an Auditory Lexical Decision Task. In this experiment, listeners were asked to decide whether the target stimulus was an English word or nonword. Primes were interlingual and close interlingual homophones with acoustically modified word-initial stops. Interlingual homophones are words across languages that are phonemically identical but are semantically different. For example, the English word *coo* /ku/ ‘bird-like sound’ and French word *cou* /ku/ ‘cough’ in English. Close interlingual homophones are words across languages that are phonemically near identical (i.e., one of the phonemes differ and/or is language specific such as English /r/ versus French /ʀ/) but are semantically different. For example, the English word *cat* /kæt/ and French word quête /kɛːt/ meaning ‘quest’ in English or the English word *core* /kɔr/ and French word *corps* /kɔʀ/ meaning ‘body’ in English. The purpose of the experiment was to examine how bilingual CE and CF speakers perceive subphonemic variations such as changes in VOT values of word-initial stop consonant productions.

CHAPTER 2: LITERATURE REVIEW

I. Possible Cues to Language Identity in Canadian English & Canadian French Word-Initial Stops

In order to address the two research questions asked in this study, the literature review that follows is organized in two parts, 1) literature pertaining to possible cues to language identity in Canadian English (CE) and Canadian French (CF) word-initial stops, and 2) the role of language membership in bilingual lexical access.

Although different languages often have phonemically identical sounds, at the acoustic level they can be quite different. These fine-grained acoustic differences may be important for faster recognition of which language is being spoken. If consistent cross-language differences exist, then these differences may play a role in bilingual lexical access. For Canadian English (CE) and Canadian French (CF), stop consonants qualify as phonemically identical sounds whose fine-grained acoustic differences may aid language recognition.

In general, CE and CF stops are highly phonemically similar, and as a result, share many of their acoustic features. Bilabial and velar stops in CE and CF have identical articulatory descriptions (see Table 1 for details). The coronals, however, do show some cross-language variation. English coronals are typically produced at the alveolar ridge while French coronals are dentalized. However, English coronal stops can also be dentalized, especially when preceding interdental consonants and in certain dialects such as varieties of New York English (Newman, 2014). Furthermore, some English speakers do not distinguish between alveolar and dental stops, often substituting one for the other (Dixon, 1980). For bilingual speakers of English and

French, English alveolar stops are often treated as an allophonic variant of the French dental stop (Sundara, 2005). Thus, even coronal stops share acoustic features across CE and CF.

Table 1

Articulatory Description of Canadian English (CE) and Canadian French (CF) Stop Consonants

IPA	Articulatory Description		
/p/	voiceless	bilabial	stop
/b/	voiced	bilabial	stop
/t/	voiceless	alveolar* (CE); dental (CF)	stop
/d/	voiced	alveolar* (CE); dental (CF)	stop
/k/	voiceless	velar	stop
/g/	voiced	velar	stop

*Note. Described as dental, especially preceding interdentals and in certain dialects such as New York English.

The sections that follow examine individual acoustic cues for stop consonants and summarize important results relating to English and French stop production in monolingual and bilingual speakers.

1. Voice Onset Time

The most widely studied acoustic measure of stop consonants is voice onset time (VOT). Voice onset time is the time lapse (measured in milliseconds—*ms*) between the release of the burst and the onset of periodic voicing (Leigh & Abramson, 1964). Languages may use up to three VOT patterns (lead, short-lag, & long-lag) to distinguish voicing in stop consonants. VOT values of less than 0 ms are referred to as lead VOT[1], values between 0 and 30 ms are referred to as short-lag VOT, and values greater than 30 ms are referred to as long-lag VOT (Caramazza, Yeni-Komshian, Zurif, & Carbone, 1973; Sundara, Polka, & Baum, 2006).

The relative range of VOT varies by language (Keating, Linker, & Huffman, 1984). In English, voiced stops tend to be produced with short-lag VOT, with values ranging from 0 to 20 ms, while voiceless stops tend to be produced with long-lag VOT, with values ranging from 60 to 100 ms (Caramazza et al., 1973; Macleod & Stoel-Gammon, 2008; Nearey & Rochet, 1994). In French on the other hand, voiced stops tend to be produced with lead VOT, with values ranging from -120 to -50 ms, while voiceless stops tend to be produced with short-lag VOT, with values ranging from 0 to 40 ms (Caramazza et al., 1973; Macleod & Stoel-Gammon, 2008; Nearey & Rochet, 1994). Lead VOT has also been reported for English voiced stops, although they are typically shorter in duration than French voiced stops (Macleod & Stoel-Gammon, 2008; Sundara et al., 2006).

With respect to Canadian English (CE) and Canadian French (CF) bilingual speakers' VOT productions, studies have repeatedly shown that CE and CF differ in their VOT patterns (Macleod & Stoel-Gammon, 2008; Sundara et al., 2006). Rather than producing a two-way contrast, as monolinguals do, bilinguals produce a four-way contrast across both of their languages (Macleod & Stoel-Gammon, 2008; Sundara et al., 2006). Furthermore, the VOT productions of each of these four categories are significantly different (Macleod & Stoel-Gammon, 2008). CE voiceless stops are

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[1] Lead VOT also known as negative VOT, is when voicing onset begins before the release burst (often as much as 70 to 100 ms before), whereas short-lag and long-lag VOT (i.e., positive VOT) is when the voicing onset begins after the release burst.

produced with long-lag VOTs while CF voiceless stops are produced with short-lag VOTs. CE voiced stops are produced with short-lag VOTs and sometimes lead VOTs while the CF voiced stops with long-lead VOT and sometimes short-lag VOT. Long-lead VOTs are negative VOT values of -100 ms or more (Garcia-Sierra, 2007). As a result, bilinguals not only maintain voicing contrasts within each of their languages but also across both of their languages (Macleod & Stoel-Gammon, 2008).

Language dominance has been shown to affect the distribution of VOT in bilingual speakers. If bilingual speakers are dominant in one of their languages, the VOT values tend to shift towards the dominant language (Caramazza et al., 1973; Watson, 1991). For example, English-dominant bilingual speakers could potentially have French voiceless stop consonant productions with long-lag VOT and signs of aspiration, and voiced stop consonant productions with short-lag VOT (e.g., Watson, 1991). However, their French long-lag VOT values tend to be shorter than their English long-lag VOT values, and the equivalent is true for their voiced stop consonant productions. It is important to note that even though VOT values shift towards the dominant language, perceptually this difference is undetectable. In other words, when asked, native speakers were unable to distinguish the speech of bilinguals from that of monolingual speakers (Watson, 1991).

2. Closure Duration

In addition to VOT, closure duration has also been shown to be an important cue for stop voicing (Repp, 1984). Closure duration is the time lapse (ms) between the articulatory closure of the stop consonant and the onset of the burst release (Cho & Ladefoged, 1999). Closure durations and VOT are inversely related, and since English

VOT durations are typically longer than French VOT durations, it is expected that closure durations for English stops will be shorter than closure durations for French stops. Indeed, this is the exact pattern observed when comparing studies on monolingual American English (AE) and Parisian French (PF) speakers (AE: 58.67 ms vs. PF: 76 ms; see Byrd, 1993 and Abdelli-Beruh, 2004).

As summarized above, VOT varies as a function of voicing (Caramazza et al., 1973). Furthermore, studies have also shown that VOT varies with place of articulation (Caramazza et al., 1973). Generally, VOT duration increases as the stop consonant moves from an anterior to a posterior place of articulation. Given this relationship, we would expect the opposite pattern for closure duration, that is, we would expect bilabials to have longer closure durations than velars. Several studies, both in American English (AE) and in Parisian French (PF), report bilabial stops as having longer closure durations than coronal and velar stops (AE: Zue , 1976; Byrd, 1993; Yao, 2007; PF: Abdelli-Beruh, 2004). However, some studies report coronal stops as having the shortest closure duration (e.g., Byrd, 1993), while others report no significant differences between coronal and velar stop closure durations (AE: Zue, 1976; Yao, 2007; PF: Abdelli-Beruh, 2004).

3. Burst Measures

The release burst has also been shown to be an important acoustic cue to stop identity. The release burst is the moment following the closure when the obstructed airflow is released. The release of the airflow causes a burst of noise, hence the name release burst. The release burst can be measured in several ways, two of which consist of obtaining the relative burst intensity and the burst spectral properties. Relative burst intensity (measured in dB) is the difference between the peak burst amplitude and the peak vowel amplitude (Macleod & Stoel-Gammon, 2008; Sundara, 2005). Larger relative burst intensity values indicate a greater difference between peak burst amplitude and peak vowel amplitude, and thus the presence of a softer burst and/or a louder vowel.

The spectral properties of the burst are characterized by four spectral moments: mean, standard deviation (SD), skewness and kurtosis. The spectral mean is the value of the average energy distribution, in Hertz of the burst release. The spectral mean indicates the location of the center of gravity (COG) of the burst release. The spectral standard deviation is the value of the spread of frequencies, in Hertz around the mean of the burst release. The spectral SD indicates how widely distributed (compact vs. diffuse) the energy is around the COG of the burst release. Spectral skewness is the value of the degree of symmetry or tilt in the distribution of frequencies around the COG of the burst release. Spectral skewness values can be positive or negative. Positive values imply that more energy is in the lower frequencies than in the higher frequencies, while negative values imply the opposite pattern. If the skewness value is zero or near zero, this indicates that, the energy distribution around the COG is symmetrical. Spectral kurtosis is the value of the degree of peakedness in the distribution of frequencies around the COG of the burst release. Spectral kurtosis values can be positive or negative. Positive values imply that the spectrum has clearly defined peaks, while negative values imply that the spectrum is flat (Nissen, 2003).

Relative burst intensity (RI) and burst spectral properties were used by Sundara et al. (2006) to measure voicing differences in CE and CF coronal stops in simultaneous bilingual speakers. For relative burst intensity, the bilingual speakers produced significant language differences between CE and CF /t/ tokens only. On average, CE /t/ tokens had smaller relative intensity values (i.e., higher burst amplitude) than CF /t/ tokens, indicating louder bursts. When comparing within language, Sundara and her colleagues found that bilingual speakers produced relative intensity differences between /d/ and /t/ in Canadian English, but not in Canadian French. In CE, /d/ tokens had greater relative intensity values (i.e., smaller burst amplitude) than /t/ tokens and consequently had softer bursts.

For burst spectral mean, the bilingual speakers did not produce any consistent language differences for coronal stop consonants. According to these results, it would appear that mean burst frequency is not an acoustic cue that CE-CF bilinguals can use to distinguish their two languages. However, differences in mean burst frequency were observed within Canadian English for /d/ and /t/ tokens produced by the bilingual French and English speakers. In Canadian English, the bilingual speakers produced /d/ tokens with lower mean burst frequencies than /t/ tokens. Thus, mean burst frequency may not be a cue for language identification but may be a possible voicing cue for within language differences, specifically in CE stops.

For burst spectral SD, Sundara et al. (2006) found that bilingual speakers produced consistent language differences for English and French coronal stops. CE coronal stops had lower burst spectral SDs than CF coronal stops. Compared to CF coronal stops, the burst spectra of the CE coronal stops were more compact, with more energy concentrated around the center of gravity (COG) of the burst. Thus, burst spectral SD differences may help differentiate CE from CF coronal stops produced by bilingual speakers. For burst spectral skewness, the bilinguals did not produce consistent language differences across English and French stops or consistent within language differences for English and French stops. Thus, skewness was neither useful for distinguishing CE from CF coronal stops, nor for distinguishing /d/ from /t/ tokens within CE and CF.

Finally, for burst spectral kurtosis, the bilinguals consistently produced language differences for CE and CF coronal stops. CE coronal stops had higher burst kurtosis than CF coronal stops. Thus, compared to CF coronal stops, the burst spectra of the CE coronal stops were more defined with clear delineated peaks. As such, kurtosis may help differentiate CE from CF coronal stops produce by bilingual speakers.

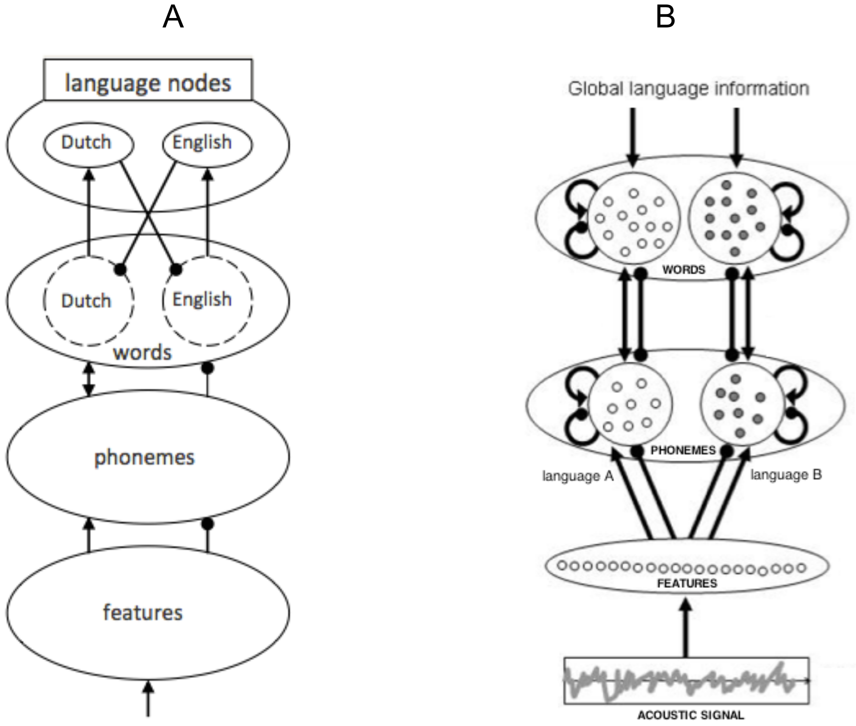
In summary**,** it would appear that VOT, closure duration, relative burst intensity, and burst spectral properties, specifically, burst spectral SD and burst spectral kurtosis, could potentially cue language identity in addition to stop identity in CE and CF stop consonants.

II. The Role of Language Membership in Bilingual Lexical Access: Current Models

Models of lexical access stipulate different roles for language membership in bilingual lexical access. For example, proponents of the Bilingual Interactive Activation Plus (BIA+: Dijkstra & van Heuven, 2002) model stipulate that language membership is established via language nodes which receive activation directly from lexical representation. The language nodes do not collect information outside of the lexical level (i.e., from the phoneme or feature level) and, as a result, do not affect the relative activation of words within a given language (Schwartz & Arêas Da Luz Fontes, 2008). Word recognition, as a result, is determined by the degree to which a speech input is similar to internal lexical representations and not language membership. The main role of the language nodes is to act as language tags; consequently, they do not have the ability to filter one language from another. The BIA+ model does not predict that language information could be obtained from the phoneme or feature level, or that language information could affect activation levels of individual entries.

In terms of the architectural structure, the BIA+ model has four levels, beginning from lowest to highest, they are: the feature, phoneme, word, and semantic levels. The language nodes are in a separate store, interacting only and directly with the word level (see Figure 1). The BIA+ has a single feature and single phonological store with separate nodes for words in each language. The BIA+ assumes a non-selective language access, insinuating that both languages are activated simultaneously.

Figure 1: A. The BIA+ model for bilingual word recognition (Dijkstra & Van Heuven, 2002, p. 182). This image pertains to a model of visual word recognition, as such for the auditory word recognition system the letter level would be replaced by phonemes. B. The BIMOLA model for bilingual recognition (Grosjean, 2000).



The Bilingual Model of Lexical Access (BIMOLA; Grosjean, 1988, 2000) also assumes a language-nonselective process, where both languages are activated simultaneously. The main difference between the BIA+ and the BIMOLA is in the way the two languages are represented. In the BIMOLA, languages are stored in separate networks both at the phoneme and word level, such that each language has a separate subset of phonemes and words. In the BIA+, both languages are stored in one single store at the phoneme and word level. However, at the feature level, both the BIA+ and BIMOLA assume a single store representation (see Figure 1).

In the BIMOLA, features can excite and inhibit phonemes in both languages in parallel, but phonemes interact with the word level only within their respective language (Chen, 2008). In other words, phonemes can excite or inhibit between levels, but only within a language. Language activation occurs from top-down language information (e.g., semantic context) and from within-language connections at the phoneme and word levels (Chen, 2008).

In summary, both the BIA+ and BIMOLA assume a language-nonselective process, however they differ in the way language is represented. In the BIA+, languages are organized under a single store at the feature, phoneme and word levels, such that features, phonemes, and words compete with one another regardless of the language in use. In the BIMOLA, languages are organized as separate stores both at the phoneme and word levels. If features match phonemes from both languages, then both language networks will be activated in parallel.

Interestingly, neither model predicts nor explains the role of language membership at the feature level. Both models assume that at the feature level, one single store exists for both languages. The features depicted in both models follow the distinctive feature theory proposed by Chomsky and Halle (1968). In other words, for a word-initial stop /p/, the features +consonantal, labial, and –voicing (just to name a few) would be activated. It is my belief that, at the acoustic level, our system is further refined than the above. For a word-initial stop, I believe acoustic cues such as VOT, burst spectra, and closure duration are activated and aid in lexical access. Furthermore, if these cues contain information that is language specific, such as long-lag vs. short-lag VOT for word-initial stops, then these cues may have the ability to cue language identity since these have been shown to vary with language.

CHAPTER 3: AN ACOUSTIC MEASUREMENT STUDY OF WORD-INITIAL STOP CONSONANTS IN ENGLISH-FRENCH INTERLINGUAL HOMOPHONES

The purpose of the present study is to examine how word-initial stop consonants differ in terms of acoustic properties in Canadian English (CE) and Canadian French (CF) interlingual homophones. Interlingual homophones (IH) are words across languages that are phonemically identical but phonetically and semantically different, for example, English *coo* /ku/ and French *cou* ‘neck’ /ku/. Even though they are deemed phonemically identical, at the acoustical level they may be quite different.

For this study, Canadian bilingual English and French speakers were asked to produce interlingual homophones embedded in carrier phrases and in isolation. Closure duration, voice onset time (VOT), relative burst intensity (RI) and burst spectral properties (i.e., mean, standard deviation, skewness, and kurtosis of burst frequency) were measured and compared across languages. Although burst spectral properties and relative burst intensity were measured and compared, the main goal was to document language differences in VOT and closure duration in CE and CF word-initial stops. The information obtained from the acoustic measurement of VOT and closure duration was used to modify recorded stimuli in the Language and Phoneme Categorization study.

I. Methods

1. Participants

Eight adult bilingual French and English speakers (4 women and 4 men, M_{age} = 29.38 years, age range: 20-33 years) were recorded for analyses (see Table 2). No one reported any language or learning disability or any hearing or vision impairment. To ensure that participants were indeed proficient in English and French they were screened using the Language Experience Questionnaire: Status and Skills Identification (LEQ-SSI; Castonguay and Andruski, 2013 November). The questionnaire provides demographic and language experience information, such as age of acquisition for L1/L2, current language use and preference – including percentage of daily use, self-rated proficiency in L1/L2, and external factors that influence L1/L2 learning and/or acquisition. According to the participants' responses, the participants could be classified as simultaneous, sequential (early vs. late) or late learners; balanced vs. dominant speakers; highly, moderately, or not at all fluent/ proficient speakers. Of the 8 bilingual participants, 7 were early sequential bilingual speakers (i.e., learned English after the age of 4 but before the age of 8) and 1 was a simultaneous bilingual speaker (i.e., learned English and French before the age of 3). All 8 participants reported being 'quite fluent' or 'very fluent' in speaking, listening, reading and writing in both English and French. Of the 8 participants, 3 were balanced bilinguals (B4, B7, and B8), while 5 were English dominant speakers (B1 – B3, and B5 – B6).

It is important to note that all participants resided in a region where English is the predominant language. To compensate for potential effects of living in a predominantly English-speaking region, the participants needed to meet the following 4 criteria to be selected. First, they had to report French as their main language spoken during childhood. This was assessed by asking the participants which language was used to communicate with their parents and caregivers. Second, participants had to report being schooled in French. They may have taken English classes, as it is common in most Canadian schools, however, the primary language of instruction was in French. Third, participants had to report being ‘quite fluent’ or ‘very fluent’ in speaking and comprehension in both English and French. Fourth, the participants had to report using English and French on a weekly basis. This was assessed by asking the participants which language they used at home, at work, and for social and media-related activities.

Table 2

Participant Demographics

					% French Used		
Participant	**Gender**	**Age**	**L1**	**Age of L2 Acquisition**	**At home**	**At work**	**Overall**
B1	M	33	CF	4 – 8	75	0	25
B2	F	31	CF	4 – 8	25	50	25
B3	F	29	CF	4 – 8	75	0	25
B4	F	30	CF	4 – 8	75	100	50
B5	M	33	CE - CF	At Birth	50	75	25
B6	M	29	CF	4 – 8	25	25	25
B7	F	30	CF	4 – 8	75	75	50
B8	M	20	CF	4 – 8	75	25	50

*Note. Overall is the overall average of language used at home, at work, with family members living outside of the home (father, mother & siblings) and for media related activities.

2. Stimuli

To ensure that any acoustic differences found between CE and CF word-initial stop productions are not due to the phonetic environment in which they are produced, interlingual homophones (IH) were used. Interlingual homophones (IH) are words across languages that are phonemically identical but phonetically and semantically different, for example, English *coo* /ku/ and French *cou* ‘neck’ /ku/.

Seventeen IH pairs were selected for the current study (see Appendix A). All IHs were monosyllabic nouns ensuring that suprasegmental features such as stress or syllable timing were not differentiating the pronunciations of the IHs. In addition, all IHs began with a stop consonant /p, b, t, d, k, g/ followed by the vowel /ɛ/, /u/ or /ɔ/. These vowels were selected since they were found to be the most similar, in terms of their articulatory descriptions, across CE and CF (Picard, 2001; Sundara et al., 2006). The goal in selecting IH pairs was to have 18 IHs (6 consonants x 3 vowels). However, for /k/ only two IH words could be found. As a result, the stimuli consisted of 17 different English words in English with 17 IHs in French.

3. Production Task

The recording sessions took place at the participants' homes. Any electrical devices that might introduce noise into the recordings (computers, fans, furnace, etc.) were switched off for the recording session. Recordings were made using a Sony DAT recorder with a microphone placed 2 feet in front of the participant. Participants read the interlingual homophones from a PowerPoint presentation presented on a Macintosh laptop computer. The recording procedure was briefly summarized in English for half the speakers, and in French for the other half of the speakers. The directions were: "Read each sentence in its entirety as they appear on the screen. Each sentence will flash 2 times to remind you to say the sentence 2 times. After this, the target word will appear by itself on the screen. The target word will flash 2 times, to remind you to say the target word 2 times". Participants were asked to read several sentences as trial runs, to ensure they understood the procedure of the task and then read the set of sentences in the order presented in the PowerPoint file. The task took between 30 and

45 minutes to complete. The two carrier sentences were: "*Say* <target word> *again*", and "*Dis* <target word> *encore*". For example, for the English word *two*, participants produced the following utterance: "*Say <two> again*, *say <two> again*, *<two>, <two>"*.

4. Analysis Preparation

All of the recorded carrier phrases and target words for each speaker were transferred from the Sony DAT recorder to a MAC computer using PRAAT (Boersma & Weenink, 1992) and were saved as a single .wav file. Using PRAAT, each speaker's .wav file was edited and separated by target word such that each target word .wav file contained the two carrier sentences and the two isolated productions. There were a total of 34 .wav files for each bilingual speaker. A TextGrid was then created for each .wav file using PRAAT software. Each TextGrid had five tiers: 1) Word tier, 2) International Phonetic Alphabet (IPA) tier, 3) CVC tier, 4) VOT tier, and 5) Stop tier. Each TextGrid was then edited with its sound file to create intervals and labels that were used later by a PRAAT script to extract acoustic measurements. At the word tier level, the onset and offset of each target word were indicated using boundary markers and target words were marked with orthographic spelling. At the word tier level, the word produced in the embedded sentence was spelled out and the onset and offset of each target word was indicated using boundary markers. At the IPA tier level, a broad transcription of the word was provided, and the onset and offset of each sound was marked. At the CVC tier level, each sound was labeled as either a consonant or a vowel. Vowel onsets were marked at the zero-crossing before the first positive peak in the periodic waveform and the vowel offset was defined as the beginning of the stop closure or, in the case of an open syllable, at the location where formant energy dissipated (Jacewicz, Fox, & Salmons, 2007). In closed syllables, the final consonant boundary was also marked. At the VOT tier level, VOT components such as closure and VOT were marked. Closure intervals were marked with a boundary to the left of the vowel offset of the preceding vowel, and a marker to the left of the burst onset. Burst onset was defined as the first sharp spike in the waveform with a corresponding dark vertical band in the spectrogram (Macleod & Stoel-Gammon, 2008). VOT intervals were marked with a boundary to the left of the burst onset, and a marker to the right of voicing onset of the following vowel (Fowler, Sramko, Ostry, Rowland, & Halle, 2008). Finally, at the Stop tier level, pre-voicing, burst, and aspiration were marked. Pre-voicing intervals were marked with a boundary to the left of the onset of vocal fold vibration and one to the right of the stop burst release. Burst intervals were marked with a boundary to the left of burst onset and one to the right of the burst offset. In other words, from the first sharp spike in the waveform until a new waveform pattern emerged. Aspiration intervals were marked with a boundary to the left of the burst offset, and one to the right of the vowel onset of the following vowel. Once the coding of TextGrids was completed, a script was written and run to measure closure duration, VOT, relative burst intensity, and burst spectral properties of all the initial consonants. The results were summarized by stop, speaker, and language.

5. Acoustic Analyses

A small number of tokens were excluded from the analyses due to extraneous noise, mispronunciations, or instances where no clear burst could be detected. Prior to exclusion, there were 1088 tokens; 30 tokens were omitted due to mispronunciations and extraneous noise, and 14 tokens were omitted due to productions containing no clear bursts. This omission accounts for 4% of the data. As a result, a total of 1044 tokens, 532 CE and 512 CF tokens, were analyzed. All analyses were performed using PRAAT. Only tokens produced in sentential context were included in the closure duration analyses. Burst amplitude and the shape of the burst spectrum were measured over the entire burst duration beginning at the burst release (Sundara, 2005). Aspiration was not included in the measurement of the burst duration, and thus was not part of any subsequent burst intensity or burst spectra analyses (Sundara, 2005).

In order to compare intensity and spectral measures in CE and CF stops, all stops produced with pre-voicing were filtered using a 250 Hz high-pass filter (a similar technique was used in Sundara, et al., 2006; Jongman, Blumstein, and Lahiri, 1985). The filter was set at 250 Hz since some speakers had fundamental frequencies (F0) as high as 238 Hz. Using a high-pass filter with a cut-off frequency of 250 Hz ensured that the voicing component was effectively removed (Jongman, Blumstein, & Lahiri, 1985). The burst intensity of the word initial obstruent was measured relative to the intensity of the subsequent vowel (I_{vowel} - I_{burst}; measured in dB). Relative burst intensity was calculated by subtracting the maximum intensity value of the burst from the maximum intensity value of the vowel (Stoel-Gammon, Williams, & Buder, 1994; Sundara, 2005). On this measure, larger values indicate greater intensity differences between the vowel and the obstruent, and therefore, if vowel intensity remains the same, the presence of a softer burst.

The shape of the burst spectrum was measured with four spectral moments: mean, standard deviation (SD), kurtosis, and skewness. The spectral mean is the value of the average energy distribution (Hz) of the burst release. The spectral mean indicates the location of the center of gravity (COG) of the burst release (e.g., middle vs. off-center, high vs. low). The spectral standard deviation is the value of the spread of frequencies (Hz) around the mean of the burst release. The spectral SD indicates how widely distributed (compact vs. diffused) the energy is around the COG of the burst release. Spectral skewness is the value of the degree of symmetry or tilt in the distribution of frequencies around the COG of the burst release. Spectral skewness values can be positive or negative. Positive values imply that more energy is in the lower frequencies than in the higher frequencies, while negative values imply the opposite pattern. If the skewness value is zero or near zero, this indicates that, the energy distribution around the COG is symmetrical. Spectral kurtosis is the value of the degree of peakedness in the distribution of frequencies around the COG of the burst release. Spectral kurtosis values can be positive or negative. Positive values imply that the spectrum has clearly defined peaks, while negative values imply that the spectrum is flat (Nissen, 2003).

II. Results and Discussion

The purpose of the study was to examine how word-initial stop consonants of Canadian English (CE) and Canadian French (CF) interlingual homophones differ in their acoustic properties when produced by early sequential bilingual speakers. Furthermore, the study sought to identify the acoustic features that appear to provide cues to language identity for stops produced by bilingual French and English speakers. The data were analyzed to confirm that bilingual speakers produce language-specific differences in closure duration, VOT, burst intensity, and burst spectral properties for word-initial stops in CE and CF interlingual homophones in sentences and in isolation.

A Three-Way General Linear Model (GLM) repeated measures analysis of variance (ANOVA) with Language (CE and CF), Voicing (Voiceless and Voiced), and Place of Articulation (Bilabial, Coronal, and Velar) as within-subjects variables were conducted for each acoustic measure of interest. When significant main effects were found, Bonferonni's post-hoc analysis was conducted. In cases where the assumption of sphericity was violated (i.e., the variances of the differences between pairs of groups are not the same), the degrees of freedom for that effect was corrected by using Greenhouse-Geisser Epsilon (McCall & Appelbaum, 1973).

1. Closure Duration

The average closure durations for CE and CF stop consonants produced by bilingual speakers are summarized in Figure 2A. Overall, the bilingual speakers consistently produced stop consonants in CE with shorter closure durations than in CF. In addition, the bilingual speakers consistently produced longer closure durations for voiced stops, and for stops with an anterior place of articulation in the oral cavity. In the ANOVA, the main effects of Language ($F(1, 21) = 16.74$, $p < .001$), Voicing ($F(1, 21) = 33.68$, $p < .001$) and Place of Articulation ($F(2, 42) = 7.73$, $p < .001$) were significant. No significant interactions were found between any of the variables. Bonferroni's post-hoc tests confirmed that CE closure durations were significantly shorter than CF closure durations (157 ms vs. 212 ms); voiceless stop closure durations were significantly shorter than closure durations for voiced stops (163 ms vs. 206 ms); and velar and coronal closure durations were significantly shorter than closure durations for bilabial stops (176 ms and 180 ms vs. 198 ms), respectively.

2. Voice Onset Time (VOT)

The distributions of VOT for the CE and CF stop consonants are summarized in Table 3. In English mode, the bilinguals speakers produced 77% of the voiced tokens with short-lag VOT (0 – 30 ms) and 23% with lead VOT (less than 0 ms); 100% of the voiceless tokens were produced with long-lag voicing (greater than 30 ms). In French mode, the bilinguals speakers produced 84% of the voiced tokens with short-lag VOT (0 – 30 ms) and 16% with lead VOT (less than 0 ms); 100% of the voiceless tokens were produced with long-lag voicing (greater than 30 ms). Thus, the bilingual speakers produced more voiced tokens with short-lag VOT in CF mode than in CE mode. Overall, the bilingual speakers did not consistently produce VOT differences for CE and CF stop consonants. However, the bilingual speakers did consistently produce greater VOT values for voiceless stops, and for stops with a posterior place of articulation in the oral cavity. In the ANOVA, the main effects of Voicing (*F*(1, 46) = 258.99, p < .001) and Place of Articulation (*F*(2, 88.05) = 6.22, p < .01) were significant. A significant interaction was found between Language and Voicing (*F*(1, 46), = 10.84, p < .01). Bonferroni's post-hoc tests confirmed that voiceless stop VOT durations were significantly longer than VOT durations for voiced stops (80 ms vs. -1 ms) and that velar VOT durations were significantly longer than VOT durations for bilabial stops (44 ms vs. 33 ms), respectively. Furthermore, VOT values were in opposite direction across languages. For voiceless, stops CE VOT values were longer than CF VOT values, while for voiced stops, CF VOT values were longer than CE VOT values.

Table 3

VOT Means (ms) and Distributions for Stops Produced by Early Sequential CF-CE Bilinguals

	Canadian English			**Canadian French**		
	N	**Mean VOT**	**Frequency**	**N**	**Mean VOT**	**Frequency**
/p/	95	75	100%	94	67	100%
/t/	96	90	100%	94	80	100%
/k/	63	86	100%	60	81	100%
/b/	68	14	73%	78	18	81%
	25	-117	27%	18	-103	19%
/d/	72	24	80%	78	23	90%
	18	-145	20%	9	-134	10%
/g/	70	30	78%	77	31	81%
	20	-153	22%	18	-91	19%

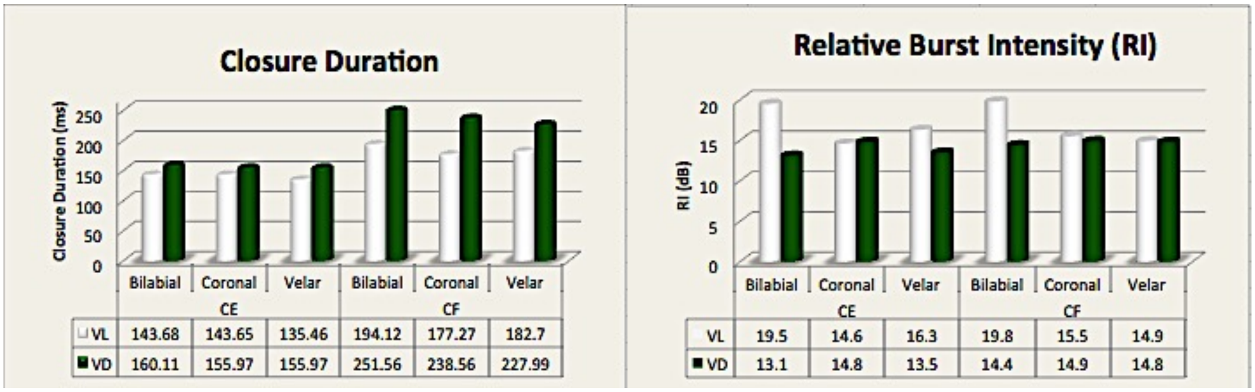
*Note. Distribution labeled as Frequency = Frequency of occurrence.

The above ANOVA included stop consonants produced with long-lag, short-lag and lead voicing. However, looking at the data, 100% of the CE and CF voiceless stop consonants were produced with long-lag voicing, while 77% of the CE and 84% of the CF voiced stop consonants were produced with short-lag. In order to obtain a more accurate depiction of the VOT values actually produced, another ANOVA was conducted with the lead VOT values removed. Overall, the bilingual speakers consistently produced stop consonants in CE with shorter VOT values than in CF. In addition, the bilingual speakers consistently produced greater VOT values for voiceless stops and for stops with a posterior place of articulation in the oral cavity. In the ANOVA, the main effects of Language (*F*(1,15) = 10.78, p < .05), Voicing (*F*(1, 15) = 300.10, p < .001) and Place of Articulation (*F*(2, 28.59) = 6.39, p < 0.01) were significant. A significant interaction was found between Language and Voicing (*F*(1, 15), = 21.76, p < .001), and Voicing and Place of Articulation (*F*(2, 24.29), = 12.55, p < .001). Bonferroni's post-hoc tests confirmed that CE VOT durations were significantly longer than VOT values for CF (51 ms vs. 46 ms), that voiceless stop VOT durations were significantly longer than VOT durations for voiced stops (74 ms vs. 23 ms), and that velar VOT durations were significantly longer than VOT durations for bilabial stops (52 ms vs. 45 ms), respectively. Furthermore, VOT values were in opposite direction across languages. For voiceless stops, CE VOT values were longer than CF VOT values, while for voiced stops, CF VOT values were longer than CE VOT values.

3. Burst Measures

3.1 Relative Burst Intensity (RI)

The average relative burst intensity (dB) for CE and CF stops produced by bilingual speakers are summarized in Figure 2B. Overall, the bilingual speakers did not consistently produce relative burst intensity differences for CE and CF stop consonants. However, the bilingual speakers did produce greater relative burst intensity differences for voiceless stops as opposed to voiced stops. This was particularly true for bilabial stops. In the ANOVA, the main effects of Voicing (*F*(1, 47) = 53.28, p < .001) and Place of Articulation (*F*(2, 94) = 7.05, p < .001) were significant. A significant three-way interaction was found between Language, Voicing and Place of Articulation (*F*(2, 94) = 4.12, p < 0.05). Bonferroni's post-hoc tests confirmed that voiceless stop RI values were significantly greater than RI values for voiced stops (16.79 dB vs. 14.24 dB) and that bilabial stop RI values were significantly greater than coronal and velar stop RI values (16.69 dB vs. 14.97 dB and 14.89 dB), respectively. As can be seen in Figure 2B, the intensity of the voiceless velar stops relative to the vowel was significantly greater than that of coronal stops, and significant in CE only – CE /k/ tokens which had softer bursts than CE /t/ tokens.



	Bilabial	Coronal	Velar	Bilabial	Coronal	Velar
	CE			CF		
□VL	143.68	143.65	135.46	194.12	177.27	182.7
■VD	160.11	155.97	155.97	251.56	238.56	227.99

	Bilabial	Coronal	Velar	Bilabial	Coronal	Velar
	CE			CF		
□VL	19.5	14.6	16.3	19.8	15.5	14.9
■VD	13.1	14.8	13.5	14.4	14.9	14.8

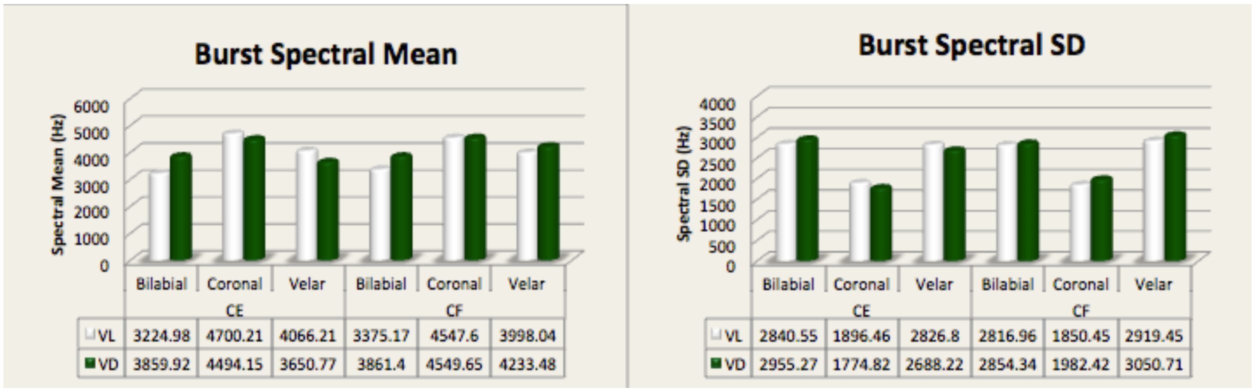
Figures 2A & 2B. Average Closure Duration (ms) and Relative Burst Intensity (dB) for Canadian English (CE) and Canadian French (CF) stop consonants produced by bilingual speakers. Light bars are voiceless (VL) tokens and dark bars are voiced (VD) tokens.

3.2 Spectral Mean

The average spectral means (Hz) for CE and CF stops produced by bilingual speakers are summarized in Figure 3A. Overall, the bilingual speakers did not consistently produce spectral mean differences for CE and CF stops consonants. In the ANOVA, the main effect of Place of Articulation ($F(2, 94) = 20.49$, $p < .001$) was significant. A significant interaction was found between Voicing and Place of Articulation ($F(1.65, 77.32) = 7.11$, $p < .01$). Bonferonni's post-hoc analysis confirmed that coronal stop spectral means are significantly greater than velar and bilabial spectral means (4573 Hz vs. 3987 Hz and 3580 Hz). As can be seen in Figure 3A, voicing differences were in opposite directions for bilabial stops, and significant only for bilabial stops, that is, /b/ tokens have greater spectral means than /p/ tokens.

3.3 Spectral Standard Deviation (SD)

The average spectral SDs (Hz) for CE and CF stops produced by bilingual speakers are summarized in Figure 3B. Overall, the bilingual speakers consistently produced stop consonants in CE with smaller spectral SDs than in CF. As a result, CE burst spectra are more compact with more energy concentrated around the center of gravity (COG) of the burst than CF bursts. In the ANOVA, the main effect of Language (*F*(1, 47) = 4.09, $p < 0.05$) and Place of Articulation (*F*(1.81, 85.25) = 145.47, $p < .001$) were significant. A significant three-way interaction was found between Language, Voicing and Place of Articulation (*F*(2, 94) = 3.22, $p < .05$). Bonferroni's post-hoc tests confirmed that CE spectral SDs is significantly smaller than CF spectral SDs (2497 Hz vs. 2579 Hz); coronal stop spectral SDs is significantly smaller than velar and bilabial spectral SDs (1876 Hz vs. 2871 Hz and 2867 Hz). As can be seen in Figure 3B, place of articulation differences were in opposite directions for stops across the two languages. Voiced bilabial stops had significantly greater spectral SDs in CE than in CF, and voiced velar stops had significantly smaller spectral SDs in CE than in CF.



	Bilabial	Coronal	Velar	Bilabial	Coronal	Velar
	CE			CF		
□ VL	3224.98	4700.21	4066.21	3375.17	4547.6	3998.04
■ VD	3859.92	4494.15	3650.77	3861.4	4549.65	4233.48

	Bilabial	Coronal	Velar	Bilabial	Coronal	Velar
	CE			CF		
□ VL	2840.55	1896.46	2826.8	2816.96	1850.45	2919.45
■ VD	2955.27	1774.82	2688.22	2854.34	1982.42	3050.71

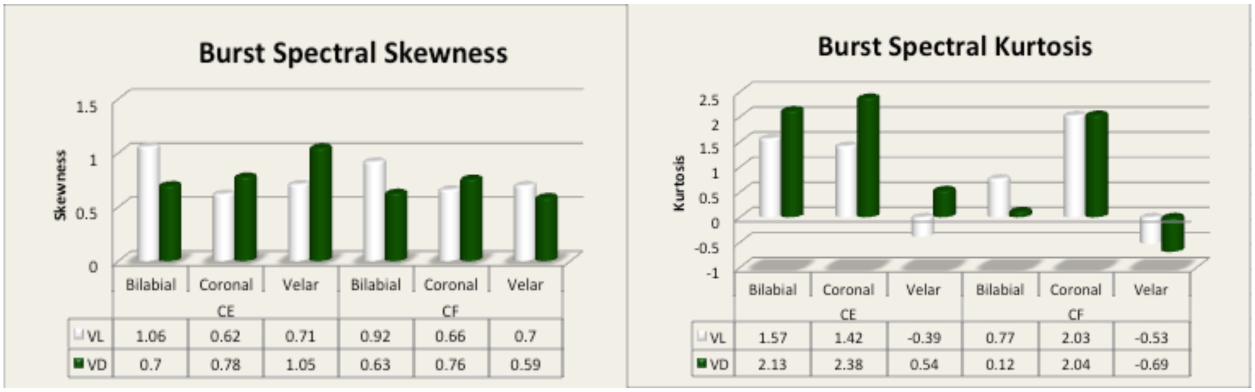
Figures 3A – 3B. Average Burst Mean and Burst Standard Deviation (SD) for Canadian English (CE) and Canadian French (CF) stop consonants produced by bilingual speakers. Light bars are voiceless (VL) tokens and dark bars are voiced (VD) tokens.

3.4 Spectral Skewness

The average spectral skewness for CE and CF stops produced by bilingual speakers are summarized in Figure 4A. Overall, the bilingual speakers did not consistently produce spectral skewness differences for CE and CF stops consonants. In the ANOVA, only the interaction between voicing and place of articulation reached significance (*F(*1.65, 75.79) = 5.84, p < 0.01). As can be seen in Figure 4A, voicing differences were in opposite directions for bilabial stops, and significant only for bilabial stops, that is, /p/ tokens have higher spectral skewness than /b/ tokens.

3.5 Spectral Kurtosis

The average spectral kurtosis for CE and CF stops produced by bilingual speakers are summarized in Figure 4B. In the ANOVA, there were no significant results. For Canadian bilingual French-English speakers in this study, kurtosis was not useful for distinguishing CE from CF stops, neither was it useful for distinguishing voiceless from voiceless stops, nor between place of articulation.



Figures 4A – 4B. Average Burst Skewness and Burst Kurtosis for Canadian English (CE) and Canadian French (CF) stop consonants produced by bilingual speakers. Light bars are voiceless (VL) tokens and dark bars are voiced (VD) tokens.

III. Conclusion

Acoustic analyses from the bilingual speakers in this study indicate that bilinguals do produce language-specific differences in CE and CF stop consonants. Stop consonants produced by bilinguals in CE and CF mode were different in closure duration, voice onset time, and burst spectral SD. CE stop consonants have shorter closure durations, longer voice onset time, and smaller spectral SDs (i.e., more energy around the COG of the bursts) than CF stop consonants. As such, closure duration, VOT, and burst spectral SD may provide cues to language identity in CE and CF stops. Due to these findings, closure duration and voice onset time were manipulated in order to create the stimuli in Experiment 2.

Furthermore, the analyses from this study indicate that Canadian French and English bilinguals produce voicing and place of articulation differences in CE and CF stops. Voiced and voiceless stop consonants produced by bilinguals in CE and CF were different in closure duration, voice onset time, and relative burst intensity. Voiceless stops have shorter closure durations, greater VOT values, and greater RI values (i.e., softer bursts) than voiced stops. Thus, closure duration, voice onset time, and relative burst intensity may cue voicing in CE and CF stops. CE and CF bilabial, coronal and velar stop consonants were different in closure duration, VOT, RI, burst spectral mean, and burst spectral SD. Bilabial stop consonants have longer closure durations, smaller VOT values, and greater RI values than coronal and velar stop consonants. Coronal stop consonants have greater burst spectral means and smaller burst spectral SDs (i.e., more compact burst spectra) than bilabial and velar stop consonants. Therefore, closure duration, VOT, RI, burst spectral mean, and SD may cue place of articulation in CE and CF stops.

CHAPTER 4: LANGUAGE & PHONEME CATEGORIZATION TASK

Cues to stop identity, such as voice onset time (VOT), relative burst intensity, formant transitions, and F0 initial contour have been shown to vary with language (Oglesbee, 2008; Sundara, 2005). If these differences are present across speakers, bilingual learners may use them to establish language identity in addition to stop identity. This study examined how stop identity cues such as VOT and closure duration influence a listener to identify word-initial stop consonants as belonging to Canadian English (CE) or Canadian French (CF). Based on the information obtained from the acoustic measurement study, recorded French-English monosyllabic interlingual homophones beginning with the stop sound /p, t/ or /k/ were acoustically modified such that the word-initial stop either agreed in value with the remainder of the word or disagreed (i.e., the intent was to make French stops that sound more like English and English stops that sound more like French). Voice onset time (VOT) and closure duration were varied such that the word-initial stop of the English tokens approximated a French-like word-initial stop, and that the word-initial stop of the French tokens approximated an English-like word initial stop. Listeners were asked to indicate which sound they heard and to judge whether the sound was most likely a CE or CF production. Results from this study were used to select the modified stop tokens for the Phonological-Semantic Priming study.

I. Methods

1. Participants

Thirty adult bilingual French and English speakers (21 women and 9 men, M_{age} = 37 years, age range: 18-59 years) were recruited for this study (see Appendix B & C). Recruitment procedures were identical to the one depicted in Chapter 3. No one reported any language or learning disability or any hearing or vision impairment. To ensure that participants were indeed proficient in English and French they were screened using the Language Experience Questionnaire: Status and Skills Identification (LEQ-SSI; Castonguay and Andruski, 2013 November). Of the 30 bilingual participants, 7 were simultaneous bilingual speakers (i.e., learned both English and French at birth or before the age of 3), 20 were early sequential bilingual speakers (i.e., learned their L2 after the age of 4 but before the age of 8), and 3 were late sequential bilingual speakers (i.e., learned their L2 after the age of 8 but before the age of 18). All the participants reported being ‘quite fluent’ or ‘very fluent’ in speaking, listening, reading and writing in both English and French. Of the 30 participants, 10 were balanced bilinguals while 11 were English dominant speakers and 9 were French dominant speakers (overall percentage daily use of French = 50% French, 25% French and 75% French, respectively).

2. Stimuli Design

Two sets of words were generated by looking up words in a French-English dictionary, from which half formed interlingual homophone pairs, while the other half formed close interlingual homophone pairs (see Appendices D – G). Close interlingual homophones are words across languages that are phonemically near identical but semantically different. The first set was a test set consisting of 36 words that begin with /p, t/ or /k/ and the second set was a distractor set consisting of 36 words beginning with /b, d/ or /g/. The author, a 32-year-old female Canadian French-English bilingual speaker, acted as the speaker for all recordings. Three repetitions of each word were recorded. All 72 words were recorded in a sound-treated booth using a Stereo DAT microphone and a Sony DAT recorder at a sampling rate of 44.1 Hz. The recordings were transferred from DAT tape to a MAC computer using PRAAT (Boersma & Weenink, 1992).

Voice onset time and closure duration were measured in the /p, t, k/ words to ensure that their values fell within the expected range of CE- and CF- voice onset time and closure durations. The expected VOT range for CE was 60 – 100 ms, and for CF 40 – 90 ms (Netelenbos, 2013; Turner, Netelenbos, Rosen, & Li, 2014). The values of the expected range for both the CE and CF stop consonants were obtained from the Interlingual Homophone production study. The mean VOT and CD values for the tokens included in the preliminary language and phoneme categorization task are summarized in Table 4. In order to achieve a relatively uniform set of tokens, CE and CF tokens whose value fell closest to the average VOT were selected for further manipulation. For the /b, d, g/ words, tokens which were most clearly enunciated were selected.

Table 4

Voice Onset Time (VOT) and Closure Duration (CD) in milliseconds (ms)

	/p/		/t/		/k/	
	VOT	CD	VOT	CD	VOT	CD
IH CE	70.6	80.2	79.3	78.0	87.3	80.9
IH CF	51.9	96.2	59.6	98.9	67.1	99.2
CIH CE	67.3	77.0	83.2	73.0	86.0	76.3
CIH CF	48.3	98.1	61.3	91.4	69.1	93.7

*Note. IH = Interlingual Homophones; CIH = Close Interlingual Homophones; CE = Canadian English; CF = Canadian French

For each /p, t, k/ interlingual and close interlingual homophone pairs, 1 English and 1 French unaltered voiceless stimuli were selected. From these, two altered versions of each English and French /p, t, k/ word were created to approximate a French-like word-initial stop for English tokens, and to approximate an English-like word-initial stop for French tokens. In the first altered version, the word-initial stop of each English and French /p, t, k/ word were created by varying the voice onset time. In the second altered version, the closure duration, in addition to the VOT, were varied for each English and French /p, t k/ word.

In order to create the first altered version of the voiceless stimuli (CF-VOT and CE-VOT), the VOT of each unaltered word was measured. VOT consists of the portion from the onset of the stop release to the initial onset of the vowel (first periodic pulse). The halfway point between the two measurement cursors was designated as the VOT midpoint. To create the French-like VOT from the CE stop tokens (called CE-VOT), approximately 7.5 ms of the full CE VOT was removed from each side of the VOT midpoint (see Table 5). Similarly, to create an English-like VOT from the CF stop tokens (called CF-VOT), approximately 7.5 ms of the full CF VOT was added to each side of the VOT midpoint (see Table 5). The full set of stimuli was then checked for transients or distortion, which may have been introduced by the alteration process.

Table 5

VOT Modifications

Stop	CF-base	CE-VOT “French-like”	CF-VOT “English-like”	CE-base
/p/	50 ms	55 ms	65 ms	70 ms
/t/	60 ms	65 ms	75 ms	80 ms
/k/	70 ms	75 ms	85 ms	90 ms

*Note the CE-VOT tokens were created by removing 15 ms from the VOT of the CE tokens, while the CF-VOT tokens were created by adding 15 ms to the VOT of the CF token.

The VOT altered tokens were used to create the second altered version of the voiceless stimuli (CF-VOTCD and CE-VOTCD). To create the second altered version of the voiceless stimuli, the closure duration (CD) of each VOT altered word was measured. For this study, closure duration consists of the portion from the offset of the previous vowel, where formant energy dissipated, to the burst onset, where the first spike in the waveform is observed. The halfway point between the two measurement cursors was designated as the closure duration midpoint.

The same overall methodological approach as described in the VOT section was used to create the manipulated closure duration tokens. The only difference was that closure duration was increased approximately by 15, 14, and 13.5 ms for the CE /p/, /t/, and /k/ tokens, and decreased approximately by 15, 14 and 13.5 ms for the CF /p, t/, and /k/ tokens, respectively (see Table 6). As stated earlier, closure duration is expected to be shorter in CE than in CF stop consonants. In order to create a French-like closure duration from an English stop token (called CE-VOTCD), the closure duration was increased and the reverse was true for English-like closure duration (called CF-VOTCD).

Table 6

Closure Duration Modifications

Stop	CF-base	CE-VOTCD “CF-LIKE”	CF-VOTCD “CE-LIKE”	CE-base
/p/	99 ms	94.0 ms	84.0 ms	79 ms
/t/	95 ms	90.0 ms	81.0 ms	76 ms
/k/	96 ms	91.5 ms	82.5 ms	78 ms

*Note the CE-VOTCD tokens were created by adding 15 ms for /p/, 14 ms for /t/, 13.5 ms for /k/ to the CD of the CE tokens, while the CF-VOTCD tokens were created by removing 15 ms for /p/, 14 ms for /t/, 13.5 ms for /k/ from the CD of the CF token.

Overall, listeners heard six versions of each of the 36 /p, t, k/ test words (CE-base: unaltered English tokens; CF-base: unaltered French tokens; CE-VOT: - VOT; CE-VOTCD: -VOT, +CD; CF-VOT: +VOT; CF-VOTCD: +VOT, -CD) plus the distractor set of 36 /b, d, g/ words. Six separate blocks of words were created for presentation in the language and phoneme categorization task. A different version of each /p, t, k/ word (CE-base, CF-base, CE-VOT, CE-VOTCD, CF-VOT and CF-VOTCD) was randomly assigned to each block. The resulting blocks consisted of 72 words, where half of these began with a voiceless stop while the other half began with a voiced stop.

3. Procedure

Participants were told that they will hear a series of words that are either English or French and which begin with one of the six consonant sounds /b, d, g/ or /p, t, k/. They were required to indicate, by a press of a button, whether the manipulated token was most likely 1) an English or French production, and 2) the sound /b, d, g/ or /p, t, k/.

They were instructed to answer as quickly and as accurately as possible. The task took approximately 10 minutes to complete.

II. Results and Discussion

The purpose of the study was to examine how stop identity cues such as voice onset time and closure duration influence a listener to identify word-initial stop consonants as belonging to Canadian English (CE) or Canadian French (CF). The data were analyzed to confirm that bilingual speakers perceive language-specific differences in closure duration and VOT for word-initial stops in CE and CF interlingual and close interlingual homophones.

A Three-Way General Linear Model (GLM) repeated measures analysis of variance (ANOVA) with Language (CE and CF), Acoustic Modification (Unaltered, +/-VOT, and +/-VOT+/-CD), and Word Type (Interlingual Homophones and Closed Interlingual Homophones) as within-subjects variables were conducted. When significant main effects were found, Bonferonni's post-hoc analysis was conducted on the response scores and reaction times. In cases where the assumption of sphericity was violated (i.e., the variances of the differences between pairs of groups are not the same), the degrees of freedom for that effect was corrected by using Greenhouse-Geisser Epsilon (McCall & Appelbaum, 1973).

1. Language Categorization Task

In order to establish whether the participants were perceptually sensitive to the acoustic differences between the unaltered and altered (+/-VOT, +/-VOT+/-CD) stimuli, mean and standard deviation RTs and language responses for the language categorization task were determined. The percentages of "French" and "English" responses across conditions are shown in Table 7. Predicted Response corresponds to the predicted language of the speech token, for example, CE-VOT (i.e., French-like) stimuli were predicted to be perceived as French stimuli.

Table 7

Means of the Percentages of "French" and "English" Responses in the Language Categorization Task (Experiment 2)

Prime Type	Example		Predicted Response	%		Actual Response	%	
	IH	CIH		IH	CIH		IH	CIH
CE-Base	*coo*	*core*	English	52	79	English	52	79
CE-VOT[2]	$c^{-VOT}oo$	$c^{-VOT}ore$	French	50	21	English	50	79
CE-VOTCD[3]	$c^{-VOT+CD}oo$	$c^{-VOT+CD}ore$	French	50	21	English	50	79
CF-Base	*cou*	*corps*	French	70	67	French	70	67
CF-VOT	$c^{+VOT}ou$	$c^{+VOT}orps$	English	47	34	French	53	66
CF-VOTCD	$c^{+VOT-CD}ou$	$c^{+VOT-CD}orps$	English	32	42	French	68	58

Note. IH = Interlingual homophones and CIH = Close interlingual homophones

1.1 Language Response Data

Overall, participants were more accurate at determining language membership for close interlingual homophones than interlingual homophones. In the ANOVA, the main effect of Word Type (*F*(1, 89) = 19.97, p < .001) was significant. Bonferroni's post-hoc tests confirmed that participants were more accurate at determining language membership for close interlingual homophones than interlingual homophones (71.1%

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[2] CE-VOT (e.g., $c^{-VOT}oo$): where the VOT of the word-initial stop consonant of an English word was modified to approximate a French-like VOT. For example, the English word *coo*, the VOT of the /k/ was reduced from long-lag to short-lag voicing to represent a French-like VOT. The reverse would be true for CF-VOT.

[3] CE-VOTCD (e.g., $c^{-VOT+CD}oo$): where the VOT and the Close Duration (CD) of the word-initial stop consonants was modified to approximate a French-like VOT and CD. For example, the English word *coo*, the VOT of the /k/ was reduced from long-lag to short-lag voicing, and the duration of the Closure was increased to represent a French-like VOT and CD. The reverse would be true for the CF-VOTCD.

vs. 57.2%), respectively. Although, no main effects of Acoustic Modification were found, it is interesting to note that the acoustically modified stimuli were on average identified as belonging to the language of origin rather than the predicted language. For example, "French-like" tokens such as c^{-VOT}*oo* were perceived as English productions (i.e., the English word *coo*) rather than French productions (i.e., the French word *cou*). In addition, participants were slightly more accurate at determining language membership for unaltered stimuli than altered stimuli (Base: 67% vs. VOTCD: 64% vs. VOT: 62%). This suggests that the participants did not perceive the acoustically modified stimuli as poor exemplars, but rather as a variation of the unaltered stimuli.

In addition to the main effect, a significant interaction between Word Type and Language ($F(1, 89) = 13.86$, $p < .001$) was found. Bonferroni's post-hoc tests confirmed that participants were significantly more accurate at determining language membership for "English" than "French" close interlingual homophones (English: 79.9% vs. French: 63.3%), whereas they were more accurate at determining language membership for "French" than "English" interlingual homophones (French: 63.7% vs. English: 50.7%).

In order to examine the effect of the acoustic modification on language membership, RTs were compared for "French" and "English" responses to Interlingual- and Close Interlingual Homophones containing unaltered and altered voiceless stops. RTs that were either faster than 400 ms or slower than 4000 ms were excluded from analyses. Furthermore, RTs that were more than 2 SD above or below a given participant's mean RT were excluded as well.

1.2 Reaction Time Data

The average reaction time RTs (ms) for CE and CF tokens are summarized in Figure 5. As the figure shows, RTs were fastest for the unaltered followed by the VOTCD altered stimuli, and considerably slower for the VOT altered stimuli. In the ANOVA, the main effects of Word Type (*F*(1, 89) = 10.08, p < 0.01) and Acoustic Modification (*F*(2, 178) = 3.06, p < .05) were significant. Bonferroni's post-hoc tests confirmed that RT for close interlingual homophones was significantly faster than RT for interlingual homophones (2532 ms vs. 2648 ms), and that RT for unaltered (BASE) stimuli was significantly faster than RT for VOT altered stimuli (2525 ms vs. 2648 ms), respectively.

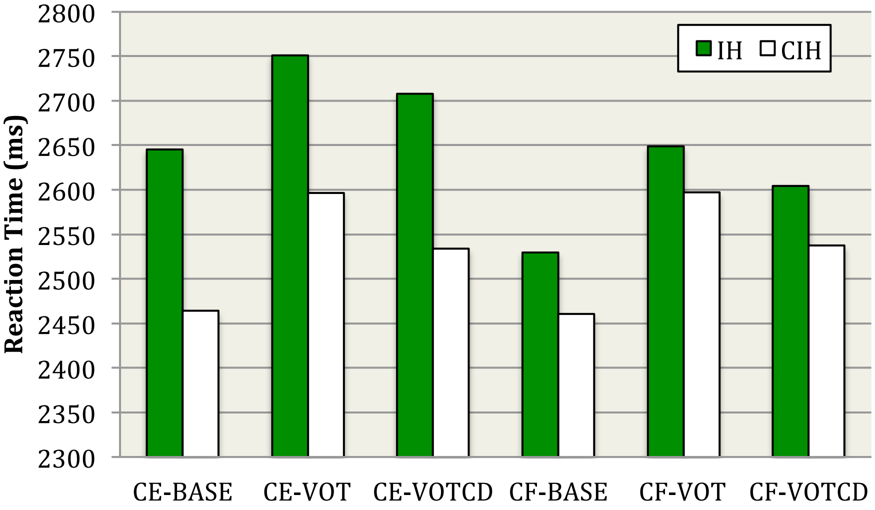

Figure 5. Mean RTs (ms) of the 72 /p, t, k/ words in the Language Categorization Task

2. Phoneme Categorization Task

The test stimuli were analyzed for correct categorization and mean RT to correct responses. Mean correct categorization rates and RTs for each version of the test stimuli are summarized in Table 8. Those /p, t, k/ stimuli of which each version was categorized at least 90% of the time were selected for analyses. 64 words were selected (i.e., 32 IH and 32 CIH). The mean correct categorization rate for the 64 /p, t, k/ words was 97.3%.

Table 8

Mean correct categorization rates and RTs (ms) for the altered and unaltered stimuli

Stimuli	Interlingual Homophones		Close Interlingual Homophones	
	% Correct	Mean RT	% Correct	Mean RT
CE-BASE	97.5	2526	98.8	2361
CE-VOT	98.8	2358	98.8	2467
CE-VOTCD	98.8	2437	97.5	2389
CF-BASE	98.7	2452	96.0	2525
CF-VOT	97.3	2454	98.7	2497
CF-VOTCD	93.3	2469	97.3	2475

To determine whether participants could perceive the within-category acoustic modifications (i.e., VOT and CD) and correctly categorized the stimuli in the three /p, t, k/ conditions, an analysis was conducted on the reaction times (RTs) of the selected 64 words. RTs that were either faster than 400 ms or slower than 4000 ms were excluded from analyses. Furthermore, RTs that were more than 2 SD above or below a given participant's mean RT were excluded as well.

The average reaction time RTs (ms) for CE and CF tokens are summarized in Table 8. As the table shows, RTs were fastest for Canadian English tokens. In the ANOVA, the main effect of Language (*F*(1, 79) = 4.54, p < .05) was significant. Bonferroni's post-hoc tests confirmed that RT was significantly faster for CE than CF tokens (2423 ms vs. 2479 ms).

III. Conclusion

The RTs from the bilingual listeners in this study indicate that bilinguals do perceive language-specific differences in CE and CF stop consonants. In the language categorization task, even though the participants categorized the altered stimuli as belonging to the language of origin, slower RTs and lower categorization rates for VOT altered stimuli indicate that they are sensitive to the acoustic manipulation of the VOT. The VOT altered stimuli are presumably poorer exemplars of the unaltered stimuli, and thus categorization responses are slower. Slower RTs and lower categorization rates for interlingual homophones indicate that bilingual listeners are sensitive to the phonological similarity of the interlingual homophones. Perhaps the presentation of one version results in the activation of both homophones, which then compete for recognition, and as a result, RTs are slower. In the phoneme categorization task, participants perceived both the unaltered and altered speech tokens as the voiceless stop /p, t/ or /k/ 90% of the time. Although no significant differences were found for Word Type and Acoustic Modification, slower RTs for CF speech tokens indicate that bilingual listeners are sensitive to language-specific acoustic differences when determining which sound they heard. Based on these results, the unaltered and altered VOT stimuli were chosen as test stimuli for the lexical decision task.

CHAPTER 5: THE EFFECTS OF SUBPHONETIC DIFFERENCES IN ACOUSTICALLY MODIFIED WORD-INITIAL STOP CONSONANTS OF CANADIAN ENGLISH AND CANADIAN FRENCH INTERLINGUAL HOMOPHONES

This study explored the role of subphonetic differences on bilingual lexical access using a lexical decision task. Listeners heard prime-target pairs and were asked to decide whether the second item of each pair was a real English word. Primes were either interlingual homophones or close interlingual homophones. Half were French- or English-base tokens (no acoustic manipulation), while the other half were French- or English-like tokens, where the voice onset time (VOT) of the word-initial stop was modified acoustically. Primes were followed by either a semantically related or semantically unrelated target word. Within the semantically related prime-target pairs, the target was semantically related to the English meaning of the prime. For example, the phonetic string [ku], which corresponds to the English word *coo* and French word *cou* ‘neck’ was paired with the target word *baby* (e.g., [ku], *coo/cou – baby*). For the unrelated prime-target pairs, the prime and target had no semantic relationship (e.g., [ku], *coo/cou – field*). An equivalent distractor set was also created, however, the targets were nonwords rather than English words. This was to ensure that for half the stimuli the lexical decision task responses were ‘yes’, while for the other half, the responses were ‘no’. Reaction time and error rate were measured and compared across participants. Results from this study provided insight on the acoustic-phonetic representation of stop consonants in Canadian bilingual English and French speakers.

I. Methods

1. Participants

Fifty bilingual French and English speakers (34 women and 16 men, M_{age} = 37.36 years, age range: 19-59 years) were recruited for this study (see Appendices H & J). Recruitment procedures were identical to those presented in Chapter 3. No one reported any language or learning disability or any hearing or vision impairment. To ensure that participants were indeed proficient in English and French they were screened using the Language Experience Questionnaire: Status and Skills Identification (LEQ-SSI; Castonguay and Andruski, 2013 November). Of the 50 bilingual participants, 17 were simultaneous bilingual speakers (i.e., learned both English and French at birth or before the age of 3), 23 were early sequential bilingual speakers (i.e., learned their L2 after the age of 4 but before the age of 8), 9 were late sequential bilingual speakers (i.e., learned their L2 after the age of 8 but before the age of 18), and 1 was a late learner of English (i.e., learned English after the age of 18). All the participants reported being ‘quite fluent’ or ‘very fluent’ in speaking, listening, reading and writing in both English and French. Of the 50 participants, 19 were balanced bilinguals (overall percentage daily use of French = 50%), while 14 were English and 17 were French dominant speakers (overall percentage daily use of French = 25% French and 75% French, respectively).

2. Stimuli

Eighteen real-word targets were preceded by five priming conditions. These five priming conditions were considered the test items (see Appendices K – N). In the five priming conditions, the prime was either an interlingual homophone or close interlingual homophone where the voice onset time of the word-initial stop /p, t, k/ was either acoustically modified to reflect French- or English-like tokens, or not acoustically modified to reflect French- or English-unaltered tokens (see the language and phoneme categorization task for the acoustic manipulations).

The target following these words was either semantically related to the English pronunciation or unrelated to both the English and French pronunciation of the prime, such that the phonetic string [ku], corresponding to the English word *coo* and French word *cou* ‘neck’, would be paired with either the word *baby* (semantically related) or *field* (Unrelated). For example, [k$^{\text{CE-base}}$u] – *baby*, [k$^{\text{CE-like}}$u] – *baby*, [k$^{\text{CF-like}}$u] – *baby*, [k$^{\text{CF-base}}$u] – *baby*, or [k$^{\text{CE-base}}$u] – *field*, [k$^{\text{CE-like}}$u] – *field*, [k$^{\text{CF-like}}$u] – *field*, [k$^{\text{CF-base}}$u] – *field*. Targets were either one- or two- syllable words and beginning with a sound other than /p, t, /k/.

Five equivalent distractor conditions were created. Targets in the distractor conditions were one- or two-syllable words. The nonword target words were constructed by replacing the initial sound or consonant cluster of real English words with some other sound or cluster, all the while respecting the phonotactic constraints of English, for example, *cake* → *chake*. Consistent with the above five test priming conditions, there were five distractor priming conditions: all contain either an interlingual or close interlingual homophone that was either unaltered (base token) or altered (+/- VOT), creating an equivalent set of prime word distractors.

Five separate blocks were created for presentation. A different version of each /p, t, k/ word (CE-base, CF-base, CE-like and CF-like) was randomly assigned to each block. The resulting blocks contained an equal number of CF- and CE-base, and CF-and CE-like tokens. Thus, each /p, t, k/ word appeared five times, once in each block. Overall, the experimental stimuli consisted of 360 trials, half of which consisted of YES responses (word targets) and half of which consisted of NO responses (nonword targets). The interstimulus intervals (ISI) between the prime and target words was set at 50 ms, and the intertrial interval (ITI) was set at 1000 ms.

3. Procedure

Stimuli were presented to participants via Sony headphones in a soundproof room. The participants were told that they would hear a series of word pairs and that the second item of each pair would be either a word or nonword. The participants were instructed to press a button labeled “Word” if the second item of the pair was a word, or to press the button labeled “Nonword” if it was not. They were asked to respond as quickly and as accurately as possible. A practice set of five stimuli was given prior to the experimental set. No feedback was provided to the participants in regards to their practice responses, however, they were provided with the opportunity to ask questions before the experiment began.

Following the lexical decision task, the participants completed a language categorization task. This task was included to see in which language the participants categorized the interlingual homophones and close interlingual homophones. In this task, the participants heard both versions (altered and unaltered) of the 72 prime test words used in the lexical decision task. Stimuli were randomized using the same method described in the preliminary language categorization task and participants were given the same instructions as for that task. On average, it took the participants 15 minutes to complete both the lexical decision and language categorization task.

II. Analysis of Results

1. Language Categorization Task

In order to establish whether the participants were perceptually sensitive to the acoustic differences between the unaltered and the altered (+/- VOT) prime stimuli, mean and standard deviation RTs and language responses for the language categorization task were determined.

The participants were expected to have greater difficulty determining language membership for the altered stimuli since the initial stop consonants were acoustically modified to approximate French- and English-like pronunciation of the 'same' cross-language phonetic category, that is, English unaspirated [p] vs. French aspirated [p^h]. As a result, longer reaction times and reduced categorization rates were expected for the altered stimuli. To determine whether this pattern of results was due to the general perceptual effect of the acoustic manipulation on language membership, the identification responses of the language categorization task were examined across items. Items that failed to be identified correctly by at least 66% of the participants were eliminated from all subsequent analyses.

A Three-Way General Linear Model (GLM) repeated measures analysis of variance (ANOVA) with Language (CE and CF), Acoustic Modification (Unaltered and Altered VOT), and Word Type (Interlingual Homophones and Closed Interlingual Homophones) as within-subjects variables were conducted. When significant main effects were found, Bonferonni's post-hoc analysis was conducted on the response scores and reaction times. In cases where the assumption of sphericity was violated (i.e., the variances of the differences between pairs of groups are not the same), the degrees of freedom for that effect was corrected by using Greenhouse-Geisser Epsilon (McCall & Appelbaum, 1973).

1.1 Language Response Data

The percentages of “French” and “English” responses across conditions are shown in Table 9. Overall, participants were more accurate at determining language membership for close interlingual homophones than interlingual homophones. In the ANOVA, the main effects of Word Type ($F(1, 899) = 421.51$, $p < .001$) and Language ($F(1, 899) = 42.74$, $p < .001$) were significant. Bonferroni’s post-hoc tests confirmed that participants were more accurate at determining language membership for close interlingual homophones than for interlingual homophones (76.6% vs. 55.7%) and for Canadian English tokens than for Canadian French tokens (71.5% vs. 60.7%), respectively. Although no main effects of Acoustic Modification were found, it is interesting to note that the acoustically modified stimuli were, on average, identified as belonging to the language of origin rather than the predicted language. For example, “French-like” tokens such as $c^{-VOT}oo$ were perceived as English productions (i.e., the English word *coo*) rather than as French productions (i.e., the French word *cou)*. In addition, participants were slightly more accurate at determining language membership for unaltered stimuli than altered stimuli (Base: 67% vs. VOT: 66%). This suggests that the participants did not perceive the acoustically modified stimuli as poor exemplars, but rather as a variation of the unaltered stimuli.

Table 9

Means of the Percentages of "French" and "English" Responses in the Language Categorization Task (Experiment 3)

Prime Type	Example		Predicted Response	Percentage		Actual Response	Percentage	
	IH	CIH		IH	CIH		IH	CIH
CE-Base	*coo*	*core*	English	63	81	English	63	81
CE-VOT[4]	$c^{-VOT}oo$	$c^{-VOT}ore$	French	39	18	English	61	82
CF-Base	*cou*	*corps*	French	50	72	French	50	72
CF-VOT	$c^{+VOT}ou$	$c^{+VOT}orps$	English	50	28	French	50	72

Note. IH – Interlingual homophones; CIH = Close interlingual homophones

1.2 Reaction Time Data

In order to examine the effect of the acoustic manipulation on language membership, reaction times were compared for "French" and "English" responses to Interlingual- and Close Interlingual Homophones containing unaltered and altered speech tokens. RTs that were either faster than 400 ms or slower than 4000 ms were excluded from analyses. Furthermore, RTs that were more than 2 SD above or below a given participant's mean RT were excluded as well.

A three-way repeated-measures analysis of variance (ANOVA) was performed on the RT data, with Language (CE and CF), Acoustic Modification (Unaltered and Altered VOT), and Word Type (Interlingual Homophones and Close Interlingual Homophones) as within-subjects variables. The average reaction time RTs (ms) for CE and CF tokens are summarized in Figure 6. As the figure shows, RTs were fastest for Canadian French tokens. In the ANOVA, the main effect of Word Type (*F*(1, 899) =

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[4] CE-VOT (e.g., $c^{-VOT}oo$): where the VOT of the word-initial stop consonant of an English word was modified to approximate a French-like VOT. For example, the English word *coo*, the VOT of the /k/ was reduced from long-lag to short-lag voicing to represent a French-like VOT. The reverse would be true for CF-VOT.

4.937, p < .05) was significant. Bonferroni's post-hoc tests confirmed that reaction time was significantly faster for interlingual homophones than for close interlingual homophones (1299 ms vs. 1317 ms), respectively.

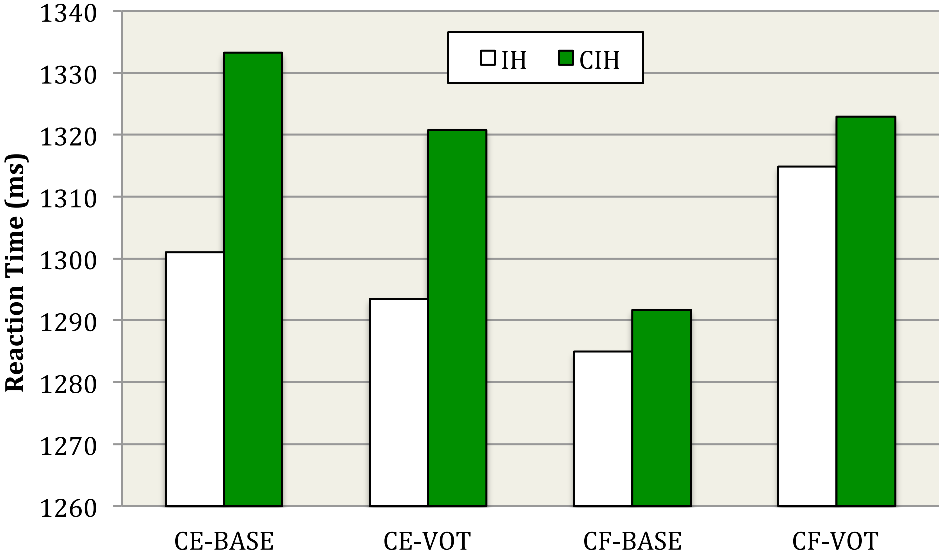

Figure 6. Mean RTs (ms) of the /p, t, k/ words in the Language Categorization Task

A significant interaction was found between Language and Acoustic Modification (*F*(1, 899) = 7.05, p < 0.01). Bonferroni's post-hoc tests confirmed that RT for CE altered VOT stimuli was significantly faster than CE unaltered stimuli (1307 ms vs. 1317 ms), while RT for CF altered VOT stimuli was significantly slower than CF unaltered stimuli (1318 ms vs. 1288 ms), respectively.

2. Lexical Decision Task

In order to establish that the acoustic manipulation of the close interlingual homophones and the interlingual homophones did not affect the lexical status of the primes, mean and standard deviation RTs and error rates for the lexical decision task were determined. Percent correct lexical decisions are shown in Table 10. The data shows that the participants performed very well in making correct lexical decisions for the prime stimuli. However, they made more errors on the Canadian English Base (CE-BASE) non-word stimuli. Nonetheless, a three-way repeated-measures analysis of variance (ANOVA) was performed on the correct response data, with Lexical Status (word vs. nonword), Language (CE vs. CF), and Acoustic Modification (Unaltered vs. Altered VOT) as within-subjects variables. A significant main effect was found for Lexical Status (*F*(1, 42) = 28.67, p < .001). Bonferroni's post-hoc tests confirmed that lexical decisions were less accurate for nonword stimuli than for word stimuli (88.96% vs. 97.21%), respectively.

Table 10

Percent correct lexical decisions for each version of the prime stimuli

Stimulus	**Word**		**Nonword**	
	CE	**CF**	**CE**	**CF**
Base	97.39%	97.02%	86.09%	91.49%
VOT	96.82%	97.21%	90.45%	87.91%

Note. CE = Canadian English; CF = Canadian French

In order to examine the effect of the acoustic manipulation on lexical decisions, RT of correct lexical decisions were compared for "word" responses. RTs that were either faster than 400 ms or slower than 4000 ms were excluded from analyses. Furthermore, RTs that were more than 2 SD above or below a given participant's mean RT were excluded as well.

RT data of correct lexical decision for real word targets are summarized in Figure 7. As the figure shows, the bilingual participants exhibited faster lexical decision latencies for the CE-BASE and CE-VOT priming conditions. A two-way repeated-measures analysis of variance (ANOVA) with Word Type (IH vs. CIH) and Prime Type

(CE-BASE, CE-VOT, CF-BASE, CF-VOT, and unrelated) as within-subjects confirmed this. Significant main effect was found for Prime Type (*F*(3.39, 155.84) = 2.73, p < .05). Bonferroni's post-hoc tests confirmed that lexical decision latencies were significantly faster for CE-BASE and CE-VOT than for CF-VOT prime words (1638 ms, 1633 ms vs. 1737 ms), respectively.

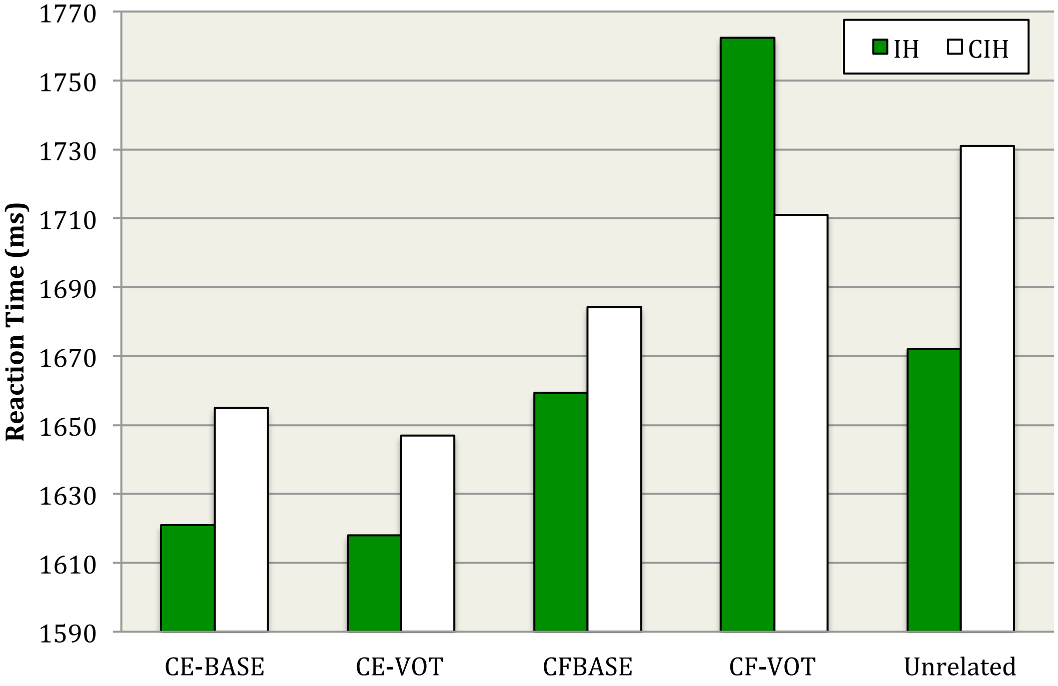

Figure 7. Mean RTs (ms) to real word targets by word type in the Lexical Decision Task

Since no significant differences were found between the RT of interlingual homophones and RT of close interlingual homophones, IH and CIH were combined for the remainder of the analyses. As a result, another similar analysis to the one above was conducted, but RT to nonword was also added. Consistent with the results found for IH vs. CIH, the bilingual participants exhibited faster lexical decision latencies for the CE-BASE priming conditions (see figure 8). A two-way repeated-measures analysis of variance (ANOVA) with Lexical Status (real word and nonword) and Prime Type (CE-BASE, CE-VOT, CF-BASE, CF-VOT, and unrelated) as within-subjects variables confirmed this. Significant main effects were found for Lexical Status (*F*(1, 47) = 66.15, p < .001) and Prime Type (*F*(4, 188) = 5486, p < .001). Bonferroni's post-hoc tests confirmed that lexical decision latencies were significantly faster for real word targets than for nonword targets (1683 ms vs. 1923 ms); and significantly faster for CE-BASE than CF-BASE and CF-VOT prime words (1730 ms, 1821 ms vs. 1875 ms), and significantly faster for CE-VOT than CF-VOT (1771 ms vs. 1875 ms), respectively.

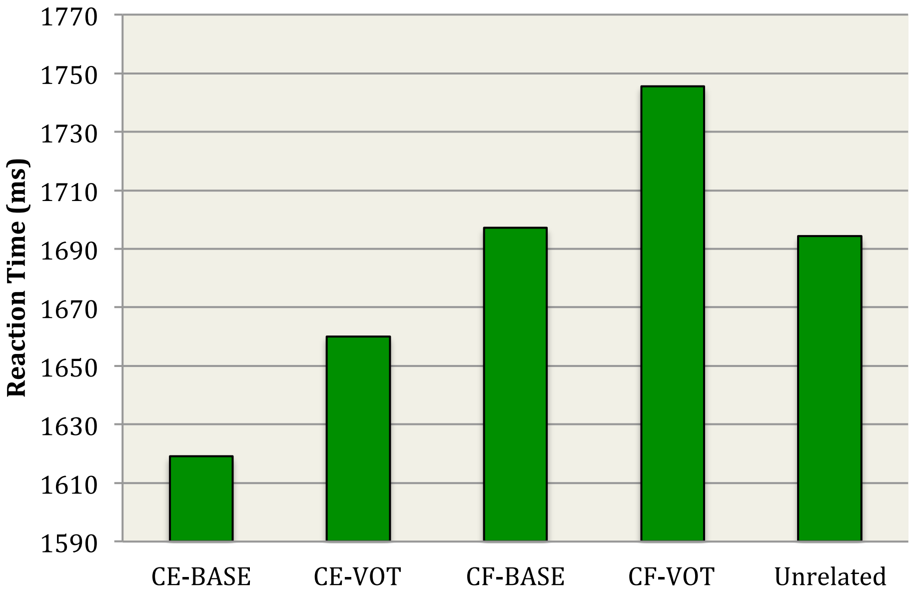

Figure 8. Mean RTs (ms) to real word targets in the Language Decision Task

These results suggest that the VOT manipulations do have an effect on lexical access. However, it is also possible that the results reflect lesser amounts of semantic facilitation for CF-BASE and CF-VOT than CE-BASE and CE-VOT primes. In other words, the CF-BASE and CF-VOT primes may be perceived as Canadian French tokens, and as a result are viewed as unrelated to the target, whereas CE-BASE and CF-VOT primes are perceived as Canadian English tokens and related to the target. If this were the case, then lexical decision latencies should be slower for CF-BASE, CF-VOT, and unrelated primes when compared to CE-BASE and CE-VOT primes. This is the pattern observed in the figure above. However, lexical decision latencies for the CE-VOT priming conditions are not more significantly different than the CF-BASE and unrelated conditions, suggesting that the differences observed in the CE-VOT and CF-VOT lexical decision latencies are not due to semantic facilitation, but rather to subphonetic variations in the VOT value.

To further explore the effect of semantic facilitation on prime type, a second analysis was conducted to examine the effect of prime type on semantically related and unrelated word targets. In order to conduct this analysis, the data for the unrelated targets were sorted and reorganized. Rather than combining all the unrelated targets into one category as done above, the unrelated targets were sorted by prime type, that is, CE-BASE, CE-VOT, CF-BASE, and CF-VOT. From there, RTs to semantically related targets were compared to RTs to semantically unrelated targets. If the slower RTs to the semantically related CE-VOT and CF-VOT primes reflect semantic facilitation, rather than subphonetic variations in the VOT value, then RTs to semantically unrelated CE-VOT and CF-VOT should be significantly different. As can be seen in Table 11, the mean RTs for semantically related CE-VOT and CF-VOT primes were faster than the mean RTs for semantically unrelated CE-VOT and CF-VOT primes (by 22 ms and 36 ms, respectively). However, a paired, two-tailed t-test indicates that the 22 ms and 36 ms difference in RTs is not significant (p = .70 and p = .56, respectively).

Table 11

Mean RTs (ms) to semantically related and unrelated targets

	Mean RT		
Prime Type	**Semantically Related**	**Semantically unrelated**	**Difference**
CE-VOT	1660	1682	22
CF-VOT	1746	1785	36

Considering the new data structure and organization, the same analysis as the one conducted earlier on the combined unrelated target word data set was conducted once more to ensure that the effects found were not due simply to the layout of the data. As such, in order to examine the effect of the acoustic manipulation on lexical decisions, RT of correct lexical decisions were compared for real-word responses. RT data of correct lexical decisions are summarized in Figure 9. As the figure shows, the bilingual participants did not exhibit semantic facilitation in the lexical decision task; RTs were not faster for target words preceded by a semantically related prime than by a semantically unrelated prime. However, RTs appear to be affected as a function of subphonetic variations in the VOT value. A two-way repeated-measures analysis of variance (ANOVA) with Semantic Relationship (related and unrelated) and Acoustic Modification (CE-BASE, CE-VOT, CF-BASE, and CF-VOT) as within-subjects variables confirmed this. A significant main effect was found for Acoustic Modification ($F(3, 141) = 3.99$, $p > .01$). Bonferroni's post-hoc tests confirmed that lexical decision latencies were significantly faster for CE-BASE than for CF-VOT tokens (1633 ms vs. 1765 ms), respectively. The same results as reported earlier were found with the new data structure, and these results, as before, suggest that the acoustic manipulations do have an impact on lexical access.

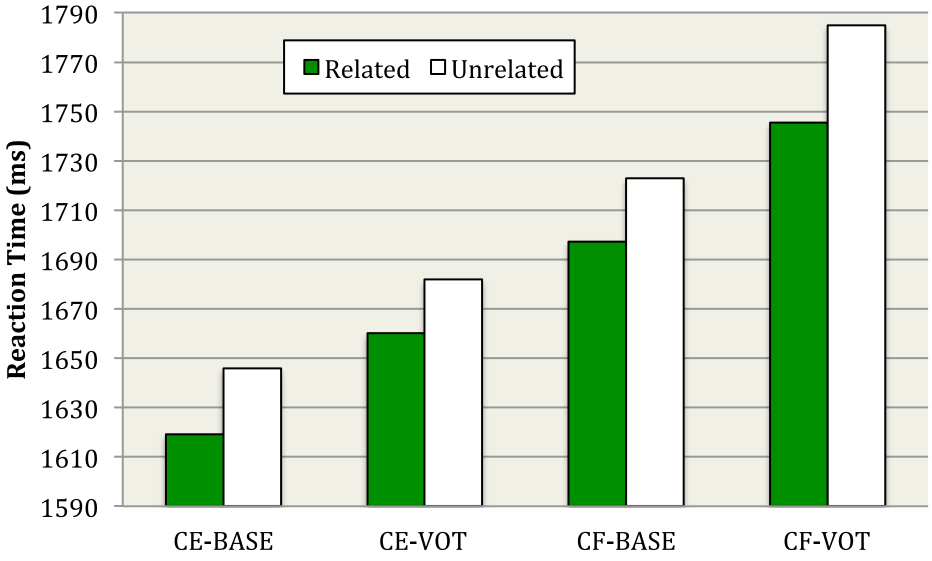

Figure 9. Mean RTs (ms) to target word in the Lexical Decision Task

III. Conclusion

The results of Experiment 3 suggest that subphonetic variations, such as changes in the VOT value of initial voiceless stop consonants in CE and CF interlingual and close interlingual homophones, affect lexical access. However, these effects were primarily observed in CF interlingual and close interlingual homophones with English-appropriate VOT values (CF-VOT).

In the language categorization task, the participants categorized close interlingual homophones with higher accuracy than interlingual homophones. This suggests that phonological similarity affects the accuracy with which a word is categorized as belonging to one language or another, and that the more phonologically similar two words are, the harder it is to determine their language membership. Interestingly, RT was slower for close interlingual homophones than interlingual homophones. This was unexpected since, in Experiment 2, RT for close interlingual homophones resulted in faster RTs than interlingual homophones. Note that in Experiment 3, participants (N = 50) heard all four versions of the prime type, while in Experiment 2 (N = 30) participants heard only one version of the prime type. The increase in participant and stimuli number in Experiment 3 may have yielded a truer depiction of RT since the RT in the language categorization task of Experiment 3 reflect the same pattern as the one observed in the Lexical Decision task.

In the Auditory Lexical Decision task, slower RT was observed for close interlingual than for interlingual, however this difference did not reach significance. As a result, all analyses from there on were analyzed with IH and CIH combined. Phonetic effects emerged when the VOT of the initial voiceless stop consonants in CF and CE interlingual and close interlingual homophones was modified to approximate an English-like VOT value and a French-like VOT, respectively. Notably, compared to the CF-VOT speech stimuli, significantly slower RTs were obtained for the CE-BASE and CE-VOT speech stimuli. Additional tests indicated that RTs to real word targets preceded by semantically unrelated primes were unaffected by manipulation of the prime word VOT. This suggests that the effect observed is truly due to subphonetic variations in the VOT value of the initial word stop consonants and not to semantic facilitation effects. Furthermore, the fact that slower RT was obtained for the CF-VOT priming conditions compared to the CE-BASE and CE-VOT priming conditions, suggests that acoustic fine structure of the prime word does affect lexical access. In particular, the extent to which language-specific cues are present in the signal increases competition and language interference in the lexicon.

CHAPTER 6: GENERAL DISCUSSION

The purpose of the present study was to determine whether language membership could potentially be cued by the acoustic-phonetic detail of word-initial stops and retained all the way through the process of lexical access to aid in language identification. Of particular interest were language-specific differences in CE and CF word-initial stops. Experiment 1 consisted of an interlingual homophone production task. The purpose of this study was to examine how word-initial stop consonants differ in terms of acoustic properties in Canadian English (CE) and Canadian French (CF) interlingual homophones. The analyses from the bilingual speakers in Experiment 1 indicate that bilinguals do produce language-specific differences in CE and CF word-initial stops, and that closure duration, voice onset time, and burst spectral SD may provide cues to language identity in CE and CF stops. Experiment 2 consisted of a Phoneme and Language Categorization task. The purpose of this study was to examine how stop identity cues, such as VOT and closure duration, influence a listener to identify word-initial stop consonants as belonging to Canadian English (CE) or Canadian French (CF). The RTs from the bilingual listeners in this study indicate that bilinguals do perceive language-specific differences in CE and CF word-initial stops, and that voice onset time may provide cues to phoneme and language membership in CE and CF stops. Experiment 3 consisted of an Auditory Lexical Decision task. The purpose of this study was to examine how subphonetic variations, such as changes in the VOT, affect lexical access. The results of Experiment 3 suggest that language-specific cues, such as VOT, affects the composition of the bilingual cohort and that the extent to which English and/or French words are activated is dependent on the language-specific cues present in a word. The implications of these findings and their theoretical applications to models of Bilingual Lexical Access are discussed below.

I. Experiment 1: Interlingual Homophone Production Task

In general, the pattern of results obtained from the bilingual speakers in the Interlingual Homophone production task was similar to that obtained in Sundara et al. (2006). In the current study, stop consonants produced by bilinguals in CE and CF mode were different in closure duration, voice onset time (VOT), and burst spectral SD. Similarly, Sundara et al. (2006) found that CE alveolar and CF dental stops differed in voice onset time (VOT) and burst spectral SD. For voice onset time and burst spectral SD, both the current study and Sundara et al. (2006) found that CE stop consonants have longer VOT values and smaller spectral SDs than CF stop consonants. Thus, CE bursts are more compact (i.e., have more energy concentrated around the COG of the bursts) and CE VOTs are more aspirated than CF burst and CF VOTs, respectively.

In addition, the bilingual speakers in Experiment 1 consistently produced shorter closure durations for CE stop consonants. To our knowledge, studies on closure durations in bilingual speakers are scarce, even non-existent. As a result, we turn our attention to findings in the monolingual literature. Studies on stop closure durations in monolingual English and French speakers report that, on average, monolingual American English speakers produce shorter closure durations than monolingual Parisian French speakers (72.6 ms and 101.7 ms, respectively; see AE: Byrd, 1993; Yao, 2007; Vicenik, 2008; Laeufer, 1996 ; PF: Abdelli-Beruh, 2004; Laeufer, 1996). Our findings are in line with the monolingual studies, that is, bilingual speakers produced shorter closure duration for CE than for CF stop consonants.

1. VOT production by bilingual CF-CE speakers

Upon further inspection of the data, Canadian French VOT values produced by the bilingual speakers were not in the expected range of typical Canadian French VOT productions (see Table 12). As can be seen in Table 12, the bilingual speakers in Experiment 1 produced French VOT values typically found in the English VOT range. Specifically, the CF voiced stop consonants were produced with short-lag VOT values rather than lead voicing, and the CF voiceless stop consonants were produced with VOT values higher than the expected French VOT distribution (typically between 0 – 40 ms). Together, these findings suggest that the bilingual speakers may have never reached 1) native-like CF VOT productions, and 2) adult-like CF voiced VOT productions.

Table 12

Mean VOT (in ms) for Canadian English and French stop consonant productions

	/p/		**/b/**		**/t/**		**/d/**		**/k/**		**/g/**	
Participant	**CE**	**CF**	**CE**	**CF**	**CE**	**CF**	**CE**	**CF**	**CE**	**CF**	**CE**	**CF**
B1	78	75	13	16	100	97	34	24	96	99	39	39
B2	87	81	16	18	86	82	19	20	88	84	24	28
B3	71	64	13	18	85	75	17	13	79	73	23	23
B4	73	70	14	18	90	83	16	21	83	73	20	24
B5	71	65	15	23	91	70	28	25	94	87	36	38
B6	84	68	18	20	93	89	30	30	88	83	44	39
B7	85	64	11	18	103	91	23	25	95	79	20	24
B8	52	46	14	15	70	54	22	22	68	66	33	30

There are several reasons why the bilingual speakers in this study may not be producing native-like VOT production for each of their respective languages. One of those reasons could be that lead voicing is inherently more difficult to acquire, as they require more subglottal motor control than short-lag or long-lag voicing (Allen, 1985; Westbury & Keating, 1986). Studies have shown that bilingual children generally do not produce lead VOT until the age of 10 (Allen, 1985; Khattab, 2000; Sundara et al., 2006). Even for children whose native language contains voiced stops, mastery of lead voicing does not generally occur before the age of 5 (Kong, Beckman, & Edwards, 2012; Simon, 2010).

Another reason may be due to increased exposure to English in the environment. The bilingual speakers in Experiment 1 live in Windsor, Canada, where the primary spoken language is English. Thus, the VOT system of the CF-CE bilingual speakers may be shifting towards values typically occupied by Canadian English VOT values. This general pattern has been observed in monolingual CF speakers, as well as bilingual CF-CE speakers (see Tables 13 and 14). As can be seen in Tables 13 and 14, the Canadian French VOT values produced by monolingual and bilingual speakers do indeed show a shift towards Canadian English VOT values, especially in regions where English predominates (e.g., Lethbridge). The latter brings us to another important point. Language dominance in Canada varies greatly based on the region in which the speaker resides. Thus, a speaker who lives in Quebec City, where the dominant language is French, can be expected to have the typical unaspirated short-lag VOT. In comparison, a speaker living in Lethbridge, Alberta, where French is the minority language, can be expected to have an English shift in their French VOT production since English exposure is more prominent (see Table 13). This is the exact pattern reported by Robillard (2014). In an attempt to code voice onset time based on language, Robillard (2014) analyzed voiceless plosives in spoken vernacular French of bilingual speakers in the Ottawa-Hull corpus. Robillard (2014) found that the VOT values fell along a continuum ranging from 5.2 ms to 106.6 ms. Specifically, voice onset time produced by bilingual speakers from the Quebec city region were typically unaspirated with values ranging from 5.2 to 25 ms, while bilingual speakers from the Ottawa region typically produced aspirated VOT with values ranging from 46 to 106.6 ms. Furthermore, out of the 630 tokens analyzed, 50.3% were unaspirated while 13.5% were aspirated. The remaining 36.2% were categorized as ambiguous VOT productions (i.e., VOT in the range of 26 to 45 ms). Robillard (2014) concluded that Canadian French VOTs were more likely to be aspirated if they were produced by a person with a high level of bilingualism and in an environment where English is the dominant language. Linguistically, Canadian French word-initial stops were more likely to be aspirated if they were produced following a pause or a vowel, and if they were articulated posteriorly in the mouth (Robillard, 2014).

Table 13

French Canadian monolingual speakers

Authors	**Region**	**/p/**	**/t/**	**/k/**
Expected FRE VOT average		*16 ms*	*23 ms*	*33 ms*
Ryalls & Larouche (1992)	Quebec	32 ms	60 ms	65 ms
MacLeod & Stoel-Gammon (2009)	Montreal	35 ms	36 ms	–
Turner et al., (2015)	Lethbridge	41 ms	54 ms	64 ms

*Note. Expected CF voiceless stop VOT range: 0 to 40 ms.

Table 14

Mean VOT (in ms) for Canadian Bilingual English and French Speakers

				Voiceless Stops			Voiced Stops		
Authors	**Region**	**L1**	**L2**	**/p/**	**/t/**	**/k/**	**/b/**	**/d/**	**/g/**
						French Mode			
Fowler et al., (2008)	Montreal	Both	Birth	22	32	42	–	–	–
Turner et al., (2014)	Lethbridge	CF	5	39	53	59	-3	-12	-8
MacLeod & Stoel-Gammon (2009)	Montreal	CE	4	51	56	–	-80	-83	–
Netelenbos (2013)	Lethbridge	CE	7	61	70	84	-1	-5	15
						English Mode			
Fowler et al., (2008)	Montreal	Both	Birth	52	68	69	–	–	–
Turner et al., (2014)	Lethbridge	CF	5	69	75	88	-18	-6	3
MacLeod & Stoel-Gammon (2009)	Montreal	CE	4	82	97	–	-55	-14	–
Netelenbos (2013)	Lethbridge	CE	7	80	89	98	-4	-5	5

To summarize, the bilingual speakers in this study lived in an English dominant area, were instructed in a French school system, and spoke French and English interchangeably on a daily basis. All of these factors, that is, English-dominant environment and high degree of bilingualism, may have shifted the VOT system of the CF-CE bilingual speakers towards French VOT values that approximate English VOT values.

II. Experiment 2 & 3: Language Categorization Task

In general, lower accuracy rates were found for interlingual homophones in the language categorization task of both Experiment 2 and 3. This suggests that the bilingual listeners are sensitive to the phonological similarity of the stimuli. As a result, both the English and French lexical candidates are activated and compete for selection. The lower accuracy scores, average 56.5% for both Experiment 2 and 3, suggest that language membership is difficult to determine and that both versions of the interlingual homophones seem to be viable candidates for both English and French production. It appears that high phonological similarity between words across languages, such as interlingual homophones, makes them harder to distinguish than words containing a language-specific phoneme, such as close interlingual homophones. This is consistent with Marian, Blumenfeld, and Boukrina (2008)'s findings. In their study, participants were less accurate on trials where Russian words shared 2-3 phonemes with English words than on trials where Russian words contained a unique Russian phoneme. Thus accuracy rates appear to decrease as a function of phonological overlap.

RT for Experiment 2 and 3 were in opposite directions in the language categorization task. Faster RT was observed for interlingual homophones in Experiment 3, while faster RT was observed for close interlingual homophones in Experiment 2. As mentioned in the Conclusion of Experiment 3, a possible explanation for this difference may be due to the increase in participant and stimuli numbers in Experiment 3 since the RT in the language categorization task of Experiment 3 reflect the same pattern as the one observed in the Auditory Lexical Decision task. Another possible explanation is that close interlingual homophones are processed slower than interlingual homophones because words with shared phonology are easier to process than words containing a language-specific phoneme. This is in line with Marian et al. (2008) who found that slower reaction times were observed for Russian words containing unique Russian phonemes than Russian words containing 2-3 phonemes overlap with English. Thus language membership appears to be identified more quickly in words that phonologically overlap. It is possible that the high degree of phonological similarity between the interlingual homophones facilitated their retrieval as reflected by faster RT, but that distinguishing them apart and accurately determining their language membership was harder to do as reflected by lower accuracy rates.

The most interesting finding of Experiment 2 and 3 was that altered stimuli were perceived as belonging to their language of origin. Specifically, English words with French-appropriate VOT and French words with English-appropriate VOT were perceived as English and French words, respectively. In addition, accuracy scores were similar across the unaltered and altered stimuli (i.e., Experiment 2: unaltered: 67%, altered VOT: 62% and altered VOT & CD: 64%; Experiment 3: unaltered: 67% and altered VOT: 66%). This suggests that bilingual listeners accept a wider spectrum of VOT values for within-language VOT productions. The latter is supported by the widespread VOT values reported in Robillard (2014) of bilingual Canadian French speakers across different Canadian regions, and the VOT productions of the bilingual participants in Experiment 1. Specifically, participants in Experiment 1 were immersed amongst bilingual speakers from various geographical regions. For example, some were from Quebec, Ottawa, Sudbury, New Brunswick, France, and even several countries in Africa. Not only were they exposed to European French; they were also exposed to several varying Canadian French dialects. Add to the mix that some were second language speakers of French or English. The linguistic variability present in the bilingual participants' environment probably allows them a great deal of flexibility in regards to what is viewed as an acceptable English and French VOT production.

Slower RTs were found for VOT altered stimuli in the language categorization task of Experiment 2. In Experiment 3, RT for VOT altered stimuli varied as a function of language. Consistent with Experiment 2, slower RTs were found for French VOT altered stimuli. In contrast with Experiment 2, faster RTs were found for English VOT altered stimuli. This suggests that the bilingual listeners are sensitive to the acoustic manipulation of the VOT. The VOT altered stimuli were presumably poorer exemplars of the unaltered stimuli, and thus in general categorization responses were slower. Similarly, Andruski et al. (1994) found slower RT for VOT altered stimuli (i.e., VOT reduced by two-third) than for unaltered VOT stimuli (i.e., an English voiceless VOT), suggesting that the VOT altered stimuli were perceived as poorer exemplars of English voiceless VOT. In the phoneme categorization task (Experiment 2), participants perceived both the unaltered and altered speech tokens as the voiceless stop /p, t/ or /k/ 90% of the time. This suggests that the acoustic manipulation of the VOT did not affect the goodness of the word-initial stop consonant as a stop consonant. Perhaps then, the altered VOT stimuli are not perceived as poor exemplars, but rather as within-language VOT variations of bilingual speech.

To summarize, the RTs from the bilingual listeners in the language categorization task indicate that bilinguals do perceive language-specific differences in CE and CF word-initial stops, and that voice onset time may provide cues to phoneme and language membership in CE and CF stops. Furthermore, the following conclusions can be made from the language categorization task. First, compared to close interlingual homophones, interlingual homophones were more difficult to identify as to which language they belong to. Second, higher degree of phonological similarity between words across languages facilitates retrieval, however hinders language membership accuracy. Third, bilingual listeners accept a wide spectrum of VOT values for within-language VOT productions of interlingual and close interlingual homophones.

III. Experiment 3: Lexical Decision Task

Findings from Experiment 3 suggest that the acoustic-phonetic detail of word-initial stops, such as VOT, do provide language cues to the lexical level and aid in language identification. Specifically, subphonetic variations such as VOT changes do affect lexical access in bilingual listeners.

The word type of the prime word also affected participants' overall RT, but since word type did not reach significance, this effect must be interpreted with caution. Participants exhibited slower RTs to targets preceded by close interlingual homophones than by interlingual homophones. This suggests that the presence of language-specific cues can lead to language interference during word recognition processes. Specifically, the extent of competition present in the lexicon appears to be dependent on which language-specific cues are present in the word. In other words, it appears that language-specific cues present at the acoustic level (i.e., VOT differences) and at the phonetic level (i.e., Canadian English /r/ vs. Canadian French /ʀ/) introduce more language interference than language-specific cues present only at the acoustic level, such as in IH. The latter is reflected in the longer delays in decision latencies for close interlingual homophones.

Interlingual homophone facilitation effects have been reported in several studies (Carrasco-Ortiz, Midgley, & Frenck-Mestre, 2012; Dijkstra, Grainger, & Van Heuven, 1999; Haigh & Jared, 2007; Lemhöfer & Dijkstra, 2004). In Haigh and Jared (2007) facilitatory homophone effects were found for participants performing the lexical decision task in their L2 but not their L1, and for interlingual homophones with and without orthographic overlap. However, when cognates or interlingual homographs were added to the interlingual homophone prime's list, the facilitatory homophone effect disappeared from the latency data. In the current Auditory Lexical Decision task, both the interlingual and close interlingual homophones were prime words and the lexical decision task was done in the participants' L1 (English). Both of these factors may have contributed to the disappearance of the interlingual homophone facilitation effects between the interlingual homophones and close interlingual homophones. Since no significant differences were found between interlingual homophones and close interlingual homophones, all analyses from thereon were conducted with the IH and CIH combined.

Largest priming effects were observed for CE-BASE and CE-VOT prime words. This can be interpreted as evidence that the recognition of interlingual homophones is facilitated during within-language processing. Studies consistently show that prime-target pairs that share the same language (within-language priming) are perceived faster than prime-target pairs that differ in language (cross-language priming) (Chauncey, Grainger, & Holcomb, 2008; Chauncey, Grainger, & Holcomb, 2011; Dijkstra et al., 1999; Grosjean, 2000, 2008; Schulpen et al., 2003; van Heuven, Dijkstra, & Grainger, 1998). This suggests that during within-language discourse the interlingual homophone matching the language of input receives the most activation. In addition, the fact that the CE-VOT stimuli had comparable lexical decision latencies to CE-BASE prime words provides further support that the French appropriate-VOT of the English interlingual homophone (CE-VOT) was perceived as an acceptable English VOT variation. Further proof of this can be seen in the differences of lexical decision latencies between CE-BASE, CF-BASE and CF-VOT. RTs were significantly faster for CE-BASE than for CF-BASE and CF-VOT. This suggests that the CF-VOT was ultimately perceived as a French production just as the CE-VOT was perceived as an English production, which is in line with the findings of the language categorization task. Thus for both the language categorization task and auditory lexical decision task, the bilingual participants perceived the altered stimuli as belonging to their language of origin.

Interestingly, RT for the CE-VOT and CF-VOT diverged significantly. The RT of the CE-VOT was not significantly different from the RT of the CE-BASE or CF-BASE. On the other hand, RT of the CF-VOT was not significantly different from CF-BASE, however the longer delay suggests that language membership for CF-VOT was also inherently ambiguous. It would appear then that the presence of language-specific cues affects the composition of the bilingual cohort (Grosjean, 2008; Schulpen et al., 2003). In other words, the proportion of English and French words activated in the bilingual cohort is dependent on the acoustic-phonetics cues present in the word. For the altered VOT prime words, language-specific cues from both languages are present within the word. The onset of the word suggests a different language membership than the nucleus and coda. Considering that CE-VOT and CF-VOT had longer RT than their unaltered VOT counterparts (i.e., CE-BASE and CF-BASE) suggests that the altered VOT activated the interlingual homophones in both the languages, which in turn activated the interlingual homophone’s meanings. This resulted in an increase in competition and delayed responses.

Thus, there appear to be two factors contributing to the lexical decision effects in Experiment 3. The first concerns the acoustic and phonological similarity of a word candidate and its activation, and the second concerns the presence of other language counterparts. The results in Experiment 3 indicate that when two words are phonologically identical across languages, subphonetic cues such as VOT may help in the language identification of the word and reduce activation of other language counterparts. These results have important implications for current models of bilingual lexical access. Although most models account for language nodes at the phonological level, none explicitly account for the role of language membership at the acoustic level, nor do they predict that VOT changes will produce graded activation up to and including the lexical level.

IV. Theoretical implications

From the combination of the three experiments in this study, the following view on bilingual lexical access can be construed. Upon hearing a word, lexical candidates from both languages may be activated depending on the degree of overlap between the language of input and its acoustic-phonetic representation. If the word is highly phonologically similar to another language counterpart, than both lexical candidates from each language are activated. From there, the language-specific cues present at the acoustic and phonetic level are weighted. These cues increase or reduce activation of lexical candidates from one language to another, such that the lexical candidate that best corresponds to the language membership of the acoustic-phonetic signal is selected. In the current study, the presence of subphonetic cues, such as VOT in a word, lead to the reduction of the number of lexical candidates active for selection. It is important to note that even though altered VOT were processed with longer delays than unaltered VOT, it does not suggest that the presence of language-specific subphonemic cues such as aspiration would hinder word recognition. The delay found in the current study was due to the discord between the language membership of the phonemes and the VOT. This indicates that language-specific cues such as VOT do indeed help in the recognition of words when two words across languages are phonologically identical.

The question then remains how do models of lexical access account for the role of language membership in word recognition, particularly at the feature level. Models of lexical access stipulate different roles for language membership in bilingual lexical access. However, to date no published models of bilingual lexical access account for the role of language membership at the feature level. For example, proponents of the Bilingual Interactive Activation Plus (BIA+: Dijkstra & van Heuven, 2002) model, stipulate that language membership is established via language nodes, which receive activation directly from lexical representation. The language nodes do not collect information outside of the lexical level (i.e., from the phoneme or feature level) and, as a result, do not affect the relative activation of words within a given language (Schwartz & Arêas Da Luz Fontes, 2008). Thus the BIA+ predicts that word recognition would not be affected by the language-specific cues present at the phonetic or acoustic level. The results of the current study disconfirm both predictions of the BIA+. RT of the lexical decision task indicate that cross-lexicon activation depends on bottom-up acoustic-phonetic input and that the manipulation of the VOT may have caused the interlingual homophones of both languages to be activated, especially when the language membership of the VOT did not match the language membership of the word.

Another model of bilingual lexical access is the BIMOLA (Grosjean, 1988). Both the BIMOLA and BIA+ assume that lexical access is nonselective in nature. The main difference between the BIMOLA and BIA+ is in the way language is represented. In the BIMOLA, language membership is depicted as two independent language networks from the phoneme to the word level. However, at the feature level the languages are amalgamated into one network. As a result, language membership is not depicted at the feature level. Phonemes can excite or inhibit words, but only within a language, while features can excite and inhibit phonemes in both languages in parallel. Such that if features match phonemes from both languages, then both language networks will be activated in parallel. The BIMOLA predicts that word recognition is affected by language membership both from top-down language information, such as semantic context and from within-language connections at the phoneme and word levels (Chen, 2008). Furthermore, the BIMOLA predicts that words or phonemes that are specific to one language will increase activation only in its corresponding language network. On the other hand, phonemes or words that are similar across languages will be activated in parallel in both language networks. Thus, the degree of similarity between phonemes and words appears to have a graded activation affect on lexical access (Grosjean, 2000). As Grosjean (2000) described, when a bilingual listener hears an English /b/, its French counterpart will also be activated. However, when a bilingual listener hears an English /p/, its French counterpart will be activated but to a lesser degree, since English /p/ and French /p/ differ significantly due to the presence of aspiration in English. Finally, when a bilingual listener hears an English /r/, its French counterpart should receive little activation since the English /r/ and French /ʀ/ are phonetically distinct. For example, the BIMOLA predicts that upon the presentation of an interlingual homophone (e.g., /ku/) the features present in the word activates phonemes of both languages (since the features match the phonemes of both languages), which in turn activates both lexical representations of the interlingual homophone (e.g., *coo* and *cou* ‘neck’). On the other hand, upon the presentation of a close interlingual homophone (e.g., *core* /kɔr/) the features present in the word activates the corresponding phonemes of each language, which in turn activates the lexical representation of the close interlingual homophone. In this case, the English representation receives more activation due to the language-specific nature of /r/, which inhibits further activation of the French representation. In the current study, this would account for the differences in RT for interlingual homophones versus close interlingual homophones. Alternatively, the presence of a language-specific phoneme such as an English /r/ distinctively signals an English word, regardless of any other phonetic cues present elsewhere in the word.

How does the BIMOLA account for the findings of the altered VOT? Upon the presentation of the French-like interlingual homophone [k$^{\text{-VOT}}$u] *c*$^{\textit{-VOT}}$*oo*, the features present in the word activate the corresponding phonemes. Here, both the French and English phoneme /u/ should receive activation, however the French /u/ should be activated to a lesser degree than the English /u/. For the phoneme /k/, the VOT appears to suggest a French /k/, and since very little aspiration is present in the signal, this should, according to the BIMOLA model, inhibit the activation of the English /k/ phoneme or activate the English /k/ phoneme to a lesser degree than the French /k/

phoneme. As a result, both the English word *coo* and French word *cou* should be activated to the same extent, leading to unresolved competition. In other words, without context both the English word *coo* and French word *cou* are possible lexical candidates. This would explain the findings of the language categorization task, where low accuracy scores were found for interlingual homophones. In the lexical decision task, however, the unresolved competition could be solved by the top-down information provided by the target word. In the lexical decision task, the target word was always a) produced in English and b) related to the English version of the interlingual homophone. As such, for the French-like word $c^{-VOT}oo$, top-down information should have further increased the activation of the English lexical representation, and as a result the word *coo* should have been selected. This would explain why RT for the CE-VOT was longer than the RT of CE-BASE (unresolved competition), and why they were not perceived as significantly different (both were perceived as English words).

So far the BIMOLA has been able to explain the findings of the current study. One more finding remains, that is, that the RT of the CE-BASE and CE-VOT were significantly different than RT for CF-VOT. For the English-like word $c^{+VOT}ou$ (CF-VOT), top-down information should have further increased the activation of the English lexical representation of the word *coo*. If this were true, we would expect similar RT for the CE-VOT and CF-VOT due to their shared unresolved competition and language membership, and lower RT for CF-VOT than CF-BASE since CF-VOT would have been perceived as an English word resulting in facilitation. However, in the current study, the CF-VOT had the longest RT. This suggests that ultimately, the French pronunciation was selected. The latter cannot be explained via the BIMOLA model.

Although the majority of the findings could be explained through the theoretical underpinnings of the BIMOLA, one finding (i.e., CF-VOT) remains unexplained. What follows is a tentative explanation. First, no semantic facilitation was found in the lexical decision task, suggesting that top-down information did not come from semantic information. However, the language of the target could have still provided top-down information. This still leaves us with the same scenario as before. If we remove top-down influence and focus solely on language activation from the phoneme and word levels, then the only way for the English-like word $c^{+VOT}ou$ to be perceived as a French word would be if the altered VOT was perceived as truly ambiguous. In this regard, both the English and French /k/ would be similarly activated. Considering that the vowel /u/ strongly suggests a French /u/, then the French /u/ should be activated to a higher degree than the English /u/. This would result in the English-like word $c^{+VOT}ou$ in being perceived as French. In this regard, top-down information was not useful in determining the language membership of the altered VOT word $c^{+VOT}ou$, and the ambiguity of the altered VOT suggests that VOT does have an impact on lexical access, and that subphonetic information such as VOT is retained all the way through the lexical level in order to help in determining language membership.

In summary, the findings of the current study suggests that subphonetic variation, such as changes in the VOT, do affect lexical access in bilingual speakers and that the role of language membership at the acoustic level should be further explored. Although altered VOT may appear to be an experimental effect of the current study, VOT values such as those depicted by the altered VOT occur in everyday speech. Evidence of this can be seen in bilingual speakers such as those studied in Robillard (2014), in second language speakers due to accented speech, in bilingual speakers due to language dominance, and even in disordered speech. In addition, knowledge about the role of language membership at the acoustic level could provide valuable information to a variety of professionals (e.g., second language teachers and speech language pathologist).

APPENDIX A

Interlingual Homophone Production Stimuli

	Canadian English				**Canadian French**			
Context	**Word**	**Broad Trans.**	**Narrow Trans.**	**Translation Equivalent**	**Word**	**Broad Trans.**	**Narrow Trans.**	**Translation Equivalent**
C + /ɛ/	*pet*	/pɛt/	[pʰɛt]	animal domestique	*pet*	/pɛt/	[pɛt̪]	fart
	bet	/bɛt/	[bɛt]	parie	*bette*	/bɛt/	[bɛt̪]	beet
	tell	/tɛl/	[tʰɛɫ]	dire	*tel*	/tɛl/	[t̪ɛl]	such as
	den	/dɛn/	[dɛ̃n]	tanière	*daine*	/dɛn/	[d̪ɛ̃n̪]	doe
	get	/gɛt/	[gɛt]	avoir	*guette*	/gɛt/	[gɛt̪]	lookout
C + /u/	*poo*	/pu/	[pʰu]	caca	*pou*	/pu/	[pu]	flea
	boo	/bu/	[bu]	huée	*bout*	/bu/	[bu]	end
	two	/tu/	[tʰu]	deux	*toux*	/tu/	[t̪u]	cough
	do	/du/	[du]	faire	*doux*	/du/	[d̪u]	soft
	coo	/ku/	[kʰu]	roucouler	*cou*	/ku/	[ku]	neck
	goo	/gu/	[gu]	gluante	*gout*	/gu/	[gu]	taste
C + /ɔ/	*pot*	/pɔt/	[pʰɔt]	pot	*pâte*	/pɑt/	[pɑᵓt̪]	dough
	bought	/bɔt/	[bɔt]	acheté	*botte*	/bɔt/	[bɔt̪]	boot
	toss	/tɔs/	[tʰɔs]	lancer	*tasse*	/tɑs/	[t̪ɑs]	cup
	dot	/dɔt/	[dɔt]	point	*dot*	/dɔt/	[d̪ɔt̪]	dowry
	cut	/kʌt/	[kʰʌt]	couper	*cotte*	/kɔt/	[kɔt̪]	overalls
	got	/gɔt/	[gɔt]	eu, obtenu	*gâte*	/gɑt/	[gɑt̪]	spoil

*Note. Trans. = Transcription

APPENDIX B

Participant Demographics Experiment 2

					% Daily Use of French		
Participant	Gender	Age	L1	Age: L2 Acquisition	At home	At work	Overall
B1	F	34	CF	4 – 8	75%	75%	50%
B2	F	51	CF – CE	At Birth	25%	50%	25%
B3	F	29	CE	4 – 8	25%	100%	50%
B4	M	21	CF	4 – 8	100%	75%	75%
B5	F	21	CE	4 – 8	25%	75%	25%
B6	F	45	CF	4 – 8	25%	50%	25%
B7	M	28	CE	4 – 8	50%	25%	25%
B8	F	51	CF – CE	At Birth	75%	75%	75%
B9	F	44	CE	4 – 8	25%	50%	25%
B10	M	28	CE	4 – 8	50%	50%	25%
B11	F	51	EF	4 – 8	50%	50%	50%
B12	F	21	Spanish	4 – 8	100%	75%	75%
B13	M	50	CF	4 – 8	100%	75%	75%
B14	M	27	CE	4 – 8	50%	50%	25%
B15	F	54	CF	4 – 8	75%	75%	50%
B16	F	52	CF	9 – 17	100%	50%	75%
B17	M	53	CF – CE	At Birth	25%	0%	0%
B18	M	22	CF	9 – 17	75%	25%	50%
B19	F	32	CF	4 – 8	75%	100%	50%
B20	M	35	CF	4 – 8	75%	0%	25%

*Note. Overall is the overall average of language used at home, at work, with family members living outside of the home (father, mother & siblings) and for media related activities. CE = Canadian English; CF = Canadian French; EF = European French.

APPENDIX C

Participant Demographics Experiment 2

					% Daily Use of French		
Participant	**Gender**	**Age**	**L1**	**Age: L2 Acquisition**	**At home**	**At work**	**Overall**
B21	F	32	CF	4 – 8	75%	75%	50%
B22	F	18	CF – CE	At Birth	100%	0%	50%
B23	F	31	CF	4 – 8	100%	75%	75%
B24	F	59	Arabic	CF 4 – 8	100%	75%	75%
B25	M	34	CF – CE	At Birth	50%	75%	25%
B26	F	34	CE – CF	At Birth	25%	50%	25%
B27	F	30	CE	4 – 8	25%	100%	50%
B28	F	36	EF	9 – 17	100%	100%	75%
B29	F	38	CF – CE	At Birth	75%	100%	75%
B30	F	37	CF	4 – 8	50%	100%	50%

*Note. Overall is the overall average of language used at home, at work, with family members living outside of the home (father, mother & siblings) and for media related activities. CE = Canadian English; CF = Canadian French; EF = European French.

APPENDIX D

Preliminary Language & Phoneme Categorization Task: Interlingual Homophones (Voiceless Stops)

	Voiceless			Voiced	
IPA	**English**	**French 'TE'**	**IPA**	**English**	**French 'TE'**
/pɑt/	*pot*	*pâte* 'dough'	/bɑt/	*bought*	*bate* 'build'
/pu/	*poo*	*pou* 'lice'	/bu/	*boo*	*boue* 'mud'
/to/	*toe*	*tôt* 'early'	/do/	*dough*	*dos* 'back'
/tu/	*two*	*toux* 'cough'	/du/	*do*	*doux* 'soft'
/kɔz/	*cause*	*case* 'box'	/gɔz/	*gauze*	*gaz* 'fuel'
/ku/	*coo*	*cou* 'neck'	/gu/	*goo*	*gout* 'taste'
/poz/	*pose*	*pause* 'break'	/boz/	*bows*	n/a
/pɑ(ɔ)ʃ/	*posh*	*poche '*pocket'	/bɑ(ɔ)ʃ/	*Bosh*	n/a
/tɔs/	*toss*	*tasse* 'cup'	/dɔs/	*DOS*	n/a
/tʌ(ɔ)k/	*tuck*	*toque* 'spur'	/dʌ(ɔ)k/	*duck*	n/a
/kot/	*coat*	*côte* 'rib'	/got/	*goat*	n/a
/kʊd/	*could*	*coude* 'elbow'	/gʊd/	*good*	n/a
/pɪst/	*pissed*	*piste* 'path'	/bɪst/	n/a	n/a
/pɑk/	*pock*	*pâque* 'easter'	/bɑk/	n/a	n/a
/tɔ/	*taw*	*tas* 'pile'	/dɔ/	n/a	n/a
/tʊk/	*took*	*touque* 'drum'	/dʊk/	n/a	n/a
/kɪt/	*kit*	*quitte* 'leave'	/gɪt/	n/a	n/a
/kɪst/	*kissed*	*kyste* 'cyst'	/gɪst/	n/a	n/a

*Note. TE = Translation Equivalent

APPENDIX E

Preliminary Language & Phoneme Categorization Task: Close Interlingual Homophones (Voiceless Stops)

	Voiceless			Voiced	
IPA	**English**	**French 'TE'**	**IPA**	**English**	**French 'TE'**
/p**a͡**ɪ/ – /p**ɑ**j/	*pie*	*paille* 'straw'	/b**a͡**ɪ/ – /b**ɑ**j/	*buy*	*bâille* 'yawn'
/pɪ**l**/ – /pɪ**l**/	*pill*	*pile* 'pile'	/bɪ**l**/ – /bɪ**l**/	*bill*	*bile* 'bile'
/tɔ**r**/ – /tɔ**ʀ**/	*tore*	*tort* 'wrong'	/dɔ**r**/ – /dɔ**ʀ**/	*door*	*dort* 'sleep'
/t**æ**ŋ/ – /t**ɛ**ɲ/	*tang*	*teigne* 'ringworm'	/d**æ**ŋ/ – /d**ɛ**ɲ/	*dang*	*deigne* 'deign'
/k**ɑ**d/ – /k**ɔ**d/	*cod*	*code* 'code'	/g**ɑ**d/ – /g**ɔ**d/	*God*	*gode* 'pucker'
/kɔ**r**/ – /kɔ**ʀ**/	*core*	*corps* 'body'	/gɔ**r**/ – /gɔ**ʀ**/	*gore*	*gare* 'station'
/pi**r**/ – /pi**ʀ**/	*peer*	*pire* 'worse'	/bi**r**/ – /bi**ʀ**/	*beer*	n/a
/pɛ**r**/ – /pɛː**ʀ**/	*pear*	*père* 'father'	/bɛ**r**/ – /bɛː**ʀ**/	*bear*	n/a
/t**ɑn**t/ – /t**ɑ̃**t/	*taunt*	*tante* 'aunt'	/d**ɑn**t/ – /d**ɑ̃**t/	*daunt*	n/a
/t**a**ɪ/ – /t**ɑ**j/	*tie*	*taille* 'size'	/d**a**ɪ/ – /d**ɑ**j/	*dye*	n/a
/kɔ**l**/ – /kɔ**l**/	*call*	*col* 'collar'	/gɔ**l**/ – /gɔ**l**/	*gall*	n/a
/k**æ**p/ – /k**a**p/	*cap*	*cape* 'cape'	/g**æ**p/ – /g**a**p/	*gap*	n/a
/p**æn**t/ – /p**ɑ̃**t/	*pan*	*pente* 'slope'	/b**æn**t/ – /b**ɑ̃**t/	n/a	n/a
/pɑ**r**t/ – /pa**ʀ**t/	*part*	*parte* 'leave'	/bɑ**r**t/ – /ba**ʀ**t/	n/a	n/a
/tɑ**r**/ – /tɑ**ʀ**/	*tar*	*tard* 'late'	/dɑ**r**/ – /dɑ**ʀ**/	n/a	n/a
/t**æ**t/ – /t**ɛː**t/	*tat*	*tête* 'head'	/d**æ**t/ – /d**ɛː**t/	n/a	n/a
/k**æ**t/ – /k**ɛː**t/	*cat*	*quête* 'quest'	/g**æ**t/ – /g**ɛː**t/	n/a	n/a
/k**æ**n/ – /k**a**n/	*can*	*canne* 'cane'	/g**æ**n/ – /g**a**n/	n/a	n/a

*Note. TE = Translation Equivalent

APPENDIX F

Preliminary Language & Phoneme Categorization Task: Interlingual Homophones (Voiced Stops)

	Voiced			Voiceless	
IPA	**English**	**French**	**IPA**	**English**	**French**
/bu/	*boo*	*boue* ‘mud’	/pu/	*poo*	*pou* ‘flea’
/bɪn/	*bin*	*bine* ‘bean’	/pɪn/	*pin*	*pine* ‘penetrate’
/du/	*dew*	*doux* ‘soft’	/pu/	*two*	*toux* ‘cough’
/do/	*dough*	*dos* ‘back’	/po/	*toe*	*tôt* ‘early’
/gɔz/	*gauze*	*gaz* ‘fuel’	/kɔz/	*cause*	*case* ‘box’
/gu/	*goo*	*goût* ‘taste’	/ku/	*coo*	*cou* ‘neck’
/bɛg/	*beg*	*bègue* ‘stutter’	/pɛg/	*peg*	n/a
/bʌ(ɔ)n/	*bun*	*bonne* ‘good’	/pʌn/	*pun*	n/a
/dɛn/	*den*	*daine* ‘doe’	/tɛn/	*ten*	n/a
/doze/	*doze*	*dose* ‘dose’	/toz/	*toes*	n/a
/gɪld/	*gild*	*guilde* ‘guild’	/kɪld/	*killed*	n/a
/gɪd/	*gid*	*guide* ‘guide’	/kɪd/	*kid*	n/a
/buz/	*booze*	*bouse* ‘dung’	/tuz/	n/a	n/a
/bʊk/	*book*	*bouc* ‘billy goat’	/pʊk/	n/a	n/a
/dɛʃ/	*desh*	*dèche* ‘argot’	/dɛʃ/	n/a	n/a
/duz/	*dues*	*douze* ‘twelve’	/tuz/	n/a	n/a
/gɛt/	*get*	*guette* ‘surveiller’	/kɛt/	n/a	n/a
/gɔʃ/	*gosh*	*gâche* ‘waste’	/kɔʃ/	n/a	n/a

APPENDIX G

Preliminary Language & Phoneme Categorization Task: Close Interlingual Homophones (Voiced Stops)

	Voiced			Voiceless	
IPA	**English**	**French**	**IPA**	**English**	**French**
/bʊ**l**/ – /bʊ**l**/	*bull*	*boule* ‘ball’	/pʊ**l**/ – /pʊ**l**/	*pull*	*poule* ‘chicken’
/b**aɪ**/ – /b**ɑj**/	*buy*	*bâille* ‘yawn’	/p**aɪ**/ – /p**ɑj**/	*pie*	*paille* ‘straw’
/di**ɚ**/ – /di**ʁ**/	*deer*	*dire* ‘say’	/ti**ɚ**/ – /ti**ʁ**/	*tear*	*tire* ‘maple taffy’
/dɔ**r**/ – /dɔ**ʁ**/	*door*	*dort* ‘sleep’	/tɔ**r**/ – /tɔ**ʁ**/	*tore*	*tort* ‘wrong’
/gɔ**r**/ – /gɔ**ʁ**/	*gore*	*gare* ‘station’	/kɔ**r**/ – /kɔ**ʁ**/	*core*	*corps* ‘body’
/g**ɑ**d/ – /g**ɔ**d/	*God*	*gode* ‘pucker’	/k**ɑ**d/ – /k**ɔ**d/	*cod*	*code* ‘code’
/b**æ**t/ – /b**ɛː**t/	*bat*	*bête* ‘beast’	/p**æ**t/ – /p**ɛː**t/	*pat*	n/a
/b**æ**k/ – /b**a**k/	*back*	*bac* ‘ferry’	/p**æ**k/ – /p**a**k/	*pack*	n/a
/dɔ**l**/ – /dɔ**l**/	*doll*	*dol* ‘fraud’	/tɔ**l**/ – /tɔ**l**/	*tall*	n/a
/d**ɑ**t/ – /d**ɔ**t/	*dot*	*dote* ‘endow’	/d**ɑ**t/ – /d**ɔ**t/	*taught*	n/a
/g**æ**p/ – /g**ɛː**p/	*gap*	*guêpe* ‘wasp’	/k**æ**p/ – /k**ɛː**p/	*cap*	n/a
/g**ɔ**t/ – /g**ɑ**t/	*got*	*gâte* ‘spoil’	/k**ɔ**t/ – /k**ɑ**t/	*cot*	n/a
/b**on**z/ – /b**ɔ̃**z/	*bones*	*bonze* ‘bonze’	/p**on**z/ – /p**ɔ̃**z/	n/a	n/a
/b**æ**g/ – /b**a**g/	*bag*	*bague* ‘ring’	/p**æ**g/ – /p**a**g/	n/a	n/a
/d**en**d/ – /d**ɛ̃**d/	*deigned*	*dinde* ‘turkey’	/t**en**d/ – /t**ɛ̃**d/	n/a	n/a
/d**æ**m/ – /d**a**m/	*dam*	*dame* ‘lady’	/t**æ**m/ – /t**a**m/	n/a	n/a
/g**æ**ŋ/ – /g**a**ɲ/	*gang*	*gagne* ‘win’	/k**æ**ŋ/ – /k**a**ɲ/	n/a	n/a
/g**u**s/ – /g**ʊ**s/	*goose*	*gousse* ‘pod’	/k**u**s/ – /k**ʊ**s/	n/a	n/a

APPENDIX H

Participant Demographics Experiment 3

Participant	Gender	Age	L1	Age: L2 Acquisition	% Daily Use of French At home	 At work	 Overall
1	F	33	CF	4 – 8	100%	75%	50%
2	F	32	CF	4 – 8	75%	100%	50%
3	M	35	CF	4 – 8	100%	0%	25%
4	M	36	CF	9 – 17	50%	0%	25%
5	F	30	CE – CF	At Birth	75%	75%	50%
6	M	35	CF – CE	At Birth	100%	0%	25%
7	F	51	CF – CE	At Birth	100%	100%	75%
8	M	35	CE – CF	At Birth	50%	0%	0%
9	M	38	CF	4 – 8	100%	75%	75%
10	M	28	CE	4 – 8	75%	50%	25%
11	F	31	CF	4 – 8	100%	75%	75%
12	F	37	CF	4 – 8	75%	100%	50%
13	F	39	CF – CE	At Birth	75%	100%	75%
14	F	37	EF	9 – 17	100%	100%	75%
15	F	31	CE	4 – 8	50%	100%	50%
16	M	50	CF	9 – 17	100%	100%	75%
17	F	44	CE	4 – 8	25%	50%	25%
18	F	19	CE – CF	At Birth	75%	0%	25%
19	M	21	CF	4 – 8	100%	75%	75%
20	F	21	CE	4 – 8	50%	75%	50%

APPENDIX I

Participant Demographics Experiment 3

Participant	Gender	Age	L1	Age: L2 Acquisition	% Daily Use of French		
					At home	At work	Overall
21	F	35	CF	4 – 8	100%	75%	50%
22	F	30	CE – CF	At Birth	50%	75%	25%
23	M	36	CE – CF	At Birth	75%	25%	25%
24	F	53	CF	9 – 17	100%	50%	75%
25	M	54	CF – CE	At Birth	25%	0%	0%
26	M	22	CF	9 – 17	100%	25%	50%
27	F	34	CE – CF	At Birth	50%	50%	25%
28	M	39	CE – CF	At Birth	25%	75%	25%
29	M	45	CE – CF	At Birth	50%	75%	50%
30	F	49	CF	After 18	100%	75%	75%
31	F	49	CF	4 – 8	50%	100%	50%
32	F	22	CE	4 – 8	75%	0%	25%
33	F	21	EF	9 – 17	100%	100%	100%
34	F	35	CE – CF	At Birth	25%	100%	50%
35	F	25	CE	4 – 8	100%	100%	75%
36	F	46	CE – CF	At Birth	75%	100%	50%
37	F	38	CF - CE	At Birth	75%	100%	50%
38	F	50	CF	9 – 17	75%	100%	50%
39	F	32	CF	4 – 8	50%	50%	25%
40	M	57	CF	9 – 17	100%	75%	75%

APPENDIX J

Participant Demographics Experiment 3

Participant	Gender	Age	L1	Age: L2 Acquisition	% Daily Use of French		
					At home	At work	Overall
41	F	36	CE – CF	At Birth	75%	100%	50%
42	F	21	SPA	4 – 8	100%	75%	75%
43	F	57	CF	9 – 17	100%	75%	75%
44	F	48	CF	4 – 8	50%	75%	50%
45	F	59	CF	4 – 8	100%	75%	50%
46	M	28	CE	4 – 8	75%	25%	25%
47	M	28	CE	4 – 8	50%	50%	25%
48	F	53	CF	4 – 8	50%	75%	50%
49	F	33	CE	4 – 8	75%	0%	25%
50	F	49	CF – CE	At Birth	75%	75%	50%

*Note. Overall is the overall average of language used at home, at work, with family members living outside of the home (father, mother & siblings) and for media related activities. CE = Canadian English; CF = Canadian French; EF = European French

APPENDIX K

Lexical Decision Task: Interlingual Homophones – Word

			Target – Word	
IPA	**Prime**	**Prime Voiced Counterpart**	**Related**	**Unrelated**
/pɔt/	*pot – pâte* ‘dough’	*bought – bâte* ‘build’	STIR	JUMPER
/pu/	*poo – pou* ‘flea’	*boo – boût* ‘end’	DIAPER	LEATHER
/to/	*toe – tôt* ‘early’	*dough – dos* ‘back’	FOOT	ACCOUNT
/tu/	*two – toux* ‘cough’	*do – doux* ‘soft’	NUMBER	HAMMOCK
/kɔz/	*cause – case* ‘box’	*gauze – gaz* ‘fuel’	REASON	EAR
/ku/	*coo – cou* ‘neck’	*goo – goût* ‘taste’	BABY	FIELD
/poz/	*pose – pause* ‘break’	*bows* – n/a	STAND	HAND
/pɑ(ɔ)ʃ/	*posh – poche* ‘pocket’	*Bosh* – n/a	FANCY	CHEEK
/tɔs/	*toss – tasse* ‘cup’	*DOS* – n/a	THROW	LIFE
/tʌ(ɔ)k/	*tuck – toque* ‘spur’	*duck* – n/a	FOLD	IRON
/kot/	*coat – côte* ‘rib’	*goat* – n/a	JACKET	RISK
/kʊd/	*could – coude* ‘elbow’	*good* – n/a	MIGHT	JELLO
/pɪst/	*pissed – piste* ‘path’	n/a – n/a	ANGRY	ASH
/pɑk/	*pock – pâque* ‘easter’	n/a – n/a	SCAR	RAIN
/tɔ/	*taw – tas* ‘pile’	n/a – n/a	MARBLE	ARM
/tʊk/	*took – touque* ‘drum’	n/a – n/a	HAD	MONEY
/kɪt/	*kit – quitte* ‘leave’	n/a – n/a	HELP	RAT
/kɪst/	*kissed – kyste* ‘cyst’	n/a – n/a	LOVE	ELF

APPENDIX L

Lexical Decision Task: Close Interlingual Homophones – Word

			Target – Word	
IPA	**Prime**	**Prime Voiced Counterpart**	**Related**	**Unrelated**
/pɑ͡**ɪ**/ – /pɑ**j**/	*pie – paille* ‘straw’	*buy – baille* ‘lease’	DESSERT	MAGIC
/pɪ**l**/ – /pɪ**l**/	*pill – pile* ‘battery’	*bill – bile* ‘bile’	DRUG	OLIVE
/tɔ**r**/ – /tɔ**ʀ**/	*tore – tort* ‘wrong’	*door – dort* ‘sleep’	RIP	MAIL
/t**æ**ŋ/ – /t**ɛ**ɲ/	*tang – teigne* ‘ringworm’	*dang – deigne* ‘deign’	JUICE	LOOK
/k**ɑ**d/ – /k**ɔ**d/	*cod – code* ‘code’	*God – gode* ‘pucker’	FISH	SAY
/kɔ**r**/ – /kɔ**ʀ**/	*core – corps* ‘body’	*gore – gare* ‘station’	CENTER	NOZZLE
/pi**r**/ – /pi**ʀ**/	*peer – pire* ‘worst’	*beer* – n/a	LOOK	LEAF
/pɛ**r**/ – /pɛː**ʀ**/	*pear – père* ‘father’	*bear* – n/a	FRUIT	BONE
/t**ɑn**t/ – /t**ɑ̃**t/	*taunt – tante* ‘aunt’	*daunt* – n/a	ANNOY	NOOK
/t**a**ɪ/ – /t**ɑ**j/	*tie – taille* ‘size’	*die* – n/a	SHIRT	FARM
/kɔ**l**/ – /kɔ**l**/	*call – col* ‘collar’	*gall* – n/a	PHONE	OPIUM
/k**æ**p/ – /k**a**p/	*cap – cape* ‘cape’	*gap* – n/a	BOTTLE	DARK
/p**æn**t/ – /p**ɑ̃**t/	*pant – pente* ‘slope’	n/a – n/a	BREATHE	LAMB
/pɑ**r**t/ – /pa**ʀ**t/	*part – parte* ‘leave’	n/a – n/a	SEGMENT	NERD
/tɑ**r**/ – /tɑ**ʀ**/	*tar – tard* ‘late’	n/a – n/a	BLACK	KNIFE
/t**æ**t/ – /t**ɛː**t/	*tat – tête* ‘head’	n/a – n/a	MAKE	ACID
/k**æ**t/ – /k**ɛː**t/	*cat – quête* ‘quest’	n/a – n/a	DOG	RADISH
/k**æ**n/ – /k**a**n/	*can – canne* ‘cane’	n/a – n/a	TIN	FACE

APPENDIX M

Lexical Decision Task: Interlingual Homophone – Nonword

			Target – Nonword	
IPA	**Prime**	**Prime Voiced Counterpart**	**Related**	**Unrelated**
/pɔt/	*pot – pâte* ‘dough’	*bought – bâte* ‘build’	G-IR	M-UMPER
/pu/	*poo – pou* ‘flea’	*boo – boût* ‘end’	ST-IAPER	R-EATHER
/to/	*toe – tôt* ‘early’	*dough – dos* ‘back’	N-OOT	BL-OCCOUNT
/tu/	*two – toux* ‘cough’	*do – doux* ‘soft’	B-UMBER	N-AMMOCK
/kɔz/	*cause – case* ‘box’	*gauze – gaz* ‘fuel’	D-EASON	K-EAR
/ku/	*coo – cou* ‘neck’	*goo – goût* ‘taste’	N-ABY	B-IELD
/poz/	*pose – pause* ‘break’	*bows* – n/a	THR-AND	G-AND
/pɑ(ɔ)ʃ/	*posh – poche* ‘pocket’	*Bosh* – n/a	CH-ANCY	J-EEK
/tɔs/	*toss – tasse* ‘cup’	*DOS* – n/a	SM-OW	M-IFE
/tʌ(ɔ)k/	*tuck – toque* ‘spur’	*duck* – n/a	TR-OLD	F-IRON
/kot/	*coat – côte* ‘rib’	*goat* – n/a	D-ACKET	SN-ISK
/kʊd/	*could – coude* ‘elbow’	*good* – n/a	ST-IGHT	Z-ELLO
/pɪst/	*pissed – piste* ‘path’	n/a – n/a	FL-ANGRY	SN-ASH
/pɑk/	*pock – pâque* ‘easter’	n/a – n/a	N-AR	Z-AIN
/tɔ/	*taw – tas* ‘pile’	n/a – n/a	S-ARBLE	S-ARM
/tʊk/	*took – touque* ‘drum’	n/a – n/a	SN-AD	L-ONEY
/kɪt/	*kit – quitte* ‘leave’	n/a – n/a	Z-ELP	G-AT
/kɪst/	*kissed – kyste* ‘cyst’	n/a – n/a	M-OVE	L-ELF

APPENDIX N

Lexical Decision Task: Close Interlingual Homophones – Nonword

			Target – Nonword	
IPA	**Prime**	**Prime Voiced Counterpart**	**Related**	**Unrelated**
/pɑ͡**ɪ**/ – /pɑ**j**/	*pie* – *paille* ‘straw’	*buy* – *baille* ‘lease’	M-ESSERT	D-AGIC
/pɪ**l**/ – /pɪ**l**/	*pill* – *pile* ‘battery’	*bill* – *bile* ‘bile’	G-UG	D-OLIVE
/tɔ**r**/ – /tɔ**ʀ**/	*tore* – *tort* ‘wrong’	*door* – *dort* ‘sleep’	M-IP	L-AIL
/t**æ**ŋ/ – /t**ɛ**ɲ/	*tang* – *teigne* ‘ringworm’	*dang* – *deigne* ‘deign’	F-UICE	J-OOK
/k**ɑ**d/ – /k**ɔ**d/	*cod* – *code* ‘code’	*God* – *gode* ‘pucker’	S-ISH	V-AY
/kɔ**r**/ – /kɔ**ʀ**/	*core* – *corps* ‘body’	*gore* – *gare* ‘station’	N-ENTER	S-OZZLE
/pi**r**/ – /pi**ʀ**/	*peer* – *pire* ‘worst’	*beer* – n/a	D-OOK	N-EAF
/pɛ**r**/ – /pɛː**ʀ**/	*pear* – *père* ‘father’	*bear* – n/a	BL-UIT	Y-ONE
/t**ɑn**t/ – /t**ɑ̃**t/	*taunt* – *tante* ‘aunt’	*daunt* – n/a	SH-ANNOY	Z-OOK
/t**a**ɪ/ – /t**ɑ**j/	*tie* – *taille* ‘size’	*die* – n/a	F-IRT	SH-ARM
/kɔ**l**/ – /kɔ**l**/	*call* – *col* ‘collar’	*gall* – n/a	V-ONE	S-OPIUM
/k**æ**p/ – /k**a**p/	*cap* – *cape* ‘cape’	*gap* – n/a	S-OTTLE	Z-ARK
/p**æn**t/ – /p**ɑ̃**t/	*pant* – *pente* ‘slope’	n/a – n/a	Z-EATHE	V-AMB
/pɑ**r**t/ – /pa**ʀ**t/	*part* – *parte* ‘leave’	n/a – n/a	N-EGMENT	SHR-ASS
/tɑ**r**/ – /tɑ**ʀ**/	*tar* – *tard* ‘late’	n/a – n/a	GR-ACK	V-IFE
/t**æ**t/ – /t**ɛː**t/	*tat* – *tête* ‘head’	n/a – n/a	Z-AKE	B-ACID
/k**æ**t/ – /k**ɛː**t/	*cat* – *quête* ‘quest’	n/a – n/a	R-OG	D-ADISH
/k**æ**n/ – /k**a**n/	*can* – *canne* ‘cane’	n/a – n/a	/g/-IN	N-ACE

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ABSTRACT

STOP IDENTITY CUE AS A CUE TO LANGUAGE IDENTITY

by

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Major: Communication Sciences & Disorders (Cognitive Linguistics)

Degree: Doctor of Philosophy

The purpose of the present study was to determine whether language membership could potentially be cued by the acoustic-phonetic detail of word-initial stops and retained all the way through the process of lexical access to aid in language identification. Of particular interest were language-specific differences in CE and CF word-initial stops. Experiment 1 consisted of an interlingual homophone production task. The purpose of this study was to examine how word-initial stop consonants differ in terms of acoustic properties in Canadian English (CE) and Canadian French (CF) interlingual homophones. The analyses from the bilingual speakers in Experiment 1 indicate that bilinguals do produce language-specific differences in CE and CF word-initial stops, and that closure duration, voice onset time, and burst spectral SD may provide cues to language identity in CE and CF stops. Experiment 2 consisted of a Phoneme and Language Categorization task. The purpose of this study was to examine how stop identity cues, such as VOT and closure duration, influence a listener to identify word-initial stop consonants as belonging to Canadian English (CE) or Canadian French

(CF). The RTs from the bilingual listeners in this study indicate that bilinguals do perceive language-specific differences in CE and CF word-initial stops, and that voice onset time may provide cues to phoneme and language membership in CE and CF stops. Experiment 3 consisted of a Phonological-Semantic priming task. The purpose of this study was to examine how subphonetic variations, such as changes in the VOT, affect lexical access. The results of Experiment 3 suggest that language-specific cues, such as VOT, affects the composition of the bilingual cohort and that the extent to which English and/or French words are activated is dependent on the language-specific cues present in a word. The findings of this study enhanced our theoretical understanding of lexical structure and lexical access in bilingual speakers. In addition, this study provides further insight on cross-language effects at the subphonetic level.

AUTOBIOGRAPHICAL STATEMENT

Serendipity would be the word that best describes my path towards the selected dissertation topic. I never really gave much thought to languages or bilingualism until much later in my life. After I obtained my degree in Psychology, I went abroad to Spain to teach English as a second language and to travel across Europe. There are two specific moments that made me fall in love with language acquisition while in Spain. The first moment was during a school field trip at the park with my first graders. None of my students could speak a word of English when I began teaching them. While walking to the park (this was around October I believe), one of my students came up to me and said “Miss Paula, I walking … fly up nose, tickles”. I could not believe how quickly she was mastering the language. From hereon, I began to reflect on language acquisition and what it means to be bilingual. The second event was while grocery shopping with my husband. At checkout, while I was paying the cashier, I counted the money in French rather than in English or Spanish. I never noticed this until my husband brought this to my attention. I noticed that any mathematical calculations were always done in French. I started asking random bilingual people in which language they counted and in which language they learned math to see if there was a correlation. Well to my dismay, there was not a simple pattern. Both of these events propelled me to do a degree in Speech Language Pathology. While completing my post-bachelor degree in speech-language pathology, I took a Phonetics class with Dr. Andruski. I also realized that being a clinician was not what I was particularly interested in, rather I wanted to be a researcher. I mentioned the above two events to Dr. Andruski and she said that it would make for an interesting dissertation topic. Dr. Andruski’s dissertation topic provided me with the idea to do the current dissertation, and the rest is history…