ARTICULATORY SETTINGS OF FRENCH AND ENGLISH MONOLINGUAL AND BILINGUAL SPEAKERS

by

IAN LEWIS WILSON

B.Math., University of Waterloo, 1988
M.A. (TESL/TEFL), University of Birmingham, 1998

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Abstract

This dissertation investigates articulatory setting (AS), a language's underlying or default posture of the articulators (i.e., the tongue, jaw, and lips). Inter-speech posture (ISP) of the articulators (the position of the articulators when they are motionless during inter-utterance pauses) is used as a measure of AS in Canadian English and Québécois French. The dissertation reports two experiments using a combination of Optotrak and ultrasound imaging to test whether ISP is language specific in both monolingual and bilingual speakers, whether it is affected by phonetic context, and whether it is influenced by speech mode (monolingual or bilingual).

Results of Experiment 1 show significant differences in ISP across the English and French monolingual groups, with English exhibiting a higher tongue tip, more protruded upper and lower lips, and narrower horizontal lip aperture. Results also show that for English speakers, the jaw ISP is somewhat influenced by phonetic context while the lip and tongue ISP are not. For French speakers, only certain lip components of ISP are influenced by phonetic context while the ISP of the tongue and jaw are not.

Results of Experiment 2 show that upper and lower lip protrusion are greater for the English ISP than for the French ISP, in all bilinguals who were perceived as native speakers of both of their languages, but in none of the other bilinguals. Also, tongue tip height results mirrored those of the monolingual groups, for half of the bilinguals perceived as native speakers of both languages, but for no other bilinguals. Finally, results show that there is no unique bilingual-mode ISP, but instead one that is equivalent to the monolingual-mode ISP of a speaker's currently most-used language.

This research empirically confirms centuries of non-instrumental evidence for the existence of AS, and thus supports calls for the teaching of AS to L2 learners. Additionally, the lack of phonetic carry-over effect on ISP is encouraging for studies that have used ISP as a measurement baseline. Finally, the fact that there is no unique ISP for bilingual speech mode suggests that differences between monolingual and bilingual modes do not hold at the phonetic level.

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CHAPTER I Introduction

If asked why different languages sound different, a layperson might answer that different languages use different sounds (i.e. they have different phonemes). A linguist would add that different languages use sounds differently (i.e. they have different phonologies). However, there is another factor that also plays a part in the sound of a language. As far back as 350 years ago (Wallis, 1653 / 1972) people sensed that when speaking a foreign language, one's articulators - the tongue, jaw, lips, etc. - seemed to have a whole different *underlying* or *default* posture than the one used for one's native language. A language's underlying articulatory posture is one part of what Honikman (1964) called *articulatory setting* (henceforth AS), and although it is something that has interested phoneticians for centuries, until very recently its existence had never been instrumentally verified.

For reasons to be discussed in Section 1.3, there has been no support, in the form of direct articulatory measurements, for the existence of AS until recent work by Gick, Wilson, Koch, and Cook (2004). These authors looked at inter-speech posture (the position of the articulators when they are motionless during inter-utterance pauses; henceforth ISP) to investigate AS. The reasons for this connection between AS and ISP are made apparent in Section 1.3.1. The results of Gick et al. (2004) showed that the ISP for Québécois French is significantly different from that for Canadian English[1]. Their study, however, examined only five speakers of each language and its methodology was constrained by the fact that the data they analyzed was based on existing x-ray movie films with limited spatial resolution and clarity, and they had no control over the linguistic stimuli or how they were presented to the subjects. The first major purpose of my research has been to partially replicate the study of Gick et al. (2004) using a greater number of speakers of French and English, and using an entirely different methodology

[1] In this dissertation (as well as in Gick et al. (2004)), "Canadian English" refers to a general Canadian accent as would be heard from many television newscasters on national television, in the same way as "General American English" refers to a general accent in the U.S.A. Admittedly, in different Canadian provinces there are slightly different accents and the term "Canadian English" is not meant to imply that there exists only one kind of English in Canada. See Section 5.2.3 for more on this issue.

that has enabled more measurement precision and has allowed for control over the phonetic context of the ISPs that were analyzed. In the course of this replication study, not only have I tested whether or not ISP is language specific, but I have also tested whether it is sensitive to carry-over effects of phonetic context. The measurement tools I have used to establish baseline data for English and French will allow new languages to be studied and systematically compared with these data in the future. The second major purpose of this study has been to extend previous research on AS and research on bilingual speech production by examining whether bilinguals who are perceived as native speakers of both of their languages have ISP differences that mirror monolingual group differences, and more broadly, how a bilingual's pronunciation proficiency relates to their ISP(s). Finally, I have also examined the effect of a bilingual's speaking mode (bilingual mode versus monolingual mode) on ISP.

1.1. Outline of the Dissertation

In the remainder of Chapter I of this dissertation, I describe AS and ISP in more detail, and I review a small subset of the literature dealing with both of these. Specifically, I review various researchers' non-instrumental views of AS, including some that have existed for more than a century, and I also review a study by Gick et al. (2004), the first study to quantitatively measure multiple articulatory components of AS. Shortcomings of that study are pointed out, setting the stage for Experiment 1 on how language and phonetic context affect ISP. I finish Chapter I by talking about measuring AS in bilinguals, thus motivating Experiment 2 on how perceived pronunciation proficiency and mode of speech production relate to ISP.

In Chapter II, I present the method used in Experiments 1 and 2. Subjects and apparatus used, as well as the procedure followed are laid out in detail.

Chapter III consists of the results and discussion of Experiment 1, an experiment designed to measure AS in monolingual speakers of Canadian English and monolingual speakers of Québécois French. Through direct ultrasound measurements of the tongue, and Optotrak measurements of the lips and jaw in ISP, it is tested whether or not the ISP for Canadian English is significantly different from that of Québécois French. It is also tested whether or not phonetic context has a carry-over effect on ISP.

Chapter IV consists of the results and discussion of Experiment 2, a very similar experiment to Experiment 1, but instead using subjects who were fluent bilinguals in both Canadian English and Québécois French. Data provided by these bilingual subjects is analyzed to test whether bilinguals who are perceived as native speakers of two languages have one or two ISPs. It is also tested whether ISP is sensitive to the mode of speech (bilingual mode versus monolingual mode) that the bilingual speaker is in.

Finally, in Chapter V, there is a general discussion of the results of both experiments, including implications of the research for a wide variety of speech research applications. Then conclusions are drawn, limitations of this dissertation are considered, and future directions for research are given.

1.2. Articulatory Setting (AS)

Much has been written about AS, and an attempt to provide a thorough historical review of it is not made here. For detailed historical surveys of AS, see Kelz (1971), Laver (1978), and Jenner (2001). One of the earliest references to the *concept* of AS was Wallis (1653/1972) cited by Van Buuren (1995, p. 136) as follows:

> For instance, the English as it were push forward the whole of their pronunciation into the front of the mouth, speaking with a wide mouth cavity, so that their sounds are more distinct. The Germans, on the other hand, retract their pronunciation to the back of the mouth and the bottom of the throat.

Van Buuren (1995, p. 136) also cited Sievers (1876, p. 47) as talking about "Operationsbasis" (basis of articulation), the correct tongue position for a different dialect, a position that is held even during the production of various sounds. Sweet (1890, p. 69) called the concept of AS the "organic basis" of a language:

> Every language has certain tendencies which control its organic movements and positions, constituting its organic basis or the basis of articulation. A knowledge of the organic basis is a great help in acquiring the pronunciation of a language.

As defined by Honikman (1964), AS actually includes more than simply the underlying posture of the articulators. She defined it as the "gross oral posture and mechanics" required for the "economic and fluent" production of the "established pronunciation of a language" [p. 73]. Honikman also divided AS into external setting (i.e. the lips and jaw) and internal setting (i.e. the tongue, velum, and larynx), but of the components of the internal AS, she focused primarily on the tongue, probably because it is difficult to know exactly what state the velum and larynx are in without proper measurement tools. Abercrombie (1967, pp. 92-93) made a distinction between aspects of AS that are within a speaker's control ("muscular tensions [...] which keep certain of the organs of speech adjusted in a way which is not their relaxed position of rest"), and those that are not (i.e. size and shape of an individual speaker's vocal tract). Lebrun (1970) took issue with the concept of tension and how it had been measured at the time, and he called for verification by reliable measurements. Presumably, these "muscular tensions" that Abercrombie referred to can be inferred indirectly from the position of the articulators. An oversimplified but useful analogy would be inferring the tension of the marionette's strings by observing the position of the marionette. In this study, I looked only at the *posture* of the articulators, and not the *mechanics* (i.e. static, not dynamic properties). The reason for this choice was simply one of limiting the research to a manageable scale. Specifically, because I had available methods of measuring the tongue, lips and jaw positions (ultrasound and Optotrak), I limited my observations to these three articulators. I did not measure the velum or vocal folds here. This is not to say that these two areas are unimportant; they are simply beyond the scope of this research.

There are other terms that AS is often known by, such as voice quality, voice setting, phonetic setting, and basis of articulation, but different researchers and lexicographers have defined these terms in different ways. In my research, since I only examine the tongue, lips and jaw, AS is the most appropriate term to use because terms such as voice quality seem to imply a focus on laryngeal settings. In the Applied Linguistics field, AS is usually referred to as voice quality (e.g., Esling & Wong, 1983).

In the language teaching and applied linguistics dictionary by Richards, Platt, and Platt (1992, p. 403), voice quality is equated with timbre and is seen as speaker-specific. Both Crystal's (2003) and Matthews' (1997) linguistics dictionaries have separate entries for AS and voice quality. Crystal (2003) defined AS as more of a language- or dialect-specific entity, and voice quality as a "person-identifying feature of speech" (Crystal, p. 496). Although Matthews (1997) defined voice quality as an individual quality, he also noted that AS "may identify the voice of an individual [,...] may also be characteristic of particular languages or accents [,...] and may carry affective meaning" (p. 26). In his dictionary of phonetics and phonology, Trask (1996, p. 34) defined articulatory setting as:

> The overall tendency, on the part of an individual or of the speakers of a particular language, to maintain the organs of speech in some particular configuration throughout speech, as reflected in such factors as the height of the velum, the degree of lip-rounding and the tension of the tongue and lips.

In my research, I was only concerned with the linguistic function of AS, specifically its function of characterizing a particular language, in this case Québécois French versus Canadian English. This is the first of three functions of AS succinctly summarized by Esling & Wong (1983, p. 89):

> Voice quality settings may function linguistically, to characterize the particular language or dialect or social group to which a speaker belongs; or they may function paralinguistically, to signal mood or emotion in conversational contexts; or they may also function extralinguistically to characterize or identify the individual speaker.

1.2.1. Non-instrumental Views of AS

The following non-instrumental views of English and French AS will be reviewed briefly in chronological order: Sweet (1890), Graff (1932), Heffner (1950), Honikman (1964), and Esling & Wong (1983). These are not the only non-instrumental views of AS that exist, but they are the ones most widely cited. Although these views are not quantitative, they are nevertheless important, as Laver (1978, p. 9) points out: "The contribution of auditory judgment to the analysis of settings in voice quality is particularly important, since the clues that are available are slight and subtle".

A number of these descriptions of AS are for Received Pronunciation (R.P.) of British English, as well as for Parisian French. These probably do not correspond to the AS for Canadian English and the AS for Québécois French, so direct comparison must be done cautiously. Indeed, even within Canadian English and within Québécois French there are many different dialects, each with a potentially different AS. In listing seven features of the AS for General American English, Esling and Wong (1983, p. 91) pointed out that "not all dialect groups will share the same features, and some dialect groups may even demonstrate opposite features, but settings that combine some if not all of these features are very common". Given this, I will still compare what has been said about English and French AS to the findings presented in this dissertation so that predictions are made explicit for future non-instrumental studies of Canadian English and Québécois French.

Sweet (1890, p. 72) stated that in English the tongue is flatter and lower, with the tongue blade hollowed and the tongue tip brought back from the teeth, while the lips are in a neutral position. In contrast, in French "the tongue is arched and raised and advanced as much as possible, and the lips articulate with energy". Where in English, the tongue is flat, in French it is narrow.

Graff (1932) described the tongue in (probably Parisian) French to be more forward than in British English, with the lips ready for frequent rounding and the tongue ready for tenser articulation in French. This account of the tongue in French being in a more forward position accords with Sweet's view.

Heffner (1950) echoed Graff's and Sweet's description of the tongue being forward for French, and he added that it is also high and tense, although it is not clear whether it is the tongue body or the tongue tip that is high. He also stated that the tongue in British English is comparatively lower and more relaxed, and implied that the tongue is even more relaxed in American English than in British English. It is unclear though, how this notion of a "relaxed" tongue translates into a position or shape of the tongue, and, as mentioned in Section 1.2, Lebrun (1970) has convincingly questioned this notion of tenseness of the tongue.

Honikman (1964) also described the AS for Parisian French and for R.P. English, and, although Kelz (1971, p. 204) bluntly stated that "what Honikman said, Viëtor and Sweet had said in similar words 80 or 90 years before", Honikman went into much more detail regarding these two languages and her account of the differences did not completely mirror Sweet's. Given the 74-year and 32-year differences between her account and Sweet's and Graff's accounts, respectively, it would not be surprising that differences in their accounts of the ASs are actual differences in the way sounds were produced at the time rather than simply differences of opinion. Honikman (1964, p. 78) stated about the French AS that it has the tongue tip "tethered to the lower front teeth", whereas English AS has a higher tongue tip because the sides of the tongue are tethered to the roof of the mouth and the molars. She said that the French jaw is open more often and perhaps open more widely than English due to the relatively high frequency of [a] in French as opposed to English. The English jaw is loosely closed, but not clenched. The English lips are neutral, whereas the French lips are rounded and vigorously active in spreading and rounding. She implied that the French tongue body would be higher because it is convex to the roof of the mouth, whereas the English tongue body is concave to the roof of the mouth and would therefore be lower.

The paper by Esling and Wong (1983) appears to be the only account of the AS of any variety of North American English. Esling and Wong (p. 91) listed seven features of a General American English AS: spread lips, open jaw, palatalized tongue body position, retroflex articulation, nasal voice, lowered larynx, and creaky voice. This description of American English differs from the previous accounts of British English in a number of ways: In American English the lips are spread, the jaw open, and the tongue body "fronted and slightly raised" (p. 92) as opposed to the lips being neutral, the jaw loosely closed, and the tongue body lower in British English. Esling and Wong's description of "retroflex articulation" in American English applies to the tongue tip and implies that the tongue tip in American English should be more retracted than that of French. However in a study using MRI, Tiede, Boyce, Holland, and Choe (2004) showed that American English /r/ is actually articulated in a variety of ways ranging from a bunched articulation to a retroflex one. This means that many speakers of American English probably do not necessarily have a retroflex AS and thus it cannot be assumed that the tongue tip is more retracted in English than in French.

In summary, if we assume that the Canadian-English AS is similar to the General American-English AS described by Esling and Wong (1983), then the predictions for how it compares to the Québécois-French AS depend on whether the Québécois-French AS is more like the Parisian-French AS described by Honikman (1964) or that described by Sweet (1890) and Graff (1932). Whether the Québécois-French AS is more like Honikman's description of the Parisian French AS or Sweet's and Graff's descriptions of the Parisian French AS, we would expect the lips to be relatively more spread in English than in French, and the tongue body to be equally high in English and in French. As for the tongue tip, we expect it to be higher in English if the Québécois-French AS is more like Honikman's description but lower in English if the Québécois-French AS is more like Sweet's description. Finally, we expect to see the jaw equally as open in French as in English, according to Honikman's description. In Section 3.2.2, the above non-instrumental views of AS are compared to the results of the present study.

1.3. Measuring AS

Although many people have described AS as being different for different languages and dialects, very few people have actually quantitatively *measured* aspects of AS to be able to say conclusively how it is different for two languages. The biggest impediment to measuring a language's AS is ensuring that one is measuring only AS and not being influenced by the articulation of the language's speech segments (see Laver's statements below). This problem was recognized over 55 years ago by Heffner (1950, p. 99): "No method of measurement has been devised which would permit the mathematical description of a basis of articulation." The problem still had not been solved 23 years later when O'Connor (1973, p. 289) called for future study of "bases of articulation" (i.e. AS) and stated "We know a good deal more about the detailed articulatory movements in a language than we know about the general articulatory background on which they are superimposed." Even 22 years after that, the situation still had not changed as evidenced by Collins and Mees' (1995, p. 422) statement that "At the moment, much of the description of AS features - including our own - is largely impressionistic." Some researchers have concluded that AS cannot be measured and the description of it must rely on cross-linguistic comparisons (Kelz, 1971).

There have been a number of studies trying to characterize a given language in terms of its overall acoustic properties. If AS underlies speech, surely its effects must be audible in the speech signal. The most common method of measuring the overall acoustic properties of a language is to measure its long term average spectrum (henceforth LTAS), the average of many instantaneous spectra over a reasonably long speech sample. A number of LTAS studies have found a correlation between language spoken and LTAS for individual bilingual speakers, while other studies have failed to find any correlation (see Bruyninckx, Harmegnies, Llisterri, and Poch-Olivé, 1994 for a brief summary). However, it is not necessarily the case that LTAS data should directly correlate with AS. Laver (2000, p. 40) pointed out that "all calculations of a long-term average (whether of articulatory position, auditory impression, or acoustic spectrum) based on all segments [...] will give obvious inaccuracies." The problem is that LTAS is a measure of the sounds of a language - i.e., it is directly affected by the phonetic context of the speech one is examining and there is no way to distinguish which aspects of the speech signal are based on AS, and which are a reflection of the frequency of specific articulations in the language's phonetic inventory. Laver (1978, p. 11) stated that "no articulatory setting normally applies to every single segment a speaker utters", and he called this property of speech segments *segmental susceptibility*. Laver (1980, p. 21) further added that "because the successive segments in the stream of continuous speech vary in their susceptibility to the effect of settings, a setting is audible only on an intermittent basis, and even when audible, varies in its prominence, depending on the susceptibility of the segment currently being uttered." Evidence supporting this comes from Harmegnies, Esling, and Delplancq (1989), who found that not all deliberate changes to voice quality have large effects on LTAS. Thus, although LTAS may provide a kind of spectral signature of a language, it is likely that LTAS does not accurately describe the underlying AS of that language.

1.3.1. AS and the Rest Position of the Tongue

If AS is an articulatory property that underlies speech, and yet to measure it properly we need to avoid contextual effects, then the challenge is to find a method of measuring it that eliminates the effect of context. Gick et al. (2004) proposed that the ISP is the most representative, least biased configuration at which to measure the position of the articulators in order to infer a language's AS. Because the ISP occurs between utterances, it is representative of speech in a way that absolute rest position (simply for respiration) is not. The position I take in the present research is the same as Gick et al. (2004) in assuming that one's ISP provides the best window for investigating one's AS.

Sharpe (1970, p. 124) also equated AS with rest position, but it is assumed that she was talking about absolute rest position (for respiration) and not rest position when one is still in speech mode (i.e. the ISP): "these settings [AS] are learnt early in life, and are then usually the 'rest positions' taken up by the jaws, lips, tongue, etc., when not speaking." In contrast, Hartmann & Stork (1972, p. 19, my italics), in their dictionary definition of AS, explicitly stated that AS is different from an absolute rest position: "adjustments in the vocal tract, adopting a posture of the articulatory organs which is maintained by a speaker throughout the whole time he is talking, *but which is different from the relaxed position.*" Abercrombie (1967, p. 91) stated that some of the features of voice quality are even present when we simply cough, or sigh, or clear the throat. Presumably though, he was referring to the innate components of AS, namely, a speaker's anatomical make up, and not the linguistic aspects of AS.

A number of studies in the dental research literature have been conducted on the rest position of the tongue, with the intention of discovering a relationship between tongue rest position (but not pre-speech or between utterances) and malocclusion (e.g. Ballard, 1959; Eifert, 1960; Cookson, 1967). Ballard (1959), on the basis of x-ray data, reported two different types of rest positions for the tongue, The two rest positions he described are the *habitual* posture, the "true rest position" with the tongue tip making a seal with the incisors and lower lip, and the *innate* posture with the tongue backed and more arched accompanied by a lower mandible position. It is possible that Ballard's "true rest position" can be considered absolute rest position, when the person is relaxed and is not about to engage in speech activity. However, neither of these are likely to be the ISP (speech rest position) because the subjects in Ballard's experiment were not speaking during the x-ray filming.

In the speech research literature, Öhman (1967) was the first to write about a "basic speech posture", giving electromyographic (EMG) evidence of steady tonic activity in some facial muscles (e.g. the levator labii superioris) immediately prior to speech.[2] Öhman (1967) proposed that the articulatory movements of speech are superimposed on the basic speech posture, although he also found that the basic speech posture can be directly inhibited if it conflicts with some necessary articulatory posture (p. 43). Öhman did not mention the possibility that the basic speech posture could be language-specific, and Tatham (1997 (1969), p. 8) said that he (i.e. Tatham) "infer[s] that Öhman does not want, as [he] do[es] not, to make this notion of basic speech posture language-specific." Recently, Tatham (e-mail communication, Dec. 9, 2003) clarified the reasons for his opinion: He referred to "examples in the neuro-physiological literature about how tonic activity in the musculature 'gets ready' for activity" and proposed that "immediately prior to speaking the system sets itself up in a speech-ready state which is universal". He also proposed a "multi-layered modelling approach" for speech such that after the system is in its universal speech-ready state, "then the system re-sets in a language-specific speech-ready state which is overlaid on the previous one". This second layer that Tatham proposed is equivalent to the ISP that I am investigating in this study.

Around the same time as Öhman's research, Perkell (1969, p. 41) used the term "speech posture" to describe the state of the vocal tract "at the beginning of a sentence." Through observations of nonsense-word x-ray speech data pronounced by speakers of American English, he determined that the larynx, the velum, and the tongue each have a speech posture that they take up when a speaker is preparing to speak. Specifically, for the larynx he (p. 41) stated that "at the beginning of a sentence the larynx seems to rise to a speech posture [...] from which smaller, context dependent fluctuations are made." For the velum, he (p. 52) described it as being "in an intermediate 'speech posture' position which is between rest and its next highest position: the one occurring during nasalized

[2] Note, however, that Bithell (1952, p. 58) used the term "Sprechbereitschaftslage", which is defined as "the position of readiness to speak before the organs required for the sound become active". This concept seems very similar to Öhman's basic speech posture.

speech". As for the tongue, Perkell (p. 65) stated that "the tongue shape or tonus is part of a speech posture and is basically the same for all vowels; the resulting semirigid tongue body is positioned in the vocal tract by extrinsic tongue muscles attached to its periphery." Like Öhman, Perkell did not mention whether he thought that the "speech posture" he had discovered is a general posture that is the same regardless of language, or whether language-specific speech postures are more likely. However, it is likely that what Perkell had found was the universal first layer that Tatham refers to above. Examples of other references where a distinction is made between pre-speech posture and absolute rest position include Daniloff & Moll (1968), Barry (1992), and Gick (2002).

In motor control research, Brown & Rosenbaum (2002, p. 129) state that "Anticipating the perceptual consequences of one's own actions (feedforward) is a prerequisite for effective motor control." Thus it is reasonable to assume that in speech, preparatory vocal tract postures are used (see Schmidt and Lee, 1999, pp. 126-127 for a description of "preparatory postural reactions"), and that these postures are dependent on the phonetic context of the utterance one is about to produce. Indeed, this has been demonstrated for the jaw by Hamlet & Stone (1981), who found that the jaw's pre-speech posture (actually, ISP in their study, as the subjects arguably never left speech mode between stimuli) correlated with the position of the jaw required for sounds that appeared in the following utterance. In other words, anticipatory coarticulation affects not just the speech sounds one produces, but also the pre-speech posture adopted by one's articulators. If a speaker has an *utterance*-specific preparatory posture that is affected by the sounds to follow, then it follows that, more generally, the speaker could also have a *language*-specific preparatory posture, in preparation to produce *any* of the given sounds of a language (or possibly the most frequently occurring sounds).

The existence of such a language-specific preparatory posture, i.e. a language-specific ISP, was tested for and confirmed by Gick et al. (2004), who showed that not only was the ISP for Québécois French different from that for Canadian English, but the accuracy of production of the ISP was as high as that for producing the speech sound [i], consistent with the view that the ISP is a speech target posture. Specifically, Gick et al. found the following differences between the Québécois-French ISP and the Canadian-English ISP: The tongue tip (TT), tongue body (TB), and tongue root (TR) were all farther away from the opposing vocal tract surface in the French group compared to the English group. The upper lip was significantly more protruded in English, but the lower lip was significantly more protruded in French. For both the jaw and the velum, there was no difference between the French ISP and the English ISP. Gick et al. did not measure the tongue dorsum, so it is not known whether this measurement was different across languages.

Although the Gick et al. study was as accurate as possible under the circumstances, a number of problems exist, which warrant a replication of the study. First, their study examined only 5 speakers of each language and made crosslinguistic generalizations based on these 10 speakers. Obviously the more speakers used, the more accurate any generalizations will be. Second, the Gick et al. methodology is constrained by the fact that the data they analyzed were existing x-ray movie data (Munhall, Vatikiotis-Bateson, and Tohkura, 1994) with limited spatial resolution and clarity. X-ray films do not show slices of the vocal tract; they contain shadows of objects over other objects and edges are often difficult to define. Another methodological issue with the Gick et al. study is that because the data already existed, Gick et al. had no control over the phonetic content of the stimuli being used and how they were presented to the subjects. The stimuli in the original x-ray study were not designed to balance the phonetic context surrounding ISPs. In addition, they were presented to speakers as a list of sentences to be read, thus increasing the chances of anticipatory coarticulation effects on ISP, just as anticipatory coarticulation effects on the ISP of the jaw were found by Hamlet & Stone (1981). If these effects do exist and were not completely controlled for by Gick et al., it may be that the language-specific differences that they found were actually due to the phonetic context rather than language-specific properties of the ISP.

Another potential factor that may have influenced the results of the Gick et al. study is the method of statistical analysis they employed. As the experimental unit for statistical comparison in their repeated measures study, they used the data obtained from each individual measurement token produced by each individual subject, and then used the *jackknife* procedure (i.e. verification that the means of every subset of N-1 subjects was distributed in a similar way) to justify this choice. Although using data obtained from each individual measurement token as the experimental unit is a common practice among speech researchers, Max & Onghena (1999, pp. 265-266) point out that these types of analyses are at risk of having the assumption of independent error effects violated. Max & Onghena recommend using one value per measurement location per subject (i.e. the mean measurement value across all of a given subject's productions in all trials) as the experimental unit. They state that "despite the agreement on this issue in the contemporary statistical literature, the potential for violations of the assumption continues to occur rather frequently in studies addressing normal or disordered speech-language-hearing processes." (p. 266) If anything, the choice of statistical method in Gick et al. (2004) would have resulted in a greater number of significant differences being reported than should reasonably be expected.

Thus, a replication of the results of Gick et al. (2004) was warranted, using a greater number of speakers, a method of data collection that allows for greater accuracy, stimuli presentation and design that balances phonetic context, and using the statistical method recommended by Max & Onghena (1999). In order to replicate the first experiment of Gick et al. (2004), the first hypothesis that was tested in the present research was that ISP is language dependent.

Hypothesis 1: The inter-speech posture (ISP) for Canadian English is significantly different from the ISP for Québécois French.

In my study, it is unlikely that utterance-specific *anticipatory* coarticulation effects were possible because the subjects could not see the next stimulus until they had had a chance to assume an ISP. Although *anticipatory* effects were unlikely, *carry-over* effects were impossible to eliminate while still being sure the subjects remained in speech mode. So, instead of *eliminating* carry-over effects, the phonetic context of the last syllables uttered was tightly controlled across languages. Hamlet & Stone (1981) tried to eliminate any *carry-over* effect by waiting "a few seconds" before manually presenting the next stimulus for the subject to read. Therefore, they assumed that the jaw went to some intermediate position (perhaps absolute rest position, but this is not made explicit) or simply drifted around before assuming the configuration of the next pre-speech posture. Öhman (1967, p. 43) mentioned EMG "evidence" for "basic speech posture" *following* an utterance as if it was common knowledge among EMG speech researchers. Thus, he implied that one does not simply maintain the posture of the last sound of the previous utterance, but that one actively moves the articulators back to the basic speech posture. However, even if Öhman was correct, the possibility of carry-over effects of phonetic context on ISP still exists and needed to be investigated. This led to the second hypothesis that was tested in these experiments.

Hypothesis 2: Within a given speaker's speech in a given language, that speaker's ISP will differ depending on the phonetic segment that precedes the ISP.

1.4. Articulatory Setting in Bilingual Speakers

It has long been realized that one of the greatest benefits of using bilinguals in phonetic research is that vocal tract morphology is automatically controlled for - in single-subject studies, no normalization of measurements is necessary. Thus, it is tempting to think that a bilingual subject would be a good test for whether or not AS is a language-specific property. However, there are a number of reasons why comparing each of a bilingual's ISPs to the respective monolingual group's ISP is potentially imprudent. Grosjean (1989) convincingly argued that a bilingual is not equivalent to two monolinguals in one body, and researchers in bilingualism now generally agree that in the phonetic/phonological acquisition and retention of more than one language, each language has an effect on the other (Paradis, 1996, 2001). Birdsong (2005, p. 9) stated that "it is impossible for either the L1 or the L2 of a bilingual to be identical in all respects to the language of a monolingual". Elston-Güttler, Paulmann, and Kotz (2005, p. 1593) cited a number of recent neurolinguistic studies that support a word-recognition system "that allows for parallel activation of both languages where influence of one language while processing in the other is likely." Although the authors were referring to studies of speech *perception*, it stands to reason that "parallel activation" also applies to speech *production*. Given that it is unclear to what degree production of one of a bilingual's languages affects production of the other, a direct comparison of bilinguals with monolinguals may be difficult to interpret.

Just as quantitative studies of AS in monolingual speakers are very rare, so too are quantitative studies of AS in bilingual speakers. The only study that I am aware of that contains articulatory measurements of AS in bilinguals is that of Todaka (1993, 1995). In his study of four Japanese-English bilinguals (two men who were *not* perceived as native speakers of Japanese, and two women who were perceived as native speakers of both Japanese and English), Todaka (1993, 1995) used aerodynamic, electroglottograph (EGG) and a number of acoustic measures to assess the voice quality of his bilingual subjects in each of their two languages. He compared speech samples from each language, but as stated previously, the problem with this kind of approach is the same as the problem with using LTAS to infer a language's AS - namely the problem of interference from phonetic context. Todaka found that the two females had breathier voice in Japanese than in English and that all four subjects had higher fundamental frequency (f0) in Japanese than in English. However, because of a lack of language-specific properties of English and Japanese that could account for these results, Todaka admits that both these results must be due to sociolinguistic factors. One of these sociolinguistic factors could be Loveday's (1981) finding that as an indication of politeness, Japanese-speaking females use a higher pitch than English-speaking females, but it is unclear what other sociolinguistic factors Todaka is referring to. Todaka also found that the bilinguals' Japanese vowel space was smaller than their English vowel space, but this could simply be an indication of how each sound is articulated, and not a general setting that is different. In fact it is difficult to imagine an AS that would affect all vowels such that the vowel space is larger for one language than another.

Harmegnies & Landercy (1985) did an LTAS study of 20 Dutch-French bilinguals from Belgium. Unfortunately, no information was given about the subjects' abilities in each language. Harmegnies & Landercy found that the LTAS differences were greater between speakers than between languages, and that the variability between languages "mainly rel[ied] on differences between the distribution of phonemes in the languages." (p. 72) Another bilingual LTAS study was done by Bruyninckx et al. (1994), who examined the speech of 24 Spanish-Catalan bilinguals, 12 of whom were Spanish-dominant and 12 of whom were Catalan-dominant. In that study the between-language variability was higher than the within-language variability. Bruyninckx et al. ended their paper by calling for an articulatory study to be done to explain the LTAS results.

Although a direct comparison of bilinguals with monolinguals may be difficult to interpret, comparing a given bilingual's ISP in one language to his/her ISP in another language could determine whether or not having the correct ISP for a language is an important component in native-like pronunciation, something that has never been empirically tested. For if a bilingual speaker who is perceived as a native speaker of both languages does not have two distinct ISPs (one for each language), then it follows that having the correct ISP (and hence, the correct AS) is not a prerequisite for native-like pronunciation of a language.

Not all bilinguals are perceived as native speakers of both of their languages, and in fact, because of first language attrition, some are perceived as native speakers of neither of their languages. There is a myriad of factors that influence L2 pronunciation proficiency: age of first exposure to the L2, language of the home, language of the community, frequency of exposure to the L2, amount of L1 use, etc. It is possible that an additional factor is the ISP one uses in speaking an L2. It is reasonable to expect that bilinguals who are not perceived as native speakers of at least one of their languages might have only one ISP, or if they have different ISPs then the differences are not those that are most salient between the monolingual groups. The third hypothesis that was tested in these experiments is as follows:

Hypothesis 3: A bilingual who is perceived as a native speaker of both languages has a different ISP for each language and will show the same types of crosslinguistic ISP differences that monolingual groups show; conversely, a bilingual who is perceived as *not* being a native speaker of at least one language will have fewer, if any, of the crosslinguistic ISP differences that monolingual groups show.

In addition to controlling for the phonetic context of the ISP (mentioned above), another factor, this one specific to bilingual studies, that should be controlled for is the mode that the speakers are speaking in. Research on bilingual speakers has shown that the communicative setting (whether monolingual or bilingual) affects their speech production. Thus, in testing Hypothesis 3 above, only stimuli spoken in a "monolingual setting" were used (see Chapter II for more details). Grosjean (1998, p. 136) stated that bilinguals communicate in either monolingual mode or bilingual mode, where mode is defined as the "state of activation of the bilingual's languages and language processing mechanisms". This "state of activation" is difficult to define precisely, because it seems to refer to a cognitive measure. However, if part of this state of activation involves a readiness of the articulators to move into the needed configuration for a sound in either language, then it could be that bilinguals who are perceived as native speakers of two languages have only one intermediate ISP when in bilingual mode, especially in cases where they truly do not know what language they will use next. For these bilinguals, this one "bilingual-mode ISP" would be different from the "monolingual-mode ISP" of each of their two languages for ISP components where the two monolingual-mode ISPs differ. The fourth and final hypothesis that was tested in these experiments was as follows:

Hypothesis 4: Bilingual speakers who are perceived as native speakers of each of their two languages have a unique bilingual-mode ISP that differs in all significant respects from both monolingual-mode ISPs (where "significant respects" are those respects in which differences obtain between the two monolingual modes).

1.5. Purpose of this Research and Summary of Hypotheses

In summary, one purpose of this research was to partially replicate Gick et al. (2004) using an improved methodology, thereby quantitatively determining what differences exist, if any, between the ISP (and thus, as it has been argued above, the AS) of Canadian English and that of Québécois French. A group of monolingual speakers of each language was used to provide speech rest position data. In addition, the carry-over effect of phonetic context on the ISP was examined within each speaker's speech and more generally within a given language-group's speech.

Another purpose of the research was to test whether bilingual speakers of both of the above languages have one ISP (and hence, one AS) that is shared between their two languages, or instead show the same type of crosslinguistic ISP differences that monolingual groups show. This question was answered for bilinguals of various degrees of proficiency in their two languages. In addition, a comparison was made between the bilingual subjects' monolingual mode results and their bilingual mode results.

Specifically, the following four hypotheses were tested:

Hypothesis 1: The inter-speech posture (ISP) for Canadian English is significantly different from the ISP for Québécois French.

Hypothesis 2: Within a given speaker's speech in a given language, that speaker's ISP will differ depending on the phonetic segment that precedes the ISP.

Hypothesis 3: A bilingual who is perceived as a native speaker of both languages has a different ISP for each language and will show the same types of crosslinguistic ISP differences that monolingual groups show; conversely, a bilingual who is perceived as *not* being a native speaker of at least one language will have fewer, if any, of the crosslinguistic ISP differences that monolingual groups show.

Hypothesis 4: Bilingual speakers who are perceived as native speakers of each of their two languages have a unique bilingual-mode ISP that differs in all significant respects from both monolingual-mode ISPs (where "significant respects" are those respects in which differences obtain between the two monolingual modes).

CHAPTER II Method

2.1. Subjects

All subjects who participated in this research either had responded to an advertisement for subjects or had been invited to respond through word of mouth. Both English and French advertisements for subjects were used (see Appendices I and II) and were placed at strategic locations in the city of Vancouver, including the University of British Columbia campus.

Data for Experiments 1 and 2 was initially provided by 33 speakers, although 9 of these had to be excluded for various reasons (see below in Sections 2.1.2 and 2.1.3). Details about the 15 monolingual subjects and 9 bilingual subjects whose data was actually used in Experiments 1 and 2, respectively, can be found in Appendix III.

None of the speakers who provided data for these experiments had noticeably missing teeth or an extreme overbite or underbite. This is important to note because the state of one's dentition can have an effect on one's tongue's absolute rest position. Kotsiomiti, Farmakis, and Kapari (2005) found that an abnormally retracted resting tongue position is much more likely in subjects who are partially or fully toothless. Note though that even in fully dentate subjects, they found that 12.3% had an abnormally retracted resting tongue position.

All subjects were paid for taking part in the experiments, and none of them were aware of the purpose of the experiments. In addition, almost all subjects had no previous phonetic training.

2.1.1. Criteria for Classifying Subjects as Monolingual or Bilingual

As Experiment 1 used monolingual subjects and Experiment 2 used bilingual subjects, before a detailed description of the subjects is given, it is appropriate to define what is meant by "monolingual" and "bilingual" here. The literature contains a variety of disparate definitions for bilingualism, with the line between monolingual and bilingual being drawn in many different places. A review of this research is not appropriate here, but see Baetens Beardsmore (1986) for an in-depth summary.

In this research, pronunciation ability as perceived by native listeners, along with self-classification as bilingual or monolingual, were paramount in classifying the subjects. The speech of all subjects who classified themselves as bilingual, as well as the speech of a few who classified themselves as monolingual but were proficient enough in their L2 to be able to read the stimuli fluently, was judged by native-speaking listeners for degree of foreign accent. No subjects were classified as bilingual unless both of their languages received a rating of 3.0 or higher ("adequate" / "convenablement") out of 5, as judged by 10 monolingual native listeners - see below for a description of the foreign accent rating task, and see Appendix IV for the actual rating scale used. If a subject's L2 had an average rating of less than 3.0, then that subject was considered to be a monolingual for the purposes of this research. Using the native listener judgements to determine whether someone was bilingual or not was appropriate for this research because part of the research is an investigation of how perceived pronunciation ability in a language relates to the AS that different groups use.

The foreign accent rating task mentioned above was given to 10 native listeners of each of the two languages. These 20 listeners were paid for their participation. Ten monolingual French listeners (eight of whom were the monolingual subjects from Experiment 1) judged the French speech of all the bilinguals in a task in which they had to rate the bilinguals on a scale of 1 to 5. In addition, 10 monolingual English speakers (none of whom were the monolingual subjects from Experiment 1) judged the English speech of the same bilinguals on a 5-point scale (see Appendix V for detailed results)[3]. A 5-point scale has often been used in other studies where foreign accent is rated such as Bongaerts (1999), Marinova-Todd (2003), Dromey & Wheeler (2004), and Birdsong (to appear). Included as controls in the French speech samples that were judged were samples of two monolingual French speakers, as well as samples of two less-proficient L2 French

[3] In hindsight, it may have been better in this rating task to have used a 7- or 9-point Likert scale (see Jesney, 2004) where only the endpoints were given definitions and the rest of the points on the scale lacked descriptors. This would not have made a difference to whether subjects were perceived as native speakers or not (there would still be only one "native speaker" rating available), but in one or two cases it might have influenced whether a subject was considered monolingual (less than 3.0 out of 5, in the present study) or not.

speakers. The same was true of the English speech samples. Five sentences from each speaker were played in succession, with a six-second pause between speakers. The order in which the speakers were presented was the same as that listed in the tables in Appendix V. The sentences that were played were selected from the stimuli in Appendices VI and VII, and these sentences had been uttered in the experimental setting (i.e. with markers attached to their faces and ultrasound probes under their chins). Wherever possible, the same 5-sentence sample was chosen for each speaker, but if the speaker had stumbled over the words or not had time to finish the sentence, another sentence was chosen instead. The sentences chosen for each speaker's sample are given in Appendix VIII.

As mentioned above, if a subject's L2 was given an average rating of 3.0 or less, then that subject was deemed to be monolingual for the purposes of this research. Also, if a subject was given an average rating of 4.2 or above in a language, he or she was deemed to be perceived as a native speaker of that language. A level of 4.2 was chosen because that ensured that at least two judges perceived that subject to be a native speaker of the language. A level below 4.0 was considered to be too low as it would explicitly signify, according to the definitions given in Appendix IV, that that speaker's average rating was as a "near native speaker". Note, however, that it would be possible for a speaker to have an average rating below 4.0, but still be perceived as a native speaker by some judges - something that indeed occurred with Subject 23 in English. Her background is discussed in more depth in Section 4.2.1.

2.1.2. Monolingual subjects

All monolingual subjects in this research had had at least some exposure to a second language - all had studied a foreign language in school, by choice and/or by law. However, all of the monolingual subjects considered themselves to be monolingual and had not been exposed to an L2 earlier than age 6.

Of the eight monolingual French subjects, none had had formal schooling in English before age 10. All but one (Subject 14) lived in the province of Quebec at the time of the study, unless they had just moved to Vancouver within that week for a short homestay or temporary summer employment. Subject 14 had been living in Vancouver for about one year, but had been using 60% French in her daily life as a nanny for a bilingual family. Before moving to Vancouver, she used 90% French in her daily life. All the monolingual French subjects had monolingual French parents.

Of the seven monolingual English subjects, only two of them had studied French beyond high school, Subjects 2 and 5. After completing all their English trials, these two subjects were asked to read one French trial each. They received a French rating of 2.6 and 1.9, respectively, out of 5, and thus were classified as monolinguals. All the monolingual English subjects lived in Vancouver at the time of the study and all used nothing but English in their daily lives.

The data for Experiment 1 was initially provided by 10 monolingual English speakers and 12 monolingual French speakers, although 3 of the English speakers and 4 of the French speakers had to be excluded, leaving 7 English speakers and 8 French speakers for analysis. There were a number of reasons for the omission of subjects. Of the three English subjects excluded, one was fluent in Cantonese, and thus was not monolingual, a second braced her tongue against her palate between most of the utterances, and a third subject was not cleanly shaven, resulting in a chin marker that would not stay taped on and an unclear ultrasound image. Of the four French subjects excluded, one had difficulty with the stimuli and when later questioned about it admitted that French was his second language and Arabic his first. A second French subject was excluded because she was not completely comfortable with the data collection procedure and only contributed less than half the amount of data as the other subjects. A third French subject was excluded because the ultrasound image of her tongue was not clear enough to be able to make reliable measurements. A fourth French subject was excluded because she was not comfortable with the stimuli as written and wanted to alter the form of the sentences.

The mean age of all seven English subjects was 27. The mean age of all eight French subjects was 24. Since all subjects were adults and none had reached old age, their L1 was neither developing nor deteriorating, and therefore the difference in the two groups' mean ages was not considered an issue. Of the monolingual English subjects, four were female and three were male. As for the French, six were female and two were male. Since all data was scaled based on an anatomical measurement (see Section 2.3.2), the slight gender mismatch between the two monolingual groups was not considered significant.

Subject 2 had a fairly substantial amount of Québécois-French schooling (outside of Quebec) from the age of 6, but her parents, siblings, and most of her friends are monolingual English. At the time of the study, she was attending university full time in English and living in Vancouver. At that time, 100% of any given week was completely in English for her and she had not spoken or listened to French for about 3 years. As mentioned above, because her French ability, as perceived by 10 native listeners of French, was 2.6 out of 5, she was classified as a monolingual speaker of English. Her *English* was given a rating of 5 by all 10 of the judges, the only English native speaker for which this happened. Thus, her English pronunciation was probably not influenced by her French schooling.

2.1.3. Bilingual subjects

All subjects in Experiment 2 were bilingual in Canadian English and Québécois French. Some of the subjects had knowledge of a third (or more) language, but had only used it (them) in the past to a minimal degree, or more than 10 years prior to participating in this experiment. As mentioned in Section 2.1.1, all subjects who were classified as bilingual had been rated as 3.0 or above out of 5 in each of their languages.

Data for Experiment 2 was initially provided by 11 bilingual speakers of English and French, although 2 of them had to be excluded, leaving a total of 9 subjects for analysis. Of the two subjects excluded, one was not cleanly shaven, resulting in a chin marker that would not stay taped on and an unclear ultrasound image. In addition, he had poor eyesight and had difficulty seeing the stimuli. The second subject who was excluded had a French rating of 2.6 out of 5, thus, by the criteria laid out in Section 2.1.1, she was considered to be monolingual. However, she was not included in the English monolingual group of Experiment 1 because the stimuli she read were the bilingual set of stimuli, not the full set of monolingual stimuli.

The mean age of all bilingual subjects was 30. Seven subjects were female and two were male. All of the bilingual subjects admitted that they were comfortable codeswitching (i.e. alternating between two or more languages during discourse). This was important because if a subject was not comfortable codeswitching, he or she may have found the bilingual-mode task (see Section 2.3.1) unnatural or overly difficult to do.

A summary of the native listener judgements from Appendix V is given in Table 2.1 for all the bilingual subjects.

Table 2.1. Summary of perceived language abilities of all bilingual subjects (shaded cells indicate that the rating is high enough - 4.2 or above - that the subject was considered to be perceived as a native speaker)

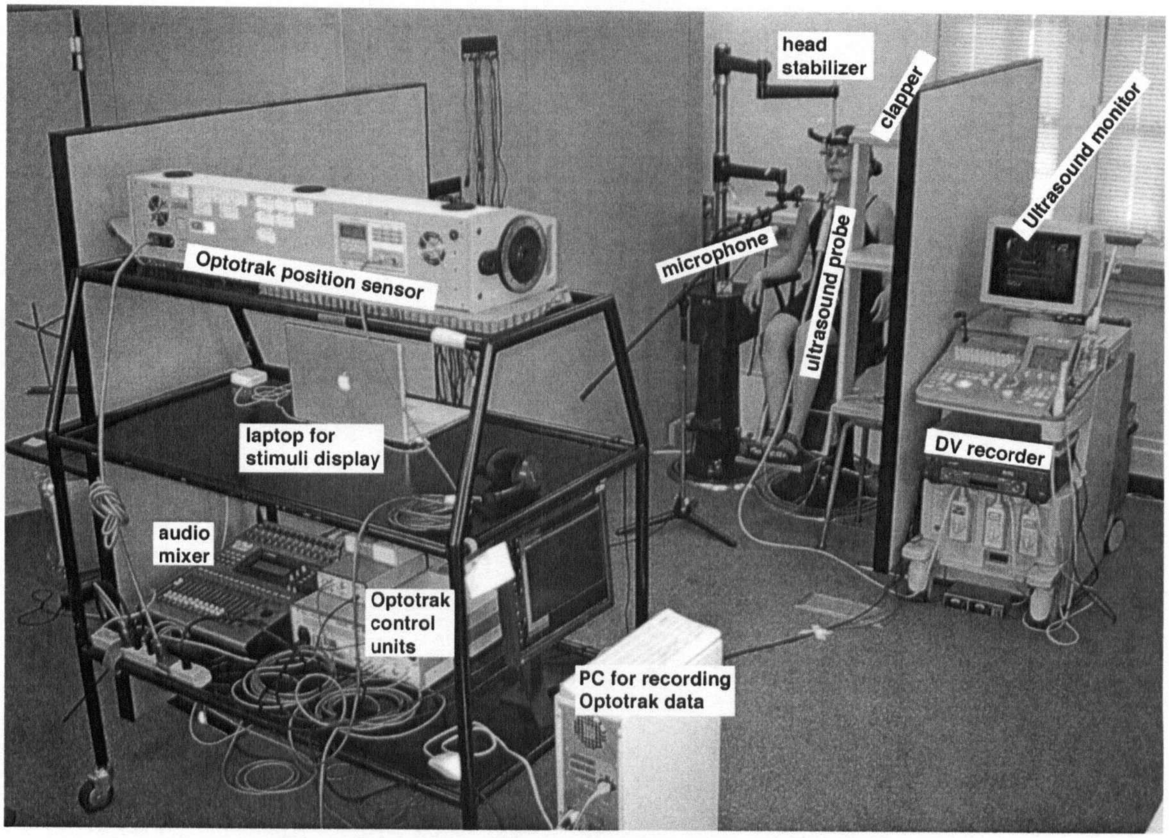
Subject number	English rating	French rating	Perceived as native speaker of...
21	4.9	4.6	Both
17	4.7	4.7	Both
22	4.3	4.9	Both
19	4.6	4.2	Both
18	3.9	4.9	French only
23	3.9	4.7	French only
20	3.8	4.4	French only
24	4.6	3.7	English only
16	3.3	3.7	Neither

In Table 2.1, note that there was at least one subject in each of the four possible groups of bilinguals: Four subjects (21, 17, 22, and 19) were perceived to be native speakers of both languages, three subjects (18, 23, and 20) native speakers of French only, one subject (24) a native speaker of English only, and a final bilingual subject (16) a native speaker of neither English nor French. To aid in interpretation of the results throughout the remainder of the dissertation, the bilingual subjects will be presented in the order shown in Table 2.1 (i.e. grouped into four groups).

2.2. Apparatus

The apparatus used to collect data in Experiments 1 and 2 can be seen in Figures 2.1, 2.2, and 2.3.

Figure 2.1. Data collection setting



The main pieces of equipment for collecting data were an ultrasound monitor for viewing the movements of the tongue in real time, and an Optotrak (Northern Digital Inc.) 3020 optical tracking system for measuring the 3D positions of the lips, jaw, and head relative to the ultrasound probe. The ultrasound monitor used was an Aloka ProSound SSD-5000 with a UST-9118 endo-vaginal 180° electronic curved array probe. The probe is specified to have a variable frequency range of 3-9.0 MHz, and according to the Medicines and Healthcare products Regulatory Agency [MHRA] (2004), the mean slice thickness width of the tissue viewed with this probe is approximately 3 mm. The Optotrak system used consists of a set of three single-axis CCD cameras, with 11-bit hardware resolution, that tracked the movements of 12 infrared-emitting diodes (markers). The Optotrak hardware was controlled using a Northern Digital software program, Collect (version 2.002), running on a PC (Micron Millennia XKU 333).

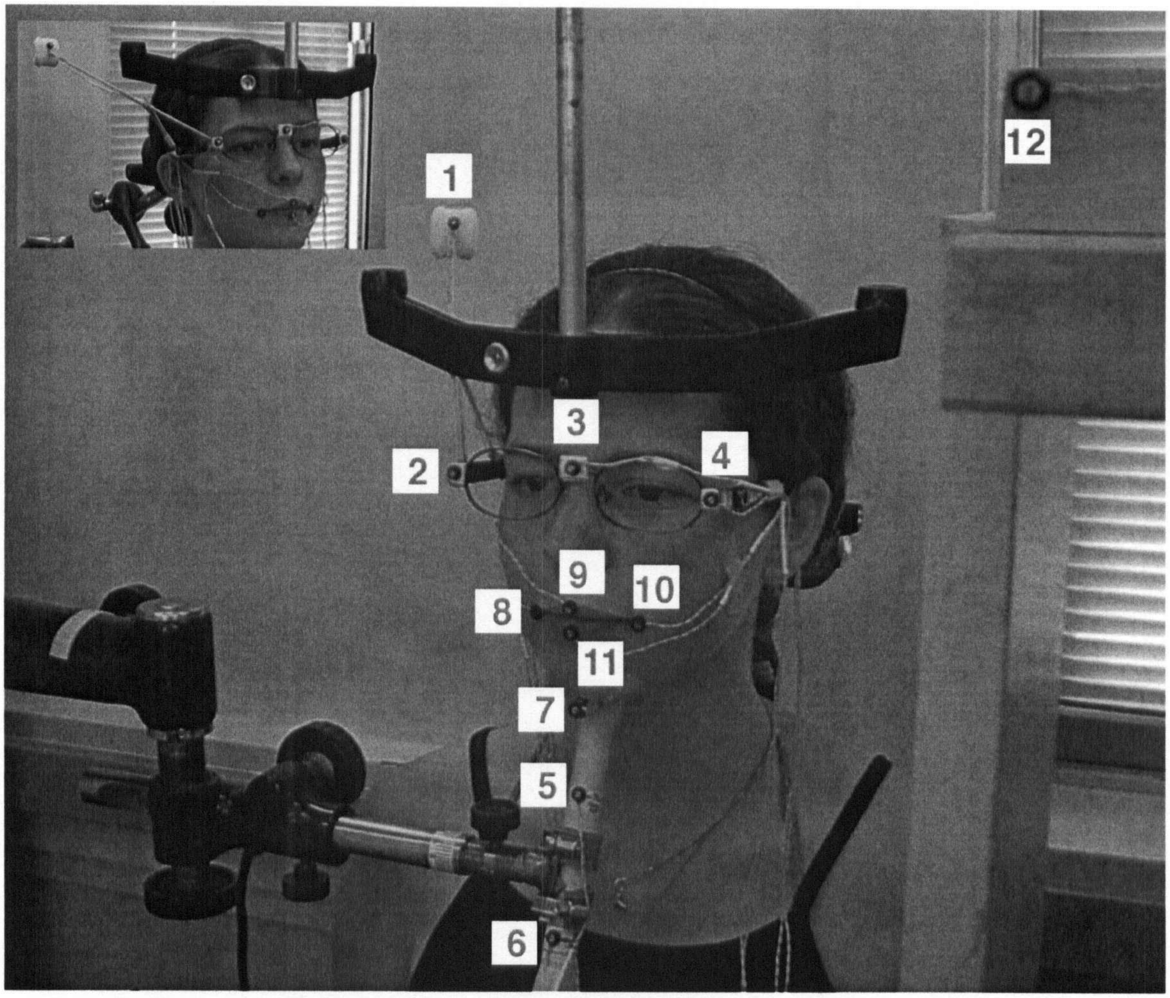
Subjects were seated in "the experiment chair", a modified antique ophthalmic examination chair (American Optical Co., model 507-A) with a 2-cup rear headrest adjusted to contact the base of the skull just above the neck, and a forehead stabilizing head restraint ("head stabilizer") with two rubber pads which were positioned to be lightly touching the subject's forehead near the hairline.

The ultrasound images seen on the ultrasound monitor were recorded onto digital video tape using a JVC SR-VS20 Mini DV/S-VHS VCR. Simultaneous audio for these ultrasound recordings was recorded using a Sennheiser MKH 416 P48 super-cardioid short shotgun condenser interference tube microphone. The microphone signal was fed into the VCR via a digital mixing console (Yamaha 01V).

Stimuli were displayed to the subjects on an Apple PowerBook G4 17-inch laptop computer at a distance of about 2.5 metres, and at approximately eye level. The stimuli were presented as Microsoft PowerPoint (version 10.1.0) slides with the English stimuli displayed in Times 88 point font and the French stimuli displayed in Times New Roman 72 point font.

Figure 2.2. Subject's view of the stimuli from the experiment chair

Figure 2.3. Placement of ultrasound probe, head restraint, and Optotrak markers (numbered)



2.3. Procedure

The data collection procedure used in this research was the same in Experiments 1 and 2, except for which six blocks of stimuli were used and the order in which these blocks were presented. This difference in choice and order of stimuli blocks was simply due to the fact that the monolingual subjects of Experiment 1 were presented with stimuli in only one language, whereas the bilingual subjects of Experiment 2 were presented with stimuli in two languages. More details on stimuli presentation can be found in Section 2.3.1.4.

2.3.1. Data Collection

When a subject arrived for a data collection session, the procedure was as follows. First the subject was shown the equipment to be used, was told the procedure to be followed, and was given the opportunity to ask any questions. Then after signing ethics forms, the subject was seated in the experiment chair and the headrest, the head stabilizer, and the ultrasound probe were adjusted to the proper height. The subject was then moved to a more comfortable chair where the Optotrak markers were attached to his/her lips and jaw.

2.3.1.1. Optotrak Setup

The position of the 12 Optotrak markers can be seen in Figure 2.3. Markers 1 through 4 were all permanently attached to a pair of lensless glasses that were worn by each subject and it was assumed that these markers did not move relative to each other. Marker 3 was on the midsagittal plane and markers 2 and 4 were equidistant from it. Marker 3 was slightly higher and more protruded from the subject's face than markers 2 and 4. Marker 1 was situated on a rigid bamboo skewer that was mounted off the right arm of the glasses. Bamboo was used because it is strong enough to remain rigid but light enough not to put the glasses off balance. For all subjects, marker 1 was located to the right of, posterior to, and superior to the subject's right ear (see inset of Figure 2.3). Note that during the course of a trial, if it is assumed that the glasses do not move relative to the subject's head, then markers 1 through 4 defined a rigid body that included the subject's skull. This was important for being able to track the movement of the subject's skull (and thus the palate as well) during a trial.

Markers 5 and 6 were attached to the ultrasound probe, 70 mm and 140 mm, respectively, from the tip of the probe (i.e. the end of the probe that made contact with the subject's skin). Marker 7 was mounted on a 1 cm cube of open cell foam that was taped under the chin using 3M Micropore surgical tape. Markers 8 and 10 were placed at the right and left corners, respectively, of the subject's mouth, as close as possible to the mouth opening without making it uncomfortable when closing the mouth. Marker 9 was placed as close as possible to the vermilion border of the upper lip on the midsagittal plane. Marker 11 was also placed on the midsagittal plane, but on the lower lip. Depending on how "pouty" the subject's lower lip was, it was sometimes necessary to place Marker 11 above the vermilion border in order for its light to be seen consistently by the Optotrak position sensor. Marker 12 was left in place on a wooden, hinged clapper between experiments. The clapper provided a sound that was used to synchronize the Optotrak data with the ultrasound data (see Section 2.3.1.4).

All affixation of markers was done using double-sided clear tape that pulled off the skin easily, but usually not so easily as to come off during the course of an experiment. If a marker did come off during a trial, it was reattached before the following trial. However, it was serendipitously the case that data from all subjects for whom a marker did come off, were later excluded for other reasons (see Sections 2.1.2 and 2.1.3). The wires coming from the Optotrak markers were kept out of the way by taping them to the subjects' cheeks with surgical tape. Once all the Optotrak markers were in place on the subject, the subject was seated in the experiment chair and the Optotrak system parameters were set as follows: Marker frequency = 2600 Hz; Duty cycle = 25%; Strober voltage = 7V; and Dynamic duty cycle = On. All Optotrak data was collected at 90 Hz.

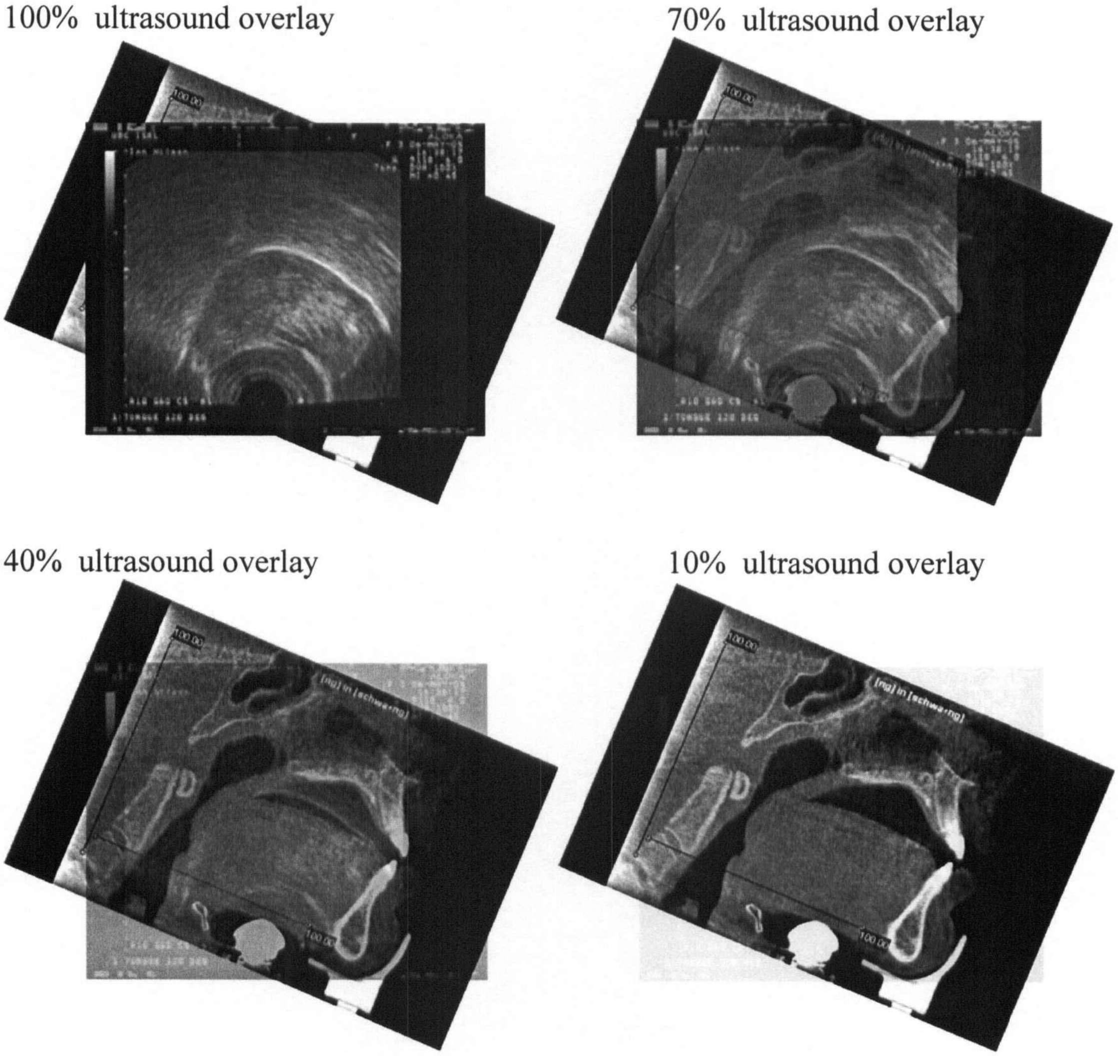
2.3.1.2. Ultrasound Setup

Throughout all preliminary and main trials involving ultrasound data collection, the forehead stabilizer and ultrasound probe were locked into position. Water-soluble ultrasound gel was applied to the head of the ultrasound transducer which was then placed against the subject's neck in the submental region. The probe was positioned so that a midsagittal image was being displayed with the tongue tip towards the right side of the screen. The probe angle was adjusted so that the image on the ultrasound monitor showed as wide a tongue region as possible, from the shadow of the hyoid bone on the left to the mandible shadow on the right. The exact angle of the probe was different for every subject, dependent on anatomy and posture. The average angle was 20° for the English subjects (with a range of 9° to 24°), 19° for the French subjects (with a range of 15° to

25°), and 18° for the bilingual subjects (with a range of 12° to 24°). As the probe was always placed so as to maximize the view of the tongue from the tongue root to the tongue tip while centring the tongue on the ultrasound monitor, the relatively similar average angle across groups indicates that vocal tract length was fairly consistent across the three groups. The probe angle was calculated from the absolute positions of Optotrak markers 5 and 6 on the ultrasound probe, and it is the number of degrees off of vertical that the tip was pointed away from the Optotrak cameras.

To give the reader an idea of a typical ultrasound probe angle relative to the skull, Figure 2.4 shows a CT scan of the author's upper vocal tract with an ultrasound scan overlay of the author's tongue. Note that in Figure 2.4, the CT scan is angled at 23° relative to the ultrasound picture, an angle that is within the range of angles found in all three groups of subjects. Both the ultrasound image and the CT image were created during production of the sound [ŋ] in [əŋ]. Since in the experiments the probe was at an angle off true vertical, each tongue image shown with ultrasound displays the tongue rotated clockwise. In Figure 2.4, where the tongue shapes are not identical, it is because the ultrasound image here was taken a number of days after the CT scan was made. The ultrasound probe that appears in the CT image was not the one used to make the ultrasound image on the right. Also, the probe in the CT image is not at an ideal angle relative to the tongue - it is simply serving as a landmark. It is interesting to note that the hyoid bone itself (not just its shadow) is clearly visible in the 100% ultrasound image, although this was certainly not always the case in the experiments. It is also clear in the 100% ultrasound image where the velum meets the tongue - the tongue line suddenly loses a lot of its brightness. But perhaps most interesting is that the tongue line that is seen in the 100% ultrasound image *is* actually the tongue line, all the way from the lower teeth to the hyoid shadow, even though the velum and epiglottis are pressed against the tongue (i.e., what is seen in the ultrasound is the tongue's surface, not the superior surface of the velum or the posterior surface of the epiglottis). This implies that the density of the tongue is different enough from the density of the epiglottis and the velum that the sound reflects at this border, confirming the reliability of the tongue surface images.

Figure 2.4. CT scan of upper vocal tract with ultrasound tongue image overlaid at various opacities

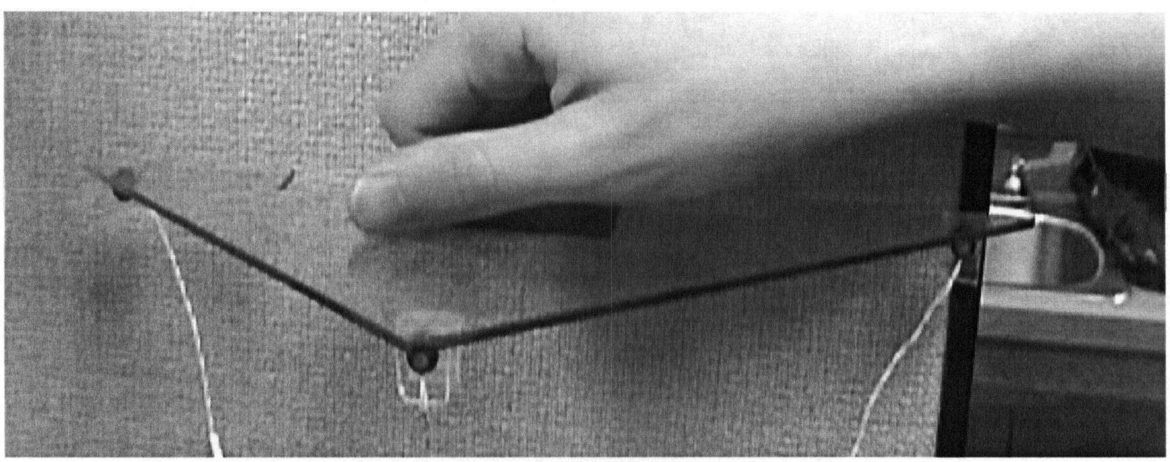


Both B-mode ("brightness modulation" mode) and M-mode ("motion" mode) ultrasound images were collected. B-mode shows a 2D section of the tongue, while M-mode shows a continuous time series of a line of B-mode dots. Only the B-mode images were used as data in this dissertation. The "range" setting on the ultrasound, the total real distance represented in the window on the screen, was set at 10 cm for both the B-mode and M-mode displays. Although not relevant in this study, the M-mode sweep speed was set for 1.5 seconds per period.

2.3.1.3. Preliminary Trials

Three preliminary measurement trials were done prior to any of the main trials where the subject was asked to read sentences. The first preliminary trial was a 40-second "wag" trial, the purpose of which was to set baselines for movements of the head, lips, and jaw. The second preliminary trial was a 15-second "bite" trial using the 12 Optotrak markers described above in addition to 3 more markers that were placed on a triangular piece of Plexiglas (see Figure 2.5). The bite trial was a way of displaying, in the ultrasound image, an anatomical landmark whose position was known in an external frame of reference. The third and final preliminary trial was a 25-second "palate" trial that ensured that palate information was available for all subjects. Only the first of these three preliminary trials (i.e. the wag trial) was used in the data analysis for this study, but all three trials are described in more detail below.

Figure 2.5. Plexiglas "bite triangle" used in the second preliminary trial



In Preliminary Trial 1, the subject was asked to turn his/her head to the extreme right, left, up and down bringing the head back to a centre position and pausing between each direction. The subject cycled through this order twice. Although these head turns could be used by the Optotrak system to calculate the centre of rotation of the head, they were not used in this study. After the head-turning task, the subject was asked to spread the corners of the lips as widely as possible, as if saying an exaggerated [i]. This was followed by the subject protruding the lips as far as possible, as if saying an exaggerated [u]. The subject was specifically asked to spread markers 8 and 10 as far to the sides as possible, and to protrude markers 9 and 11 out as far as possible. This was done twice each. This spreading and protruding of the lips enabled a baseline to be set for the extremes of lip movement of each subject. For the final few seconds of the wag trial, the subject was asked to relax, look straight ahead at the computer screen and keep the jaw and lips closed. The jaw here was not in a clenched position, but instead set a baseline for a maximally elevated rest position of the jaw. Unfortunately, for bilingual Subject 17, no wag trial was done, so the distance from the centre of the glasses to a maximally elevated jaw could not be calculated. Also, for bilingual Subject 23, although a wag trial was done, due to an oversight she was not wearing the head-tracking glasses during that trial. Thus, for these two subjects, jaw elevation data could not be properly analyzed.

Next, in Preliminary Trial 2, the subject was asked to bite down on the Plexiglas triangle seen in Figure 2.5. The subject bit the triangle with the incisors (not the molars) and held it motionless for about 10 seconds while forcing the blade of the tongue against the edge of the Plexiglas. The angle that was created as the tongue was bent around the Plexiglas was usually clearly visible in the ultrasound image, thus providing an anatomical landmark whose position was known in an external frame of reference. Although this data was not used for analysis in these experiments (because it was not collected for any of the monolingual English subjects), it also provided a way of determining both the distance from the central incisors to a point on the tongue, as well as the approximate occlusal plane of a given subject.

Finally, in Preliminary Trial 3, the subject was asked to take a small amount of water into his/her mouth through a straw. While holding the water in his/her mouth, the subject then ran the tongue tip back and forth along the midsagittal line of the hard palate. The subject then swallowed the water and was usually asked to press the whole tongue against the hard palate for about 2-3 seconds. The palate trial ensured that a relatively good image of each subject's palate was available. Although this preliminary trial was done with all subjects, it was only with the final few subjects that Optotrak data was collected simultaneously with this trial. Thus, this trial was not used in the data analysis, but the data that do exist show very clear swallowing images and may be useful in future work. The palate trial did not have to be used in this study because each subject swallowed at least once during each trial between sentences, and the alveolar ridge was visible at this time. See Epstein & Stone (2005) for issues related to imaging the palate with ultrasound.

2.3.1.4. Main Trials

After the three preliminary trials, the experiments then moved on to main trials involving the subjects reading a number of sentences aloud. Due to the fact that the English stimuli contained some nonsense or low frequency words for use in a different study (Campbell, 2004), all monolingual English subjects and all bilingual subjects were given a 15-sentence English practice trial. The practice trial was not deemed necessary for the monolingual French subjects because the French stimuli all contained standard vocabulary familiar to any French speaker. The French stimuli were chosen for a future study that needs many tense-lax minimal pairs in a carrier sentence. For a list of the English and French stimuli used, see Appendices VI and VII, respectively.

While each monolingual subject in Experiment 1 read six blocks of monolingual data, each bilingual subject in Experiment 2 read two monolingual English blocks (Blocks 1 and 2 in Appendix VI), two monolingual French blocks (Blocks 1 and 2 in Appendix VII), and two blocks that each contained a mix of 15 English and 15 French sentences that were in a pseudo-randomized order (see Appendix IX). The order of presentation of the blocks was the same for all bilingual subjects: English Block 1, French Block 1, Mixed Block 1, English Block 2, French Block 2, Mixed Block 2. Before each block the subject was told what kind of block was to appear. Thus it was assumed that during the presentation of a monolingual block, the bilingual subject was in "monolingual mode" (Grosjean, 1998), prepared to read in only one language. However, during the presentation of a bilingual block, the bilingual subject was not aware of which language would be presented next. Thus, they were in "bilingual mode", ready to read in either language with both languages fully activated at once (Grosjean, 1998). Regarding language mode, it should be noted that all of the bilingual subjects and many of the monolingual French subjects understood enough English to allow the experimenters to communicate in a mix of broken French and basic English. Thus, even though the French monolingual blocks contained only French, communication before and after the blocks was done mostly in English. This may have compromised the monolingual nature of the monolingual French mode. In future research, if a fluent French-speaking assistant were available to communicate with the subjects, it would help to create a monolingual French environment for French data collection.

The duration of Optotrak data collection was 67 seconds for the practice trial, and 131 seconds for each real trial. Each of the real trials consisted of 30 sentences that were displayed one at a time to the subject. As mentioned in Section 2.2, stimuli were displayed as PowerPoint slides in a large font size. The PowerPoint "slide transition" for each 30-sentence trial was set so that each sentence slide was displayed for 3 seconds followed by a blank slide for 1 second. The final blank slide after the 30th sentence was accompanied by a distinct sound (a loon call), indicating to all that the trial was complete. As each sentence was displayed, the computer beeped, thus making a record on the ultrasound DV tape of when the subject saw what he or she was supposed to say next. It was assumed that before the beep, any preparatory vocal tract posture (see Schmidt and Lee (1999, pp. 126-127) for a description of "preparatory postural reactions") would be for the language or speech in general and not the task of articulating the first phoneme/syllable. Since the subject was not presented with a list of stimuli, there was no list effect to take into account. Also, since the first word of each sentence was sufficiently varied, there was no way that the subject could predict what articulation would be necessary next. This most probably eliminated any anticipatory coarticulation effects on the ISP.

The clapper was used twice per trial - once at the beginning before the start of the stimuli presentation, and again at the end about 1-2 seconds after the subject had finished saying the final sentence. After the clapper was raised and released, the first minimum vertical position of marker 12 in the Optotrak data ("first", because in some cases there was a bounce) was taken to be synchronous with the start of the banging sound, on the

DV tape, of the clapper reaching a closed position. This allowed for synchronization of the Optotrak and ultrasound signals.

At the beginning of each trial, the Optotrak data collection program, Collect (version 2.002), was initiated, then the clapper was dropped, and finally the PowerPoint slide show was started. While the subject was reading the stimuli, two experimenters (the author and an assistant) monitored a real-time display of the Optotrak data for missing markers and checked the real-time ultrasound display for any problems with the ultrasound data (e.g. screen going into sleep mode, or a fuzzy tongue line because the subject was gradually sliding sideways on the probe).

The order of the trials was not randomized, but kept the same across subjects. For all monolingual subjects, the trials were collected in order from one to six. In a few cases where image quality was thought to be inferior, trial 1 was re-collected after trial 6 and this second version of trial 1 was used in the data analysis. In addition, the sentences within each trial were presented in the same order to every subject, but this order had been pseudo-randomized to ensure a balance of phonetic contexts throughout and across the trials. Since between-trial comparisons are not being made (all data from all trials are averaged together), the fact that the order of the trials is not randomized presumably affects every subject the same way.

2.3.2. Data Analysis

Since the data consisted of two types, Optotrak numeric data and ultrasound video data, the most efficient way to concurrently analyze both types of data was through a series of MATLAB programs written by the author for this purpose. Before the data could be processed by the MATLAB programs, though, it had to be pre-processed and narrowed down.

As a first step, the DV tape of the ultrasound data was transferred to a manipulable file format (Adobe Premiere 6.0 movie files) by means of a Sony DCR-TRV900 digital video camera connected via a FireWire cable to an Apple PowerBook G4 laptop computer. The Premiere video capture settings were as follows: Compressor - DV-NTSC; Frame size: 720 x 480; Pixel aspect ratio: D1/DV NTSC (0.9); Frame rate: 29.97; Depth:

Millions, Quality: 100%. The Premiere audio capture settings were as follows: Rate: 32,000 Hz; Format: 16 bit stereo; Uncompressed; Interleave: 1 frame. In retrospect, using a pixel aspect ratio of 0.9 was not a good setting and it necessitated having an extra step resampling the data to a frame size of 656 x 480 with a pixel aspect ratio setting of "square pixels (1.0)" (See Aho (2004) for formulas showing why a frame size of 656 x 480 was chosen.) This resampling was necessary in order to ensure that measurements made later were on the same scale in all directions.

The ultrasound movie files were then cropped so that the first frame in each file was the frame immediately after the clapper was first heard. Cropping the movie in this way made it easier later to determine which Optotrak frames corresponded to the ultrasound frames of interest (see below). Possible periods of rest to be used for analysis were found by playing back the ultrasound movie files and searching after every sentence for a period of at least 10 frames (i.e. 333 ms) of no tongue motion in the B-mode tongue shape and the M-mode lines. The reason for choosing a 10-frame period, as opposed to a longer or shorter period, was that a 10-frame period was the longest possible rest period such that the tongue was considered to be at rest in an average of about 50% of the inter-sentential pauses across all 24 subjects. If such a period of 10 frames of no tongue motion existed, then the centre frame of that period was chosen as a "possible rest frame" for analysis.[4] For each subject, a list of all possible rest frames was constructed for all trials that the subject completed. For each monolingual and bilingual subject, Tables 2.2 and 2.3, respectively, show the total number of times after a sentence (out of 180 possible sentences, unless otherwise stated) when that subject's tongue was at a complete stop for at least 10 frames of the ultrasound movie file.

[4] "possible" because if it was not in one of the desired phonetic contexts, it was not used.

Table 2.2. Total rest frames available and number actually used (monolingual subjects)

	Subject	Total number of times tongue at rest (out of 180)	Total number of rest times in a required phonetic context (i.e. total used in this study)
Monolingual English	1	116	61
	2	94	51
	3	131	74
	4	101	63
	5	76	46
	6	71	51
	7	103	59
Monolingual French	8	n/a	45
	9	n/a	68
	10	65	22
	11	47	22
	12	n/a	37
	13	122	58
	14	n/a	56
	15	n/a	57

Table 2.3. Total rest frames available and number actually used (bilingual subjects)

Perceived as native speaker of ...	Subject	Total number of times tongue at rest (out of 180, unless otherwise stated)	Total number of rest times in a required phonetic context (i.e. total used in this study)			
			Monolingual mode		Bilingual mode	
			English	French	English	French
Both	21	96	19	18	6	9
	17	41 (out of 90)	0[5]	6	13	5
	22	111	21	19	7	10
	19	154 (out of 210)	25	20	21	16
Fre only	18	62	8	8	5	8
	23	64 (out of 120)	12	9	7	5
	20	121	23	19	14	8
Eng only	24	99	21	9	13	7
Neither	16	n/a	13	15	12	12

For example, in Table 2.2, it can be seen that Subject 1 brought her tongue to a complete stop after 116 of the 180 sentences - thus, a total 116 possible rest frames. The rightmost column shows the actual number of rest frames analyzed in Experiment 1 once frames outside the necessary phonetic contexts were eliminated. Thus, out of the 116 frames available for Subject 1, 61 of these were in a desirable phonetic context - one that could be reasonably balanced across English and French (see below). Due to time constraints during data analysis, the total number of times the tongue was at rest was not investigated for 5 of the monolinguals and 1 of the bilinguals (appears as "n/a" in the table). The average number of frames used per monolingual English, monolingual French, and bilingual speaker was 58, 46, and 49, respectively. The total number of rest positions analyzed was 405 from monolingual English speakers, 365 from monolingual French speakers, and 443 from bilingual speakers, for a grand total of 1,213.

In at least some of the cases, the speed of the subject's speech had a direct effect on the number of possible rest frames that could be used for analysis. For example, Subject 6 spoke noticeably slower than the other English subjects and also had the fewest

[5] Due to accidental tape erasure, monolingual-mode English data is not available for Participant 17.

available rest frames to choose from. Subject 10 braced her tongue against her palate between at least 53 pairs of sentences and those tokens were not included in the analysis. Subject 11 often did not finish reading the complete sentence before it disappeared from the screen, so he ended up speaking during the time his tongue was expected to be at rest.

Because there were only two blocks of bilingual-mode data and four blocks of monolingual-mode data and these were divided between two languages, there were not as many analyzable tokens *in each language* for the bilingual speakers as there were for the monolingual speakers.

As mentioned above, only frames that were in certain phonetic contexts were used for data analysis. In order to test whether ISP is language specific, one first has to ensure that the phonetic contexts in which the ISPs appear across languages are balanced. To phrase this differently, if the phonetic context surrounding the ISP has an effect on the ISP itself, then in order to investigate whether there were other language-specific properties of the ISP, it would be necessary to control very tightly for context. In this study, since the sound following the ISP is not known to the subject until the next stimulus flashes on the screen, there could be no anticipatory effects, only carry-over effects.

In this research, phonetic context was balanced by considering the IPA representation of the standard Canadian-English and Québécois-French pronunciation of the final syllable of each sentence-final word, making the untested and probably naive assumption that, for example, an /i/ in English is articulated the same way as an /i/ in French, and then approximately balancing the number of tokens of /i/ across the two languages. For balancing the contexts, in order to have enough tokens to do a reliable statistical analysis, it was necessary to assume that a French nasalized vowel was equivalent (in terms of the articulatory configuration of the tongue, lips, and jaw) to its non-nasalized English counterpart. Admittedly, this is also probably a naive assumption as the velum is connected to the tongue body by means of the palatoglossus muscle.

Since English contains sounds that are not found in French (and vice versa), out of the 180 sentences (6 blocks of 30) that each subject said, there were only a certain number that had final words whose final sound could be reasonably matched across English and French. In the six English monolingual blocks, there were 103 sentences out of 180 that qualified as having appropriate final sounds to keep the phonetic context balanced across languages. In the six French monolingual blocks, there were 84 words out of 180 that had appropriate final sounds. Table 2.4 shows the final words from all of the English and French sentences for which the following rest position *was eligible* to be chosen (i.e., only if the tongue came to a complete stop for 10 frames during this time) for analysis in this study.

Table 2.4. Total possible available ISPs for each pre-ISP word

Broad context #	Narrow context #	English word	Narrow total	Broad total	French word	Narrow total	Broad total
1	1	Thai July	10	**26**	ail	3	**24**
	2	day holiday	11		plaie musée vallée	9	
	3	January	5		outils nuit radiographie	12	
2	4	Sue through	11	**22**	perdus trou	9	**24**
	5	show scenario	11		auto chaudron maison	15	
3	6	regatta	5	**5**	monsieur	3	**3**
4	7	again weekend	18	**29**	assiette recettes	6	**15**
	8	class	5		face	3	
	9	lunch	6		roche sacoche	6	
5	10	spring	7	**12**	camping	3	**9**
	11	week	5		clinique grecques	6	
6	12	job	9	**9**	champ étang	9	**9**

The words are grouped according to narrow, as well as broad phonetic context, but for analysis in Experiment 1, only the effects of broad phonetic context were examined. This was because there were not enough tokens of each narrow phonetic context to give sufficient statistical power. The broad phonetic contexts were as follows: 1, 2, and 3 were vowel-final contexts, 4 was a coronal-final context, 5 was a dorsal-final context, and 6 was [low vowel + labial] in English and [nasalized low vowel] in French. More specifically, the sounds included in each broad context are listed in Table 2.5, and each broad context is given a name that will be used in Section 3.1.3.

Table 2.5. Definitions of the broad phonetic contexts used in the analysis

Broad context name	Broad context #	Narrow context #	Included words with these final sounds
FrontV	1	1	[ɑɪ]
		2	[e(ɪ)]
		3	[i]
BackV	2	4	[u]
		5	[o(ʊ)], [õ]
Schwa	3	6	[ə]
CoronalC	4	7	[ɛn], [ɛnd], [ɛt]
		8	[æs], [as]
		9	[ʌntʃ], [ɔʃ]
DorsalC	5	10	[ɪŋ]
		11	[ik], [ɪk], [ɛk]
LowV	6	12	[ɑb], [ɑ̃]

All data were checked to make sure that what was actually said during the data collection matched the presented stimuli word for word. Any cases where the final word spoken was not the final word in the sentence presented to the subject were discarded. Finally, the rest frames were extracted from the video files and saved as .tiff image files.

In order to determine correctly which Optotrak frame corresponded to a given ultrasound frame, it was necessary to search through the Optotrak data for marker 12 (the clapper marker) and find the lowest vertical position for the marker (lowest x-coordinate in the Optotrak coordinate system) after the clapper was dropped. In some cases the clapper bounced, resulting in marker 12's vertical position increasing slightly before dropping slightly again. In this case, the first minimum was taken (abbreviated "clprmin", a MATLAB variable). This frame where the marker first reached its minimum value was taken to correspond to the ultrasound video frame where the clapper noise was first heard. Because the Optotrak data was collected at 90 Hz, whereas the ultrasound data was at 29.97 Hz, a formula was used in the main MATLAB program to calculate the Optotrak frames of interest based on the ultrasound frames of interest. The ultrasound frames of interest were simply multiplied by 90, divided by 29.97, and then the result was added to "clprmin" to get the Optotrak frames of interest.

In each trial, the frame where the alveolar ridge was the most clearly visible was chosen and saved as a .tiff image file. These alveolar ridge files were later used in a MATLAB program to define the (constant) location of the alveolar ridge with respect to the four glasses markers in each trial (i.e. the coordinates of the alveolar ridge in head space). This calculation of the position of the alveolar ridge in head space was accomplished by first using ultrasound data to calculate the location of the alveolar ridge relative to the probe in ultrasound image space, then using Optotrak data to calculate the location of the ultrasound probe with respect to the head. Knowing the alveolar ridge relative to the probe, and the probe relative to the head, gave us the position of the alveolar ridge relative to the head. Then knowing from the Optotrak data how the head moved about the probe during the course of a trial, we then knew how the alveolar ridge moved about the probe and we determined the coordinates of the alveolar ridge in all ultrasound frames of interest. See Appendix X for the formulas used in these geometrical calculations.

Although one can analyze ultrasound data without correcting for head movement, especially if one tries to limit head movement during data collection (see Gick, Bird, and Wilson, 2005, for why and to what extent this is valid), correction for head movement is desirable for at least two reasons: When the head rotates about the probe, the tongue line in the ultrasound image also rotates and consequently one cannot be sure of where on the tongue one is measuring. Also, while the skull including the hard palate is moving, the mandible and tongue could remain motionless with respect to the probe, thus giving no indication on the ultrasound monitor of any actual change in shape of the vocal tract airspace.

As mentioned above, a series of MATLAB programs ("m-files") were used for data organization and analysis. Certain functions contained in the MATLAB Image Processing Toolbox were also used by the m-files. Optotrak data in its original floating point file format was converted into MATLAB 3D matrixes by a program supplied by Mark Tiede (Haskins Laboratories / MIT). These 3D matrixes were used by the main m-file, which was written by the present author. This main m-file, in which measurements were made and calculations were performed, had as its input the rest position .tiff images, the alveolar ridge .tiff images, and a database of Optotrak numerical values from three other m-files.

The articulator measurements that were relevant for this experiment and on which statistical analyses were performed are shown in Table 2.6. In this dissertation, these 12 measurement locations are hereafter referred to as the "components of ISP".

Table 2.6. Definitions of the components of ISP used in statistical analyses

TTht	distance from the probe centre (a point exactly 1 cm below the surface of the probe on the midsagittal line and marked on the ultrasound) to the tongue tip
TBht	distance from the probe centre to the tongue body
TDht	distance from the probe centre to the tongue dorsum
TRrt	distance from the probe centre to the tongue root
JAWl	amount of jaw lowering from a maximally closed position
ULlo	upper lip height relative to the glasses
LLlo	lower lip height relative to the glasses
ULpr	upper lip protrusion - distance from the midsagittal upper lip marker to an imaginary plane constructed through the alveolar ridge and two end points of the glasses
LLpr	lower lip protrusion - same as upper lip, but using the lower lip marker
Lvap	vertical lip aperture
Lhap	horizontal lip aperture
Lnar	amount that horizontal lip aperture is narrowed from its maximally spread position

Coronal tongue shape was not measured, but it is admittedly an important factor to consider. It can be viewed with ultrasound, but with 2D ultrasound, it is not possible to see both midsagittal and coronal views of the tongue simultaneously. All items generated in the .csv file output of the main m-file can be seen in the left column of Table 2.7. All 30 of these items were generated for each of the 770 rest frames analyzed for the monolingual speakers in Experiment 1 and each of the 443 rest frames analyzed for the bilingual speakers in Experiment 2.

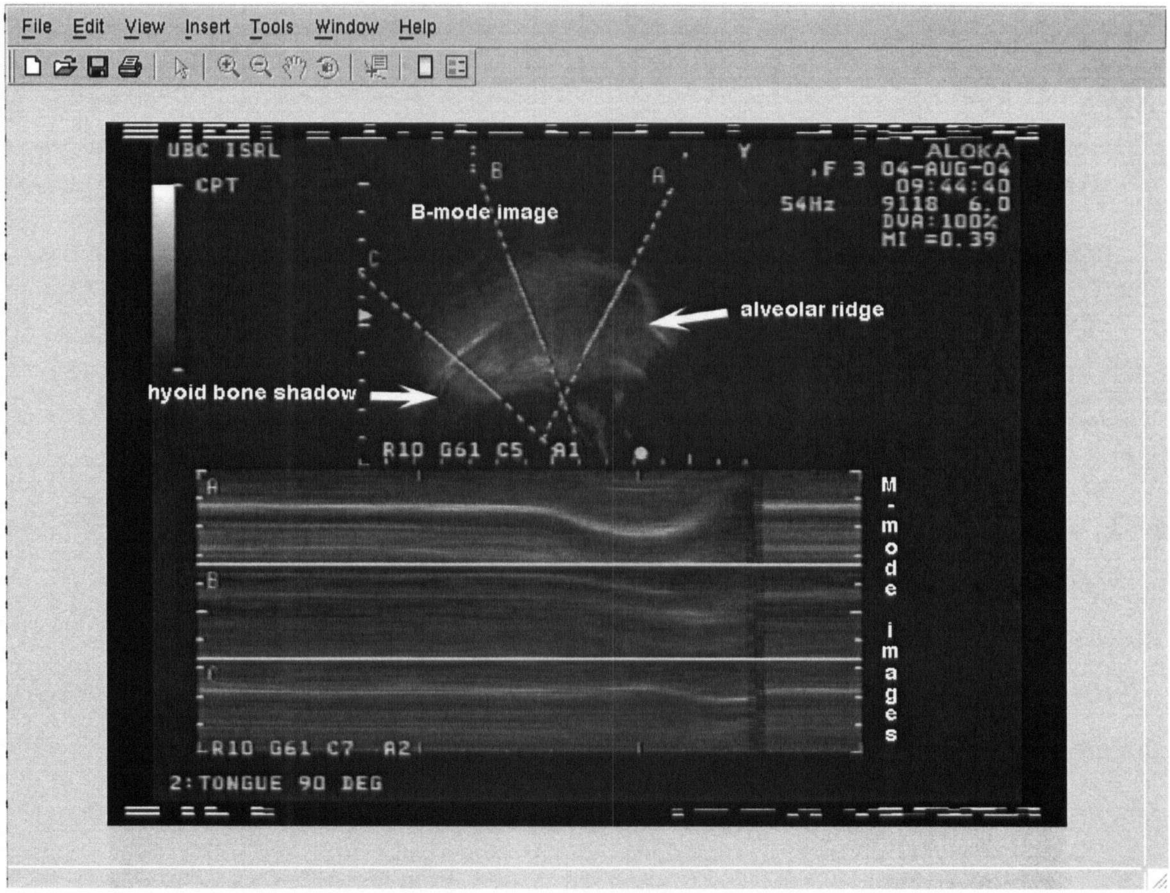
Table 2.7. Contents of numeric output file of main MATLAB m-file used

	Data output	**Notes**
1	Subject #	1-24
2	Language of previous sentence	1=English; 2=French
3	Mode (monolingual or bilingual)	1=Monolingual; 2=Bilingual
4	Trial #	1-6
5	Previous sentence #	1-30
6	Narrow phonetic context #	1-12
7	Broad phonetic context #	1-6
8	Ultrasound rest frame #	1-4000 (approx)
9	Optotrak rest frame #	1-12000 (approx)
10	Angle of ultrasound probe in degrees	See Tables 2.2 and 2.3
11	Distance in mm from probe centre to TT	Click on TT & program measures dist
12	Distance in mm from probe centre to TB	Click on TB & program measures dist
13	Distance in mm from probe centre to TD	Click on TD & program measures dist
14	Distance in mm from probe centre to TR	Click on TR & program measures dist
15	Distance in mm from probe to alveolar ridge	
16	Distance in mm from TT to alveolar ridge	
17	Distance in mm from bridge of nose to chin	Euclidean dist from marker 3 to marker 7
18	Absolute min. in mm from nose to chin	
19	Distance in mm from nose to alveolar ridge	Used as the factor in normalization of data
20	Distance in mm from chin to alveolar ridge	

21	Distance in mm from nose to upper lip	Euclidean dist from marker 3 to marker 9
22	Distance in mm from nose to lower lip	Euclidean dist from marker 3 to marker 11
23	Angle in degrees between tongue lines	one-third of angle between hyoid shadow & alveolar ridge
24	Maximum lip spread during WAG trial	Euclidean dist from marker 8 to marker 10
25	Horizontal lip aperture	Euclidean dist from marker 8 to marker 10
26	Difference between max lip spread & horizontal aperture	
27	Vertical lip aperture	Euclidean dist from marker 9 to marker 11
28	Upper lip protrusion	Perpendicular dist from marker 9 to plane defined by markers 2, 4, and the alveolar ridge
29	Lower lip protrusion	Perpendicular dist from marker 11 to plane defined by markers 2, 4, and the alveolar ridge
30	Ultrasound image space coordinates of 5 points	Pt1=alveolar ridge; Pts2-5 are the 4 points on the tongue that were clicked on by user (TT, TB, TD, TR in that order)

The procedure that the MATLAB m-files followed was first to prompt the user for the subject's 3-letter code name and a Trial number to analyze. After retrieving relevant data for the specified trial of that specified subject, the program then displayed the stored .tiff image of the frame where the alveolar ridge was visible (e.g., see Figure 2.6). The program prompted the user to click on the location of the alveolar ridge.

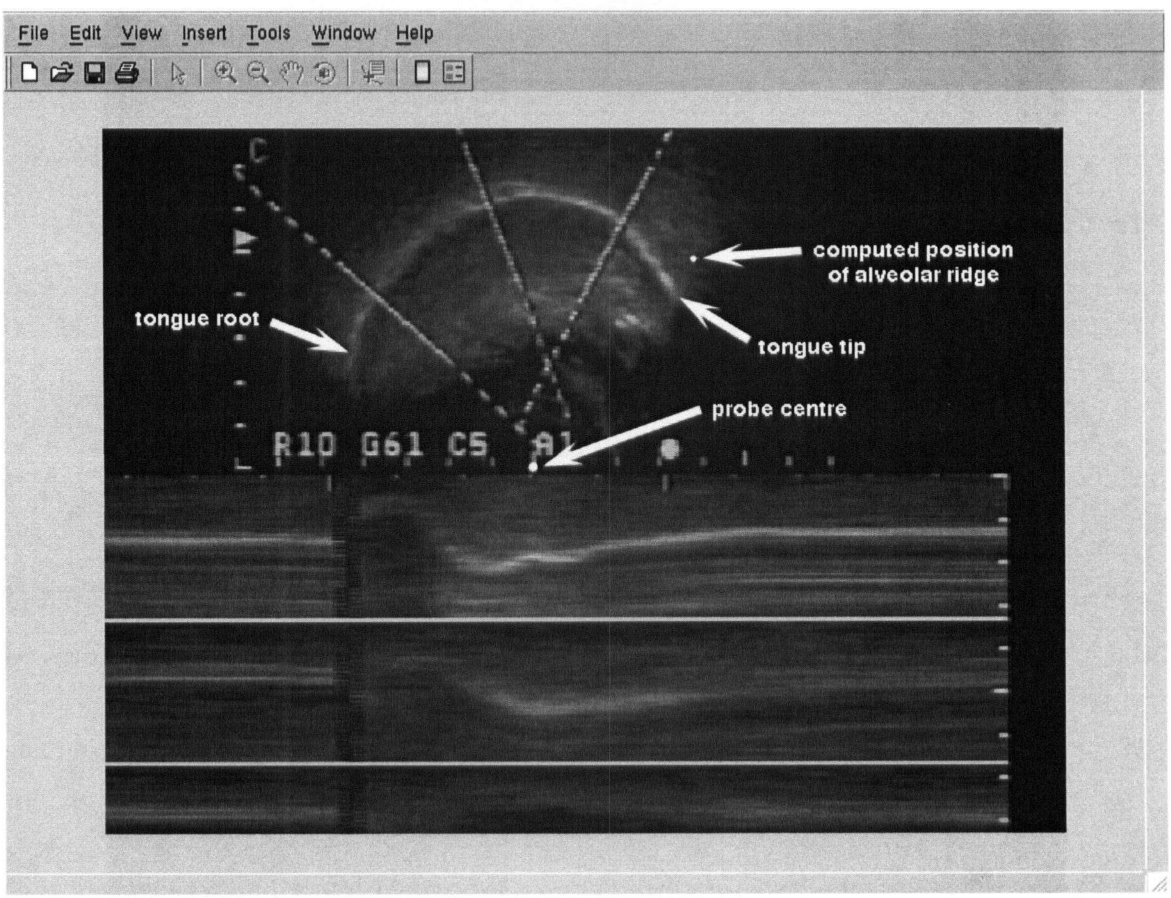
Figure 2.6. Ultrasound frame in MATLAB with alveolar ridge visible. The three lines labelled A, B, and C, and cutting through the tongue image should be ignored here and in Figures 2.7 and 2.8. These M-mode lines, which correspond to the three horizontal data tracks (labelled "M-mode images") situated under the B-mode image, are not used in the present research.



After the user clicked on the alveolar ridge, the program retrieved the first stored rest position .tiff image, and placed two red marks on it, one at the probe centre (10 mm below the surface of the probe) and the other at the point where the previously-clicked-on alveolar ridge was now computed to be after corrections for head movement. Note that in order to register the ultrasound images in a physical space defined by the Optotrak, a simplifying assumption was made that the ultrasound images always showed the midsagittal plane. This allowed the 3D coordinates of the alveolar ridge to be mapped onto the 2D ultrasound image by simply ignoring the third coordinate (i.e. the one off the midsagittal plane). Although it is very likely that the ultrasound images were not always showing the midsagittal plane, in a preliminary analysis of a subset of the data reported here, Gick et al. (2005, p. 512) showed that during ISP, the variation in head position in the direction perpendicular to the midsagittal plane was 1.86 mm, the smallest of the three possible translational movements.

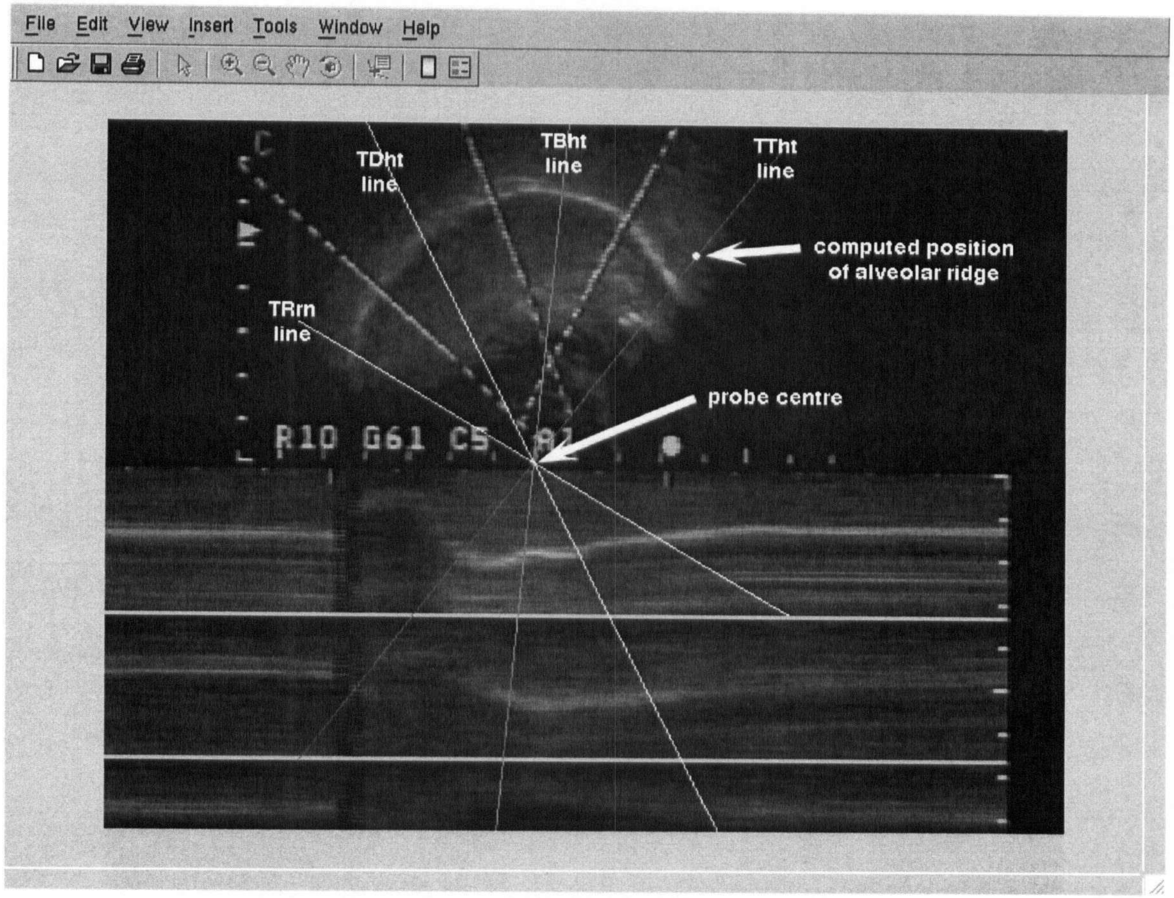
After zooming in on the tongue, the image was then displayed to the user (e.g., see Figure 2.7) and the user was prompted to click on the image enough above the "hyoid shadow" that a straight line drawn to the probe centre would intersect the tongue line. The hyoid shadow is the dark area to the lower-left of the tongue root, a shadow in the image caused by the absorption of the ultrasound waves by the hyoid bone. This can be seen most clearly in the ultrasound/CT scan overlay in Figure 2.4.

Figure 2.7. Ultrasound frame in MATLAB of an ISP to be analyzed. The user is separately instructed to click above the hyoid shadow in the picture.



After the user clicked above the hyoid shadow, a straight line was drawn through this point and the probe centre. A second straight line was drawn through the alveolar ridge and the probe centre. Finally, two more lines were drawn that trisected the angle between the first two lines (e.g., see Figure 2.8). The user was then prompted to click on the four points where each line intersected the surface of the tongue, and to do this in order from right to left (i.e. TT to TR). These measurement locations shall be called tongue tip (TT), tongue body (TB), tongue dorsum (TD), and tongue root (TR), and they correspond roughly to constrictions in the alveolar, palatal, uvular, and pharyngeal regions. Although the tongue line appears to be a thick white line, the actual surface of the tongue is the bottom edge of the white line, where it meets the black area. In the case of the tongue line not being visible, the user was prompted to click in a far corner of the image and such points were later eliminated from consideration in the analysis. After the user clicked on the four tongue points, the distance in mm from the probe centre to each point was calculated and saved.

Figure 2.8. Ultrasound frame in MATLAB showing four measurement lines



Before any statistical analyses were performed on the data, the data was normalized. Every speaker has a different sized vocal tract, and when comparing groups of speakers across languages, normalizing the articulatory measurements is likely to reduce some of the noise in the data. The method of normalization was the same for all subjects, monolinguals and bilinguals. For comparing an individual bilingual subject's French data to his/her own English data, obviously no scaling is necessary and any scaling that is done does not change the results (the same vocal tract produced both sets of data), but in order to compare across bilinguals or to compare the bilinguals to the monolinguals scaling is desirable. Although no perfect method of normalizing speech data from different speakers has been discovered yet, a number of methods have been used in other studies (see below). The method of normalization used in this dissertation was to multiply each subject's data measurements by a factor that was calculated using the distance from each subject's nose bridge (as approximated by the centre glasses' marker) to the alveolar ridge (as seen in some ultrasound images). This is effectively an anatomical measure that approximately varies with some aspects of the size of the vocal tract. The multiplication factor for a given subject was the largest subject's distance (in this dissertation, that of Subject 6) divided by the given subject's own distance. Table 2.8 shows the mean distance from a given subject's nose bridge (as approximated by the centre glasses' marker) to the alveolar ridge (as seen in some ultrasound images and then calculated for each ISP). Table 2.8 also shows a ranking of the subjects from longest (1) to shortest (24). The mean of the mean distances for the seven English subjects was 72.19 mm, for the eight French subjects was 74.75 mm, and for the nine bilingual subjects was 73.68 mm.

Table 2.8. Mean distance from subject's nose bridge to alveolar ridge

	Subject	Mean distance in mm (and standard deviation) from nose bridge to calculated alveolar ridge	Rank (1 = longest; 24 = shortest)
Monolingual English	1	69.11 (5.69)	20
	2	66.44 (1.87)	23
	3	77.85 (2.76)	7
	4	69.55 (2.12)	18
	5	70.95 (2.90)	16
	6	81.90 (2.11)	1
	7	69.52 (1.52)	19
Monolingual French	8	75.81 (1.23)	9
	9	79.16 (3.67)	5
	10	63.12 (4.79)	24
	11	76.50 (2.28)	8
	12	80.21 (1.98)	2
	13	74.44 (1.33)	11
	14	75.26 (3.35)	10
	15	73.48 (1.67)	12
Bilingual English-French	16	70.27 (1.75)	17
	17	78.49 (1.55)	6
	18	72.77 (2.09)	14
	19	80.16 (0.82)	3
	20	68.38 (5.04)	22
	21	71.57 (2.12)	15
	22	79.53 (1.26)	4
	23	69.02 (2.85)	21
	24	72.89 (4.79)	13

In Table 2.8, note that the standard deviations indicate that there is a reasonably high degree of variability in the distance from the nose bridge to the alveolar ridge. Ideally, this is a measurement that should not vary at all, assuming the glasses do not move relative to the skull. The standard deviation ranges from a low of 0.82 (Subject 19) to a high of 5.69 (Subject 1). The most probable reason for the high standard deviation in some subjects is trial-to-trial variation in the selected location of the alveolar ridge. This variation would have been due to a lack of clarity in the ultrasound frames where the subjects were swallowing. It is possible that what looked like the alveolar ridge was actually not so in some trials. If anything, this extra noise would reduce the number of significant differences found across speakers and languages, and should not introduce artificial significant effects.

Although it is intuitively apparent that tongue dimensions should vary with body size, just as across the animal kingdom, the size of the brain increases with body size (Seyfarth & Cheney, 2002), results have been mixed. Tongue measurements taken of 35 healthy Caucasian dental students by Oliver and Evans (1986) showed that the mean length, breadth, and thickness of the tongue is greater for males than for females. Note, however, that Chiang, Lee, Peng, and Lin (2003), who studied 20 Chinese medical students, found no significant difference between the 10 females' and the 10 males' mean tongue thicknesses (as measured with ultrasound from the mylohyoid muscle to the tongue body). In a three dimensional study of 25 Japanese female adults, Takada, Sakuda, Yoshida, and Kawamura (1980) showed a significant correlation between tongue volume and both the capacity of the oral cavity and the depth of the floor of the mouth, but not the height of the palatal vault. Thus, the anatomically-based method of normalization used in this dissertation is probably not perfect, but is probably an improvement over using non-normalized data.

All statistical analyses were performed using JMP 5.1 (SAS Institute Inc.) statistical analysis software.

CHAPTER III Experiment 1: AS in English and French Monolinguals

Experiment 1 was an investigation of whether or not ISP is language dependent and whether or not phonetic context has a carry-over effect on ISP. In this experiment, only monolingual speakers were used. Hypotheses 1 and 2 were tested, namely that the ISP for Canadian English is significantly different from the ISP for Québécois French, and that within a given speaker's speech in a given language, that speaker's ISP differs depending on the phonetic segment that precedes the ISP.

3.1. Results

Results of Experiment 1 on monolingual subjects are now presented such that in Section 3.1.1 a comparison of languages' ISPs is presented, in Section 3.1.2 a comparison of individuals' ISPs is presented, and in Section 3.1.3 a comparison of phonetic context effects is presented. More specifically, in Section 3.1.1, English group means are compared to French group means, in order to test the hypothesis that the English ISP is different from the French ISP. Then in Section 3.1.2, box plots of the ISPs for individual subjects are presented for English and French, showing within- and between-subject variability. Finally, in Section 3.1.3, results are presented of a test of the hypothesis that phonetic context has a carry-over effect on ISP.

3.1.1. Results: ISP Across Languages

For each measurement (e.g. tongue tip height, upper lip protrusion, etc.), group means and standard deviations were calculated for English and for French. Each group mean and standard deviation are the mean and standard deviation of the individual subject means for that measurement and that language. These *individual* subject means, as well as *within*-subject standard deviations, can be found in Appendix XI. The English and French *group* means and *between*-subject standard deviations for each language and each measurement are given in Table 3.1.

Table 3.1. Means and between-subject standard deviations (in parentheses) of monolingual English and French groups for each component of ISP

Component of ISP	**English group mean (*SD*)**	**French group mean (*SD*)**
TTht (tongue tip height)	63.88 mm (5.02)	58.35 mm (3.57)
TBht (tongue body height)	66.41 mm (4.55)	63.33 mm (5.46)
TDht (tongue dorsum height)	58.19 mm (8.83)	56.39 mm (5.77)
TRrn (tongue root retraction)	48.60 mm (9.59)	48.69 mm (6.65)
JAWl (jaw lowering)	6.36 mm (4.16)	6.53 mm (2.72)
ULlo (upper lip distance from bridge of nose)	75.39 mm (2.49)	72.38 mm (5.07)
LLlo (lower lip distance from bridge of nose)	97.14 mm (3.41)	96.16 mm (6.90)
ULpr (upper lip protrusion)	31.80 mm (6.96)	23.60 mm (4.68)
LLpr (lower lip protrusion)	36.00 mm (6.90)	27.01 mm (5.15)
Lvap (vertical lip aperture)	22.13 mm (3.82)	23.89 mm (4.42)
Lhap (horizontal lip aperture)	61.96 mm (4.21)	60.81 mm (5.62)
Lnar (degree of lip narrowing from maximum spread)	14.11 mm (5.99)	7.38 mm (3.57)

To test whether the group means in Table 3.1 were significantly different across language groups, 12 *t* tests (assuming unequal variances) were done - one at each of the 12 components of ISP. These *t* tests compared the English group mean to the French group mean, where each group mean was the mean of the individual subject means from Appendix XI. Table 3.2 shows the results of these *t* tests. For more details about the statistics, including the exact degrees of freedom - reduced because of the more conservative assumption of unequal variances - see Appendix XII.

Table 3.2. Comparison using *t* tests (assuming unequal variances) of monolingual English and French group means by component of ISP. Note that because of the assumption of unequal variances, the actual degrees of freedom are fewer than the 13 reported here. See Appendix XII for the exact degrees of freedom.

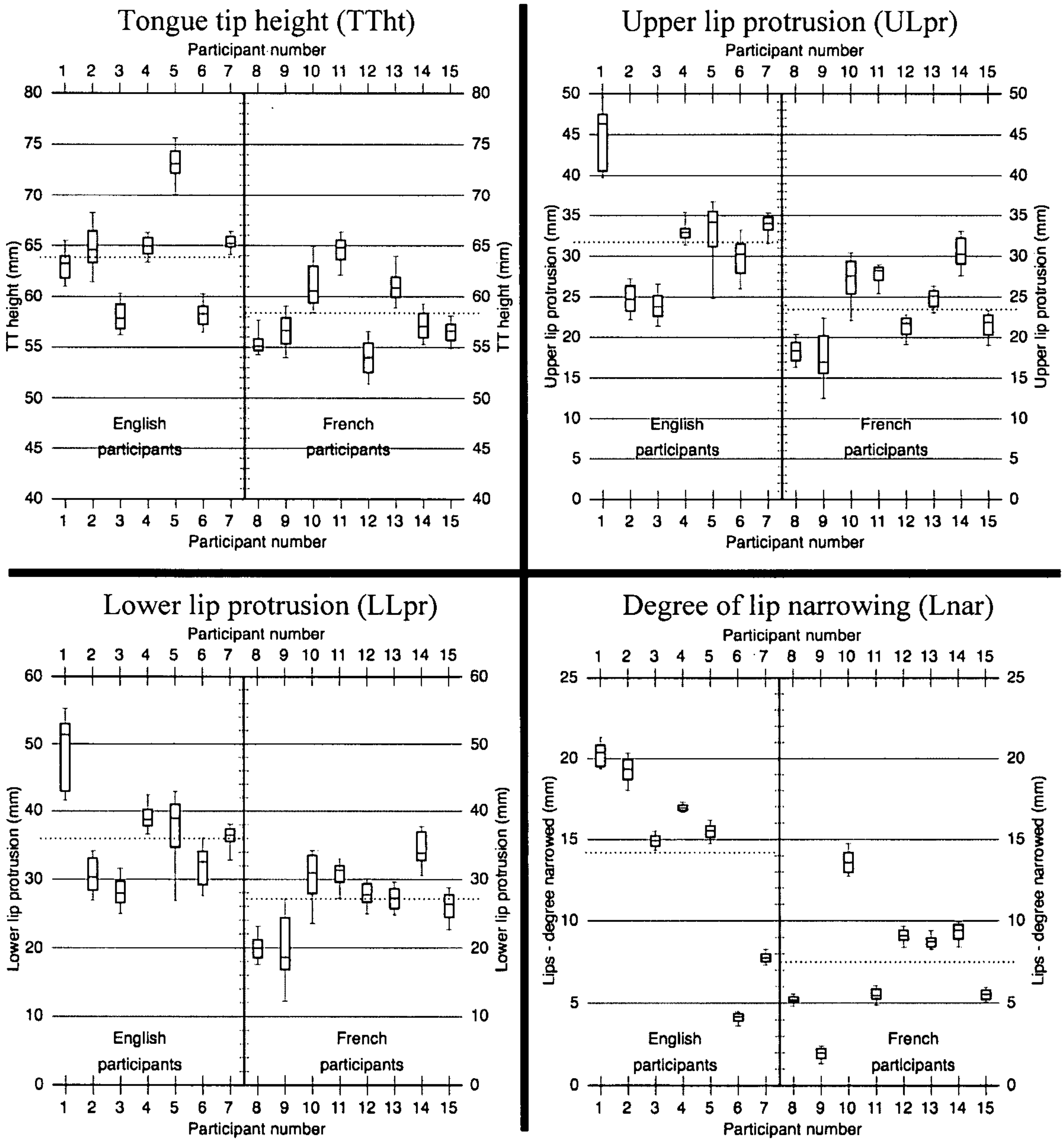
Component of ISP	**Result**	***t* Ratio**	**Prob > |*t*|**
TTht (tongue tip height)	Eng significantly higher	$t(13) = 2.43$	$p = .0340$ *
TBht (tongue body height)	Eng tending higher	$t(13) = 1.19$	$p = .2542$
TDht (tongue dorsum height)	no difference	$t(13) = 0.46$	$p = .6560$
TRrn (tongue root retraction)	no difference	$t(13) = 0.02$	$p = .9848$
JAWl (jaw lowering)	no difference	$t(13) = 0.10$	$p = .9254$
ULlo (upper lip distance from bridge of nose)	Eng tending greater (i.e. lower height)	$t(13) = 1.49$	$p = .1656$
LLlo (lower lip distance from bridge of nose)	no difference	$t(13) = 0.36$	$p = .7291$
ULpr (upper lip protrusion)	Eng significantly greater	$t(13) = 2.64$	$p = .0242$ *
LLpr (lower lip protrusion)	Eng significantly greater	$t(13) = 2.83$	$p = .0163$ *
Lvap (vertical lip aperture)	no difference	$t(13) = 0.83$	$p = .4217$
Lhap (horizontal lip aperture)	no difference	$t(13) = 0.45$	$p = .6590$
Lnar (degree of lip narrowing from maximum spread)	Eng significantly greater (i.e. more narrowing)	$t(13) = 2.60$	$p = .0277$ *

As can be seen in Table 3.2, significant differences between the English and French groups were found for tongue tip height (English higher than French), upper lip protrusion (English more protruded than French), lower lip protrusion (English more protruded than French), and degree of lip narrowing - the amount that the corners of the mouth are drawn in towards the midsagittal plane from a maximally spread position (English more narrowed than French).

3.1.2. Results: ISP Across Individuals Within a Language

In Figure 3.1, results in box plot format for individual subjects are presented for four components of ISP. These are the four components of ISP that were found to be significantly different across English and French groups immediately above in Section 3.1.1. In the box plots, the top, bottom, and line through the middle of each box correspond to the 75th percentile, 25th percentile, and 50th percentile (i.e. the median) respectively. The whiskers on the bottom and top extend from the 10th percentile and 90th percentile respectively. The box plots are provided here because they clearly indicate the amount of within-individual and across-individual variability in the measurements obtained.

Figure 3.1. Box plots of monolingual subjects' distribution for the four components of ISP that were significantly different across languages in Section 3.1.1. The dotted lines are the group means from Table 3.1. Male subjects are #3, #6, #7, #11, and #13.



In Figure 3.1, one thing that is immediately noticeable is the fairly high degree of between-subject variability within a given language. All of the subjects in a given language do not tightly cluster about that language's mean. For each of the four components of ISP shown above, there is at least one subject per language that could possibly be considered an outlier. Within-subject variability (shown by the length of each box and the distance the whiskers extend) also differs greatly across the 15 subjects. The most extreme example can be seen in the lower lip protrusion ISP values for the English subjects. Subject 1 has 50% of her lower lip protrusion data (the amount inside the box) within a range of approximately 10 mm, while Subject 7 has his corresponding data within a range of only 2 mm.

Another thing to note in Figure 3.1 is that the within-subject variability of the degree of (horizontal) lip narrowing is much lower than the other three components of ISP. Most of the subjects in both languages have 80% of their data (from the top whisker to the bottom whisker) within a 1-2 mm range.

3.1.3. Results: Carry-Over Effects of Phonetic Context on ISP

The preceding phonetic context of the ISP was controlled for across languages, and thus the four crosslinguistic differences that were found in Section 3.1.1 are due to something other than phonetic context. Nevertheless, the question still remained whether or not the effect of language on ISP was also mirrored by a carry-over effect of phonetic context on ISP. As mentioned in Section 1.3.1, the existence of a carry-over effect has implications for theories of speech motor control, for studies that use the ISP as a reference point for making measurements, and for determining the best timing for stimuli presentation in future studies of ISP.

Given the four crosslinguistic differences in ISP reported in Section 3.1.1, one would expect that if phonetic context had a very weak effect, or no effect, on ISP, then these four differences should also show up in the majority of phonetic contexts. For if the overall crosslinguistic differences from Table 3.2 only showed up in a few of the contexts, it would raise the concern that the differences were caused by the phonetic context. To investigate this issue, 24 t tests (assuming unequal variances) were conducted with the group-mean measurement of the ISP position of a given component of ISP in a given phonetic context as the dependent variable, and with language as the independent variable. There were 24 t tests because there were 6 phonetic contexts for each of the 4 components of ISP that had shown significant group differences in Section 3.1.1. Results are listed in Table 3.3 and show that out of the 24 t tests, 20 were significant. Note that for each of the four components of ISP, a significant difference is present in almost every one of the six broad phonetic contexts. Thus, based on these group means in different phonetic contexts, it is unlikely that the crosslinguistic group differences that were presented in Table 3.2 were caused by phonetic context.

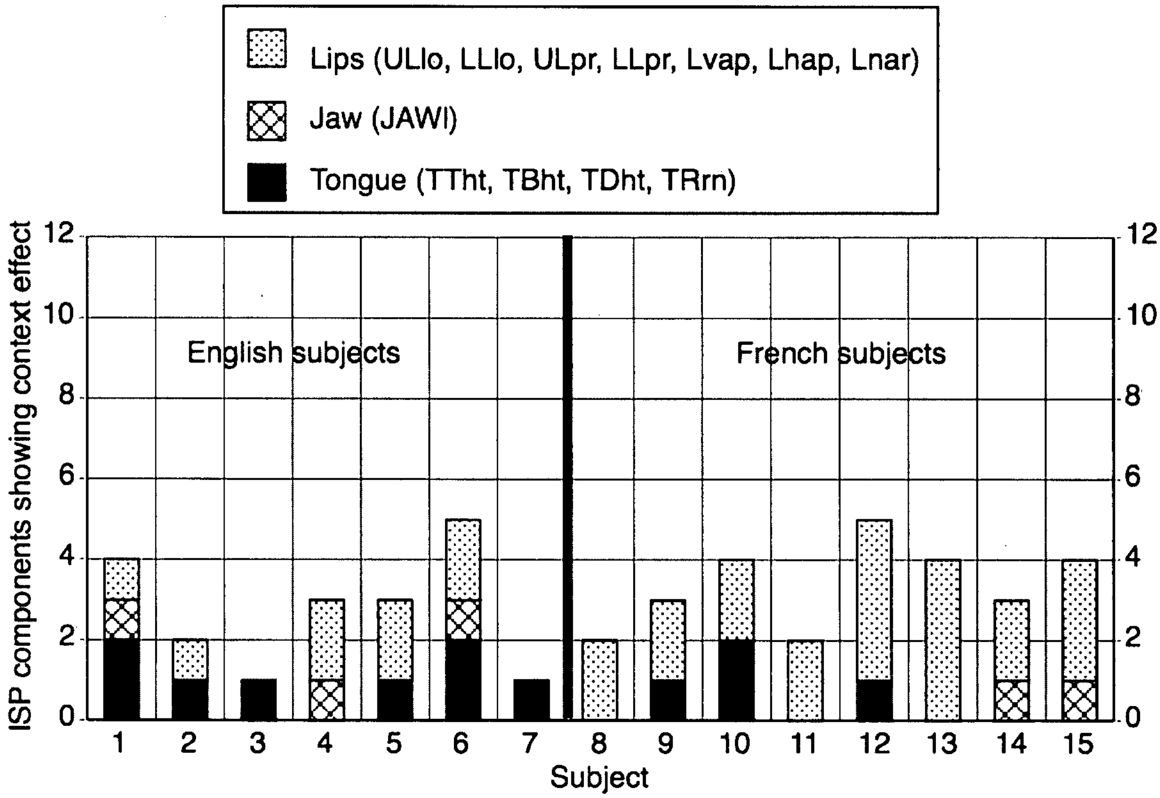
Table 3.3. Comparison of English group versus French group means by component of ISP and by phonetic context (phonetic contexts that did *not* have significant results at $p < .05$ are shaded; all others were significant across language groups)

Component of ISP	**Direction of difference**	**Broad phonetic context number**	***t* Ratio**	**Prob > |*t*|**
TTht (tongue tip height)	English higher	1	$t(13) = 2.49$	$p = .0317$
		2	$t(13) = 1.96$	$p = .0766$
		3	$t(11) = 2.52$	$p = .0338$
		4	$t(13) = 3.15$	$p = .0094$
		5	$t(12) = 2.87$	$p = .0153$
		6	$t(12) = 1.87$	$p = .0863$
ULpr (upper lip protrusion)	English greater	1	$t(13) = 2.63$	$p = .0256$
		2	$t(13) = 2.43$	$p = .0352$
		3	$t(12) = 1.70$	$p = .1168$
		4	$t(13) = 2.98$	$p = .0139$
		5	$t(12) = 2.70$	$p = .0216$
		6	$t(13) = 2.76$	$p = .0174$
LLpr (lower lip protrusion)	English greater	1	$t(13) = 2.77$	$p = .0190$
		2	$t(13) = 2.49$	$p = .0318$
		3	$t(12) = 1.70$	$p = .1169$
		4	$t(13) = 3.37$	$p = .0064$
		5	$t(12) = 2.78$	$p = .0179$
		6	$t(13) = 2.88$	$p = .0132$
Lnar (degree of lip narrowing from maximum spread)	English greater (i.e. more narrowed)	1	$t(13) = 2.68$	$p = .0248$
		2	$t(13) = 2.62$	$p = .0263$
		3	$t(11) = 2.26$	$p = .0454$
		4	$t(13) = 2.59$	$p = .0282$
		5	$t(12) = 2.91$	$p = .0183$
		6	$t(13) = 2.69$	$p = .0239$

These results in Table 3.3 above were obtained by comparing *group* means in different phonetic contexts. A more reliable indication of whether phonetic context has carry-over effects on ISP can be obtained by analyzing each subject's data individually. Hypothesis 2 stated that "Within a given speaker's speech in a given language, that speaker's ISP will differ depending on the phonetic segment that precedes the ISP." In order to statistically test whether phonetic context affects a following ISP, two contexts that intuitively seem quite different and also happen to have the most tokens available were compared[6] - the BackV context (back rounded vowels) and the CoronalC context (coronal obstruents). With 15 subjects and 12 components of ISP per subject, the total number of *t* tests performed was 180. The dependent variable was the individual mean measurement of the ISP position for a given subject-component pairing, and the independent variable was the phonetic context that preceded the ISP. A summary of the results of these 180 *t* tests (assuming unequal variance) appears in Figures 3.2 and 3.3. In the interest of clarity of presentation of the data, *t* Ratios and probabilities are not reported. A significance level of .05 was used.

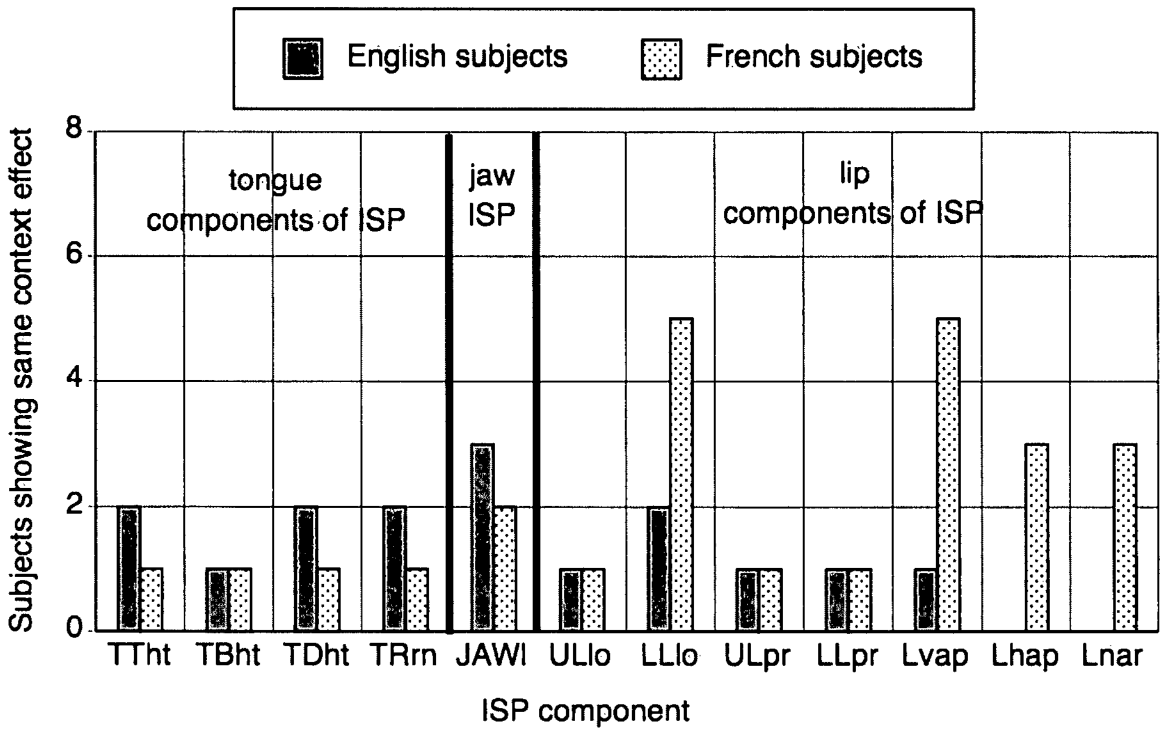
[6] As a comparison of this one pair of phonetic contexts (i.e. BackV versus CoronalC) involved 180 *t* tests, a comparison of more pairs of contexts (with probably more similar articulator positions) was not done.

Figure 3.2. Number of components of ISP (out of 12), per subject, where *t* tests (assuming unequal variance) showed a significant difference ($p < .05$) in any direction between the BackV context and the CoronalC context



In Figure 3.2, note that all 15 subjects have at least one component of ISP (i.e. one of TTht, TBht, TDht, ... , Lnar) in which the ISP measurements are significantly different across the two phonetic contexts. The highest number of components of ISP where a significant difference between contexts is found is five, and this is true for both Subjects 6 and 12. However, this is still fewer than half of the 12 total components of ISP. Also note that all of the French subjects have at least two lip components of ISP that are influenced by phonetic context. On the contrary, two of the English subjects have no context effects on the lips, and another two English subjects have only one lip component of ISP that is influenced by phonetic context. As for the tongue, all but one of the English subjects have at least one component of ISP that is influenced by phonetic context. For the French subjects, this is true for only three of them.

Figure 3.3. Number of subjects (out of 7 English and 8 French) that showed a significant difference, in the same direction, between the BackV context and the CoronalC context by component of ISP



In Figure 3.3, note that for the monolingual English subjects (solid shading), there is only one component of ISP where at least three of the seven subjects have the same significant effect of context on ISP, namely the degree of lowering of the jaw. The three subjects here all had the jaw more open in the BackV context than in the CoronalC context, i.e. more open after high and mid, back rounded vowels than after coronal obstruents.

For the monolingual French subjects, there are four components of ISP where at least three of the eight subjects have the same significant effect of context on ISP: the height of the lower lip (LLlo), vertical lip aperture (Lvap), horizontal lip aperture (Lhap), and degree of lip narrowness (Lnar). For five of the eight subjects, the lower lip was lower after coronal obstruents than after back rounded vowels. For the same five subjects, the vertical aperture of the lips was greater after coronal obstruents than after back rounded vowels. Three of the French subjects had a significantly greater horizontal lip aperture and less narrowing of the lips after the rounded vowels than after the coronal obstruents.

At a significance level of .05, it can be expected that 9 out of 180 *t* tests would give false positives, i.e. 9 of the 180 *t* tests would indicate significant differences when in fact these results were not significant. Since 46 out of 180 *t* tests were significant in Figure 3.2, and 41 out of 180 *t* tests were significant in Figure 3.3, it is very likely that a great majority of the differences obtained were indeed significant. However, since it is impossible to determine which of the significant differences were false positives, the results in Figure 3.2, where no strong trend was found, must be observed cautiously. As for the results in Figure 3.3, where a stronger trend was found, the data were analyzed further by comparing the *directionality* of *all* differences (both significant and non-significant). The prediction, if there were no phonetic carry-over effect, was that for any given component of ISP, half the subjects in a given language should have a greater value in the BackV context and the other half should have a greater value in the CoronalC context. For English monolinguals, the directionality of differences showed a trend for three components: 6 out of 7 subjects had TTht higher in the CoronalC context, 6 out of 7 subjects had TRrn greater in the CoronalC context, and 5 out of 7 subjects had ULpr greater in the BackV context. Since there is no difference in directionality of the jaw results, it is possible that this is a false positive in Figure 3.3. However, For French monolinguals, the directionality of differences showed a strong pattern. For all 12 components of ISP, at least 6 out of 8 French monolinguals showed the same directionality. Specifically, TTht, TBht, TDht, ULlo, ULpr, LLpr, Lhap were all greater for 6 or more out of 8 speakers in the BackV context, while TRrn, JAWl, LLlo, Lvap, and Lspr were all greater for 6 or more out of 8 speakers in the CoronalC context. These directionality results for the French monolinguals support the claim that the significant differences seen in Figure 3.3 are not simply false positives.

3.2. Discussion

In Experiment 1, ISP was measured in seven monolingual speakers of Canadian English and eight monolingual speakers of Québécois French in order to test Hypotheses 1 and 2. Recall that Hypothesis 1 stated that the ISP for Canadian English is significantly different from the ISP for Québécois French, and Hypothesis 2 stated that within a given speaker's speech in a given language, that speaker's ISP will differ depending on the phonetic segment that precedes the ISP. The results just presented in Section 3.1 partially support both hypotheses.

3.2.1. Discussion Regarding Test of Hypothesis 1

In a test of Hypothesis 1, the results in Table 3.2 show that the ISP for monolingual English speakers is significantly different from the ISP for monolingual French speakers in the following ways: For English speakers, the tongue tip is higher and both lips are more protruded, and the corners of the mouth are drawn farther away from a maximum spread position than for the French speakers. These significant differences match those of Gick et al. (2004) for the tongue tip height and the upper lip protrusion, but they are opposite those of Gick et al. for the lower lip protrusion. Note that the lip protrusion results are also contrary to expectation based on the non-instrumental accounts of Honikman (1964) and others (see Section 1.2.1). Since Gick et al. were not able to measure lip aperture with the x-ray data they used, no comparison of lip aperture or degree of spreading can be made. Gick et al. found that the tongue body was higher for English speakers. Table 3.2 shows that in the present study, although the English tongue body tended to be higher, there was no significant difference between the English and French speakers ($p = .2542$). Also, results from Gick et al. showed that the tongue root was more retracted for English speakers. The present results show absolutely no difference in tongue root position between English and French speakers ($p = .9848$). Finally, neither the results from Gick et al. nor the present results show any difference in jaw height between the English group and the French group.

Thus, out of the six possible comparisons that can be made between the present study and that of Gick et al., three show the same results: the same significant differences for tongue tip height and upper lip protrusion, and the same lack of significant difference for jaw height. Of the other three comparisons that do not completely agree, two were found to be significant by Gick et al. but do not differ significantly in the present results - namely, tongue body height and tongue root retraction. Although tongue body height was not found to be significantly different between English and French in this study, the tendency was for English to be higher, the same direction as the Gick et al. results. An explanation for these two differences in results between the Gick et al. study and the present one may be the more stringent statistical method employed in the present study. As mentioned in Section 1.3.1, the choice in Gick et al. of using each individual token as the experimental unit for statistical comparison makes it more likely that statistically significant differences will be found. The third comparison between the Gick et al. study and the present experiment that does not agree (i.e. lower lip protrusion) is found in both studies to be significantly different across languages, but in opposite directions. One reason for this may have to do with the effect of phonetic context on the position of the lower lip. While the definition of an ISP in Gick et al. was a minimum length of 3 ultrasound frames (i.e. about 100 ms), the minimum ISP length in this study is 10 frames (i.e. about 333 ms). Thus although the articulators may have appeared to be at rest in the Gick et al. study, it is possible that there was simply not enough time for the articulators to return to a rest position, especially given the fact that the subjects could already see the next sentence and could continue reading when ready. It should also be pointed out that one or more of the differences between the Gick et al. results and the results in Section 3.1.1 could be due to (1) the many years difference between when the x-ray data and the present data were collected, and (2) the different distribution of where the Canadian-English speakers in each study originated from.

Although they did not measure it, Gick et al. posited that the tongue dorsum could be higher for French than for English because the other three tongue measurements all indicated that French speakers' tongues have a smaller midsagittal area than English speakers' tongues. The results of the present study do not support this view - no difference was found between the English and the French tongue dorsum height. Thus it is more likely that Gick et al.'s (p. 226) other explanation is true, namely that there could be more lateral expansion of the tongue for French speakers, and that due to the fact that the tongue is a muscular hydrostat (Kier & Smith, 1985), this lateral expansion causes a reduction in the total midsagittal area of the tongue. This explanation agrees with Honikman's (1964) assertion that the English tongue tip is "tapered" whereas the French tongue tip is "untapered".

In addition to the tongue dorsum measurement, five other measurements were made in this study that were not made in the Gick et al. study: upper and lower lip height (measured as the distance from the bridge of the nose), vertical lip aperture, horizontal lip aperture, and the distance that the horizontal lip aperture differed from a maximally spread position (i.e. "degree of lip narrowing"). Neither the lip height nor the lip aperture were different across languages, but the degree of lip narrowing was significantly greater for English, meaning the lips were closer to a maximally spread position for French. As increased lip spreading naturally decreases the amount of lip protrusion, this difference is consistent with the above findings that both lips were more protruded for English speakers.

Given the higher frequency of rounded segment types in the phonemic inventory of French, it is perhaps surprising that French had a more spread-lip ISP than English did. It is customary to think of rounding as involving lip protrusion. However, "rounding" in Québécois French actually could primarily involve a decrease in vertical lip aperture and spreading the lips could cause this decrease. This type of rounding is what Heffner (1950, p. 98) referred to as "vertical lip rounding". Heffner stated that lip protrusion is "much less frequently found with vertical lip rounding" than with horizontal lip rounding. However, if vertical lip aperture were a salient component of the ISP of the lips, then we would expect to see a cross-linguistic difference in this component (i.e. "Lvap"), but we did not. Although the type frequency of rounded segments in the phonemic inventory of French is high compared to English, it is possible that the token frequency of rounded segments in French is comparable to or even lower than that of English. In that case, the results showing French having a more spread-lip ISP than English would not be surprising. Future work relating AS to token frequencies could shed light on this issue.

Another result that at first seems surprising is the fact that the English group had a higher tongue tip during ISP than the French group did. This seems surprising given the fact that coronal consonants in French have a dental place of articulation, more anterior than English coronals, which have an alveolar place of articulation. However, considering what was actually measured by TTht, at least one reasonable explanation presents itself. The measurement denoted by TTht was the distance from the centre of the ultrasound probe to the surface of the tongue and this was measured along a line that intersected the alveolar ridge. Thus, if the tongue tip were anterior to the alveolar ridge (as it is in the case of a French coronal), then TTht would actually be measuring the height of the tongue in a location posterior to the tip (i.e. the tongue blade). During ISP, if the anterior part of the tongue were in an optimal position for articulating a coronal sound (which it may or may not be), the tongue would be higher for English than for French along the line running through the alveolar ridge.

Turning from the group comparisons and examining the individual results in Figure 3.1, it is apparent that in each language the results do not cluster tightly around the group mean. Thus, although significant differences between group means were found for tongue tip height (TTht), upper lip protrusion (ULpr), lower lip protrusion (LLpr), and degree of lip narrowing (Lnar), there is a considerable amount of allowable variation in ISP across native speakers of a given language. However, it is almost always the case that the mean of a given measurement for a given speaker is closer to that speaker's group's mean than the other group's mean is. There are four exceptions to this: In the case of TTht, two of the seven English monolingual subjects had lower TTht means than the French group mean, and one of the eight French monolingual subjects had a higher TTht mean than the English group mean. In the case of Lnar, one of the English monolingual subjects had a lower Lnar than the French group mean.

No answer is forthcoming as to why Subject 1 had such a great degree of lip protrusion. Since lip protrusion was measured as a distance from an anatomically determined plane, it is possible that Subject 1 had much thicker lips than the rest of the subjects and that because the normalization was done based on a face-length measurement (mid-glasses marker to alveolar ridge), lip thickness was not corrected for. However, variation in anatomical size and proportion, even after normalization, could certainly be the reason for the above anomalies in the data. In the comparison of group means done in Section 3.1.1, it is assumed that these individual anomalies are averaged out, and thus not a concern. It is worth pointing out that even if Subject 1 is eliminated from consideration in the *t* test calculations for ULpr and LLpr, the crosslinguistic group differences are still significant ($p = .0300$ for ULpr and $p = .0188$ for LLpr).

When interpreting the unique TTht results for Subject 5 in Figure 3.1, it should be pointed out that although she is monolingual English, her language background is quite different from the other monolingual English subjects. Her parents speak Frisian and Dutch together, although the home language of her childhood was English. Also, she lived in Ontario for the first 11 years of her life and then lived in the United States for 10 years until the age of about 21, and this may have influenced her ISP tongue tip setting. Note in Appendix XI that her other tongue measurements are not out of the ordinary - it is simply her tongue tip position that is significantly higher than the other English subjects' tongue tip positions. It is interesting to note that Subject 7, who has the highest TTht value of the remaining six English subjects, grew up in Ontario like Subject 5, both further east in Canada than the other five English subjects. Due to the limited number of subjects, no conclusions can be made about differences between the ISP of speakers from Ontario and speakers from further west, but with more subjects from various parts of the country, differences in ISP within the broad category of "Canadian English" could be pinpointed. It is worth noting that if Subject 5 is eliminated from consideration when doing *t* tests on the TTht data, the *p* value changes from .0340 to .0528, pushing the difference to insignificance at $p < .05$. However, if along with Subject 5, Subject 11 (the most extreme outlier on the French side) is also eliminated, then the crosslinguistic difference in tongue tip height remains significant and the *p* value actually gets stronger at $p = .0177$.

3.2.2. Comparison of Results to Long-held Impressions of AS

Recall from Section 1.2.1 that although there exist many published impressions of AS, none of them specifically describe Canadian English or Québécois French. Thus, any comparisons of the present results to long-held impressions of AS should be taken with a grain of salt until further non-instrumental work has been done on Canadian English and Québécois French.

Sweet's (1890) description of the tongue tip and tongue body being lower in RP-English than in Parisian-French is opposite to the results of Section 3.1.1, where it was found that the tongue tip is higher for Canadian English than for Québécois French. No difference in tongue body height was found, although the tendency in the present data is in the opposite direction to Sweet's impressions. Graff (1932) and Heffner (1950) both described similar differences between RP-English and Parisian-French as Sweet did, at least as far as the tongue tip is concerned, and thus their descriptions also differ from the results of Section 3.1.1, but again for different dialects. Heffner (1950) did say that the tongue is even lower for American-English than it is for British-English (and thus for Parisian-French), and this would make his impressions of the AS for the American-English tongue very different from the results of this dissertation for the Canadian-English tongue. As for the lips, although Sweet (1890) stated that they are in neutral position for English, he did not describe their position for French, only that they "articulate with energy". Graff (1932) described the lips as being ready for frequent rounding, but it is unclear what this means as far as their ISP is concerned.

Honikman's (1964) detailed description of RP-English versus Parisian-French differs somewhat from the studies described above. As stated in Section 1.2.1, Honikman's impression was that the French tongue tip is lower, tongue body is higher, lips rounded, and jaw more open than in English. The results in Section 3.1.1 of this dissertation support only her claim of the French tongue tip being lower. The results are opposite for the tongue body height (English tends to be higher, though not significantly), and there is no significant difference for jaw height. As for the lips, it is usually the case that when one talks about lip rounding, lip protrusion is implicitly assumed. However, Zerling (1992) shows that frontal lip shape for French and English vowels is much more complex than first imagined, and that [+round] vowels can actually involve flat lips in an effort to reduce the cross-sectional area of the lip opening. Thus, depending on what Honikman meant by "lips rounded" for French, these results may agree with her impressions if she meant "flat", or disagree with her impressions if she meant "protruded".

The only similarity between Esling and Wong's (1983) description of American-English AS and the Canadian-English results here is that of a palatalized tongue body position. The results here indicate that the English tongue body tends to be higher than the French tongue body, although it cannot be said with certainty that the tongue body is "palatalized".

Overall, it can be seen that the results of this experiment do not match the long-held impressions of English and French AS by phoneticians. While these results may be taken as an indication that a language's ISP may not accurately reflect its AS in its entirety, this difference is not surprising given the fact that none of the impressions in the previous literature were of the dialects under investigation in this dissertation.

In future work, when non-instrumental studies are done on the AS of Canadian English and Québécois French, they will provide an effective measure as to how close the ISP mirrors the AS.

3.2.3. Discussion Regarding Test of Hypothesis 2

The carry-over effect of phonetic context on ISP was examined systematically. First a detailed analysis was carried out on the four components of ISP in which a cross-linguistic difference was found (i.e. TTht, ULpr, LLpr, and Lnar). It was expected that if the cross-linguistic differences only showed up in a few of the phonetic contexts, the differences might have in fact been caused by the context instead of being language specific. However, Table 3.3 shows that for each of the four significant components of ISP, at least four of the six broad phonetic contexts showed cross-linguistic differences - four contexts for TTht, five for ULpr, five for LLpr, and all six contexts for Lnar. Thus, based on these group means in different phonetic contexts, it is unlikely that the crosslinguistic group differences presented in Section 3.1.1 were caused by phonetic context.

The four *t* tests that were not significant in Table 3.3 all have plausible explanations. The two broad phonetic contexts in which TTht is not significantly different across languages (namely, the BackV context and the LowV context) are both back vowel contexts. In such contexts, the tongue tip presumably remains low and out of the way while a constriction is being made with the tongue dorsum and/or tongue root in the posterior part of the oral tract, and since it is not active in the articulation there should not be a significant difference across languages. In addition, the Schwa context is the one context in which ULpr and LLpr do not show significant crosslinguistic differences. Perhaps here, if French schwa is produced "with noticeably rounded lips" (Price, 1991, p. 77), and if lip rounding entails lip protrusion, then the underlying AS of greater lip protrusion for English (from the results in Table 3.2) is similar to the schwa's demand for greater lip protrusion for French, and this eliminates any significant difference between the French ISP and the English ISP following schwa.

In the test of Hypothesis 2, which proposes that phonetic context has a carry-over effect on a given individual's ISP, Figures 3.2 and 3.3 show mixed results. Hypothesis 2 was partially supported in that carry-over effects of phonetic context do exist, but not for the majority of components of ISP. Figure 3.3 shows that for 7 of the 12 components of ISP (i.e. for all 4 tongue components of ISP, both lip protrusion components of ISP, and the height of the upper lip), there is no clear pattern of a measurement being significantly greater after one context than the other - at most only two subjects show similar significant differences for a given language.

Although there was no systematic phonetic context effect on the position of the tongue, there was an effect on the position of the lips, but curiously only for French speakers and not for lip protrusion. Five of the eight French speakers had LLlo greater after the CoronalC context than after the BackV context, meaning that the lower lip was at a lower height (relative to the bridge of the nose) after coronal consonants than after back, rounded vowels. This makes sense as the rounding of the vowels involved a reduction of vertical lip aperture via raising of the lower lip. The same five speakers had a significantly greater vertical lip aperture after the CoronalC context compared to the BackV context. Interestingly this same pattern (LLlo and Lvap greater after the CoronalC context) only happened with one of the seven English speakers, and the opposite happened for LLlo with two of the other six English speakers. It is possible that this is an indication of a tighter degree of constriction in the French back, rounded vowels than the English ones, something that Zerling (1992) also reported based on his own European-French data and the American-English data of Fromkin (1964) and Linker (1982).

In addition to LLlo and Lvap being context dependent for French speakers, Lhap and Lnar (horizontal lip aperture and degree of lip narrowing from a fully spread position) also showed identical contextual effects for three of the eight French speakers. In these three speakers, Lhap was greater after the BackV context than after the CoronalC context, and Lnar was greater after the CoronalC context than after the BackV context. Taken together with the fact that only 1 of the 8 French subjects showed context-related differences for upper lip and lower lip protrusion, this seems to indicate that either Québécois-French back, rounded vowels are produced with lip spreading as opposed to lip protrusion, or, if they are produced with lip protrusion, then overcompensatory lip spreading occurs when returning to ISP after the rounded vowel. Subject 10 had a significant difference in the opposite direction though (i.e. significantly less lip spreading after back rounded vowels than after coronal obstruents). Due to this subject's age difference with the rest of the subjects (in her 50's as opposed to her twenties or teens), it is possibly an age related difference with older people producing rounding by protruding, while younger people produce rounding by spreading their lips and decreasing the vertical aperture. It should also be noted that Subject 10 remarked about her own pronunciation that some Québécois have heard her speaking and have asked her where (outside Quebec) she is from.

There is a part-whole problem (Barry, 1983; Munhall, 1985; Benoit, 1986) that should be mentioned when analyzing the above results for the French speakers' lower lip height (LLlo), vertical lip aperture (Lvap), horizontal lip aperture (Lhap), and degree of lip narrowing (Lnar). Since LLlo probably accounts for much of the variation of Lvap, it is likely that if one were to remove the cross-context difference in LLlo from that of Lvap, the cross-context differences in Lvap would no longer be significant. The same can be said for Lhap and Lnar. This concern was not addressed here, but is left for future research.

As for jaw height, three out of the seven English speakers had a lower jaw after the BackV context than after the CoronalC context. This is completely logical, given that the vocal tract is more open (i.e. the jaw is lower) when producing vowels than when producing coronal consonants. However, the opposite was true for two of the seven French speakers for whom data was available. Due to the apparently narrower labial constriction for back, rounded vowels in French (see above), perhaps the jaw is raised to allow the lower lip to make a constriction more easily.

A speaker-specific factor that may have had an effect on the apparent degree of influence of phonetic context on ISP is the speed at which each subject spoke. In Figure 3.2, the English subject with the *greatest* number of differences in ISP between the two phonetic contexts (Subject 6) is also one of two subjects who seemed to speak the *slowest*. He sometimes barely had time to finish one sentence before the next one was automatically presented to him to be read. In French, Subject 8 spoke noticeably *faster* than the other subjects and she had one of the *smallest* number of differences in ISP between the two phonetic contexts. Thus, it seems like speed of speech may influence the degree of context effects on ISP. However, the other English subject who spoke noticeably slowly (Subject 3) had the *smallest* number of differences in ISP between the two phonetic contexts. So, while it might be possible that for Subjects 6 and 8, speed of speech caused the phonetic context to have a greater effect on ISP than for most other subjects, it was certainly not the case for Subject 3.

The fact that ISP was found to be sensitive to carry-over effects of phonetic context is not surprising. Given that Hamlet and Stone (1981) found that jaw ISP is sensitive to anticipatory effects of phonetic context, it is possible that carry-over effects would also exist, and that they would exist for the tongue and lips as well. What *is* surprising is that no carry-over context effects were found for the tongue - only for the jaw and lips.[7] It is perhaps also surprising that the phonetic effects on the jaw and lip ISP were not the same across language groups. Since the decision on which frames to analyze as ISP frames was based solely on the lack of movement of the tongue, it is possible that the lips and jaw had not come to rest yet even though the tongue had. If this were the case, it might explain why the lips showed more phonetic context effects than the tongue in French, and why the jaw showed more than the tongue in English - the tongue and jaw had not yet moved as far away from the configuration they had been in for the sound preceding the ISP. However, that still does not explain why the lips did not show a similar effect of phonetic context in English, or the jaw a similar effect in French. In future

[7] Note, however, that the results at the end of Section 3.1.3 show directionality differences across the two phonetic contexts for all components of the tongue's ISP for French speakers and for the tongue tip and tongue root for English speakers.

studies it may be best to have articulator-specific criteria for what is counted as ISP. Thus, tongue measurements could be made when the tongue stops moving, and likewise for the lips and jaw. It may turn out that there is a time when all three are motionless, but this is an empirical question that is left for future research.

3.3. Summary of Chapter III

In Chapter III, the results were presented of Experiment 1, an investigation of whether or not ISP is language dependent (in a balanced phonetic context), and whether or not phonetic context has a carry-over effect on ISP (within a given monolingual speaker's speech). Hypotheses 1 and 2 were tested, namely that the ISP for Canadian English is significantly different from the ISP for Québécois French, and that within a given speaker's speech in a given language, that speaker's ISP differs depending on the phonetic segment that precedes the ISP.

Results support Hypothesis 1, but only for four components of ISP. For the tongue tip, the mean ISP for the monolingual English group was higher than that for the monolingual French group. This matches the findings of Gick et al. (2004) but is contrary to all of the existing non-instrumental evidence on the AS of RP English versus Parisian French. For upper and lower lip protrusion, again the mean ISP for the monolingual English group was higher (i.e. more protruded) than that for the monolingual French group. This is in accordance with Gick et al.'s findings for the upper lip, but not for the lower lip. For the degree of lip narrowing compared to a fully spread position, once again the mean ISP for the monolingual English group was higher (i.e. the corners of the mouth drawn in more in English from a fully spread position) than that for the monolingual French group.

Results in Chapter III also support Hypothesis 2, but only for some components of ISP, and those components are different in each language. Specifically, in English, only the jaw's ISP is influenced by phonetic context, but this is only in the speech of three of seven speakers. For the English speakers, no systematic effects of phonetic context were found for the ISP of the tongue or lips. In French, four components of ISP are influenced by phonetic context: the height of the lower lip and the vertical lip aperture for five speakers, and the horizontal lip aperture and the degree of lip narrowing for three speakers. For the French speakers, no systematic effects of phonetic context were found for the ISP of the tongue or jaw.

CHAPTER IV Experiment 2: AS in English-French Bilinguals

In Experiment 2, Hypotheses 3 and 4 were tested to broadly determine how a bilingual's pronunciation proficiency relates to his or her ISP(s) and how speaking mode affects a bilingual's ISP. Hypothesis 3 stated that a bilingual who is perceived as a native speaker of both languages has a different ISP for each language and will show the same types of crosslinguistic ISP differences that monolingual groups show; conversely, a bilingual who is perceived as *not* being a native speaker of at least one language will have fewer, if any, of the crosslinguistic ISP differences that monolingual groups show. Hypothesis 4 stated that bilingual speakers who are perceived as native speakers of each of their two languages have a unique bilingual-mode ISP that differs in all significant respects from both monolingual-mode ISPs (where "significant respects" are those respects in which differences obtain between the two monolingual modes).

4.1. Results

Results of Experiment 2 on bilingual subjects are now presented. In Section 4.1.1, the ISP for English monolingual mode is compared to the ISP for French monolingual mode. This comparison is done for all bilingual subjects in a test of Hypothesis 3. In Section 4.1.2, within the subset of bilinguals who were perceived as native speakers of both languages, ISP for bilingual mode is compared to ISP for monolingual mode in a test of Hypothesis 4.

4.1.1. Results: English Versus French (Monolingual Mode)

Each of Figures 4.1 to 4.3 shows a box plot containing the distribution of values at one of the components of ISP for all nine bilingual subjects in monolingual mode. Specifically, Figure 4.1 shows a box plot of values for tongue tip height; Figure 4.2 shows amount of jaw lowering, and Figure 4.3 shows lower lip protrusion. For each subject, the distribution of values is plotted for both monolingual English mode (e.g. "21E" for Subject 21) and monolingual French mode (e.g. "21F" for Subject 21). As with the box plots in Figure 3.1, the top, bottom, and line through the middle of each box correspond to the 75th percentile, 25th percentile, and 50th percentile (i.e. the median) respectively. The whiskers on the bottom and top extend from the 10th percentile and 90th percentile respectively. To allow for comparison, the dotted lines in each box plot show the group means for the French and English monolingual subjects. Figures 4.1 to 4.3 are given to show the individual variation within the bilingual subjects for one tongue, one jaw, and one lip measurement, and to show how their data compare to the monolingual group means. Results of statistical analyses of this data are presented following these figures.

Figure 4.1. Box plot of distribution of *tongue tip height* values for all 9 bilingual subjects in monolingual mode for both English and French

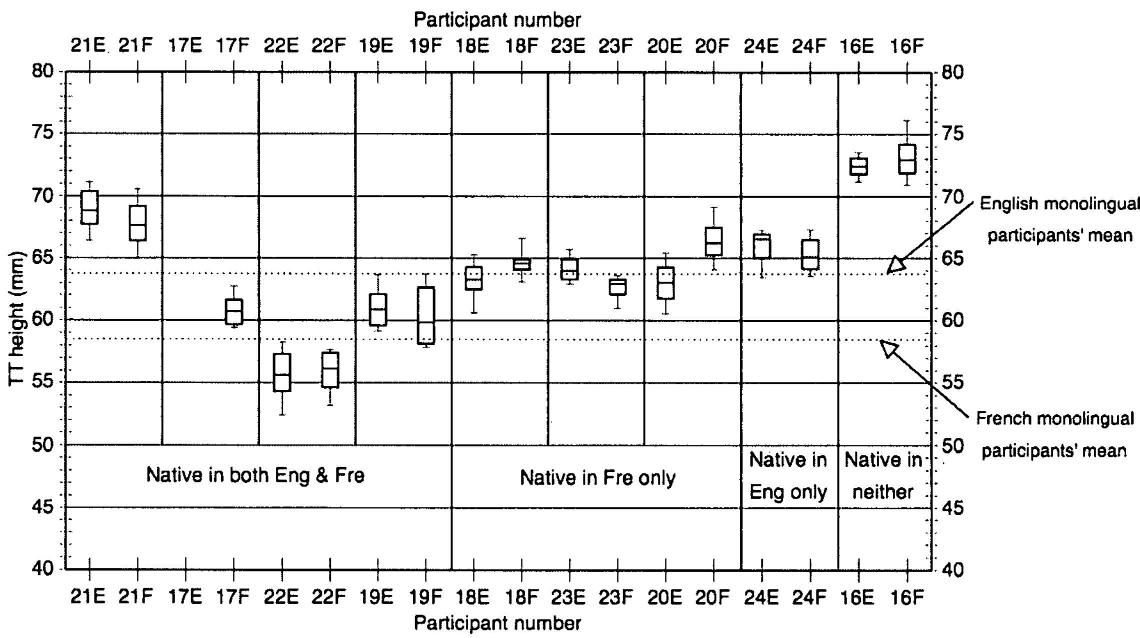


Figure 4.2. Box plot of distribution of *amount of jaw lowering* for all 9 bilingual subjects in monolingual mode for both English and French

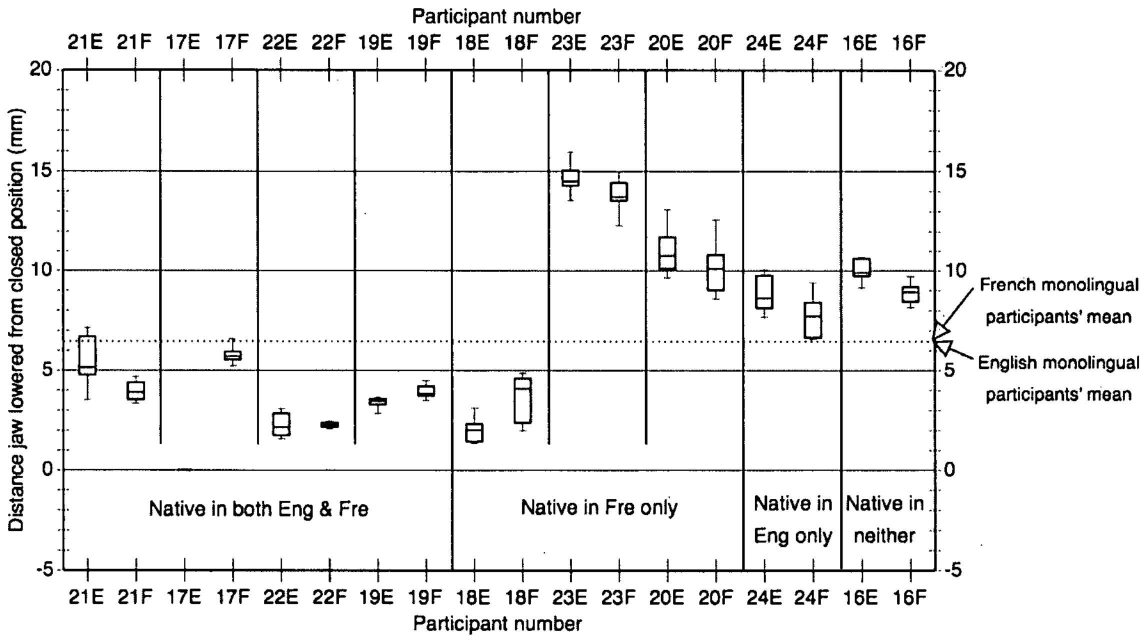
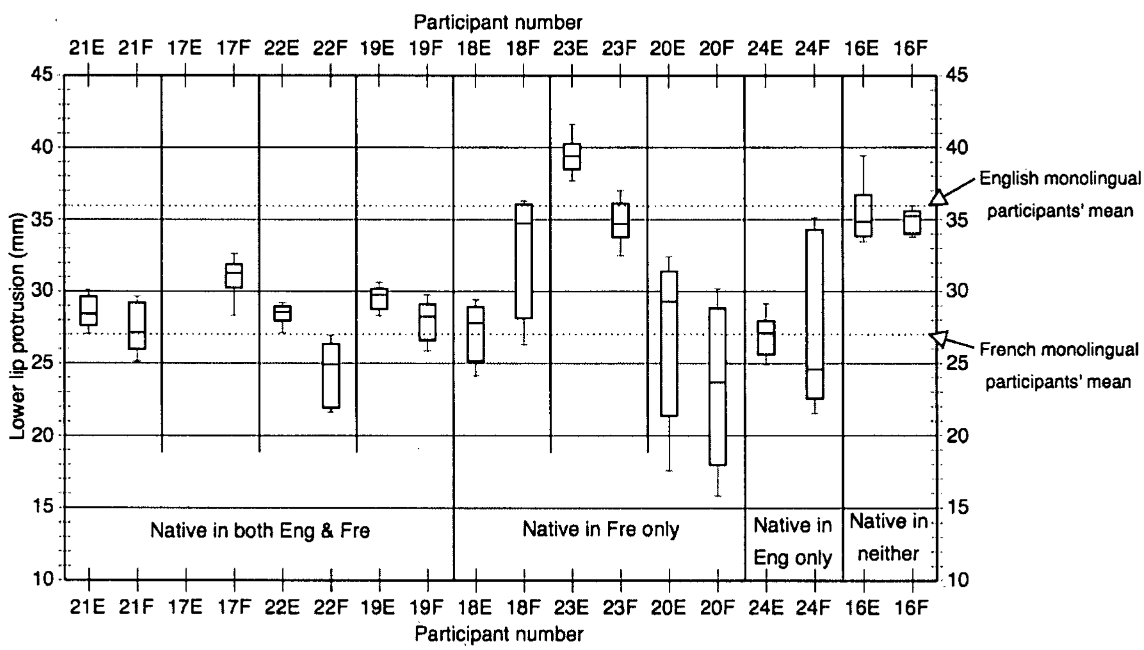


Figure 4.3. Box plot of distribution of *lower lip protrusion* values for all 9 bilingual subjects in monolingual mode for both English and French



Two things from Figures 4.1 to 4.3 are especially noteworthy. First, it is evident that there was no clear pattern as to how the monolingual groups' mean ISPs (as indicated by the dotted lines) compared to the ISPs of the different types of bilinguals. Second, the results for Subject 16, perceived as a native speaker of neither English nor French, were anomalous both from the perspective of her tongue tip height measurements and her lower lip protrusion variability. These points will be discussed further in Section 4.2.

The results in Figures 4.1 to 4.3 above show each bilingual subject's data distribution for three components of ISP, but they do not directly test Hypothesis 3. To test this hypothesis, t tests (assuming unequal variances) were carried out for each component of ISP to compare the monolingual-mode *English* means to the monolingual-mode *French* means for each bilingual subject. The dependent variable was the individual mean measurement of the ISP position of a given articulator for a given subject. The independent variable was the language of the monolingual-mode stimuli set (i.e. English versus French). Results of these 96 t tests (12 components of ISP for 8 subjects - monolingual-mode English data was not available for Subject 17) can be seen in Table 4.1 below. Grey shading indicates individual differences in these bilingual subjects that were the same as the four differences found between the monolingual groups in Section 3.1.1. A striped border surrounding a cell indicates significant differences that were opposite to the monolingual-group differences in Section 3.1.1.

Table 4.1. Significant differences ($p < .05$) between the ISP in French (F) and English (E) monolingual modes. The symbol "-" indicates no significant difference and "n/a" indicates data not available. Cell shading indicates identical results to monolingual-group differences, while striped cell borders indicate opposite results from monolingual-group differences.

		TONGUE				JAW	LIPS						
	Subj	TTht	TBht	TDht	TRrn	JAWl	ULlo	LLlo	ULpr	LLpr	Lvap	Lhap	Lnar
Perceived as Both	21	E>F	-	-	F>E	E>F	-	E>F	E>F	E>F	E>F	-	-
	17	(n/a)											
	22	-	-	-	-	-	F>E	E>F	E>F	E>F	E>F	-	n/a
	19	-	E>F	E>F	-	F>E	-	F>E	E>F	E>F	F>E	E>F	F>E
Perceived as Fre only	18	-	E>F	E>F	-	F>E	F>E	F>E	F>E	F>E	-	-	-
	23	E>F	E>F	-	-	-	-	-	E>F	E>F	-	-	-
	20	F>E	-	-	-	-	-	-	-	-	-	-	-
Perceived as Eng only	24	-	-	-	F>E	E>F	-	-	-	-	-	F>E	E>F
Perceived as Neither	16	-	-	F>E	F>E	E>F	F>E	E>F	-	-	E>F	E>F	F>E

Thus, for example, Subject 21 showed a significant difference between the English ISP and the French ISP for 7 of the 12 components of ISP. Three of these seven differences, namely for TTht, ULpr, and LLpr, were the same differences that were found between the French monolingual group and the English monolingual group in Section 3.1.1. The remaining four of the seven differences, namely for TRrn, JAWl, LLlo, and Lvap, are components of ISP that had shown no significant differences between the monolingual groups.

In Table 4.1, it is readily apparent that for all eight subjects for whom data was available, there was at least one component of ISP where the English ISP was different from the French ISP. Subject 19 had the greatest number of differences - 9 out of 12.

Subject 20 had the smallest number of differences - only 1 out of 12. All 3 subjects who were perceived as native speakers of both languages had 5 or more differences out of 12. In addition, all 3 subjects had greater upper and lower lip protrusion for the English ISP compared to the French ISP, the same difference that was found between the English and French monolingual groups in Section 3.1.1. Only one of the other five subjects had greater upper and lower lip protrusion for the English ISP, Subject 23, who could possibly be classified as a native speaker of both languages (and was indeed perceived to be a native speaker by two native listeners - see discussion in Section 4.2.1 below).

In Table 4.1, also note that three of the four subjects (18, 20, and 16) who had significant differences that were in the opposite direction to the monolingual group differences in Section 3.1.1 were all bilinguals who were either perceived as being native speakers of only one language or of none. These three speakers not only had significant differences that were opposite to the monolingual group differences, but they also had no significant differences that were in the same direction to monolingual group differences. The fourth subject who had a significant difference in the opposite direction to the monolingual group differences was Subject 19, perceived as a native speaker of both English and French. He had greater horizontal narrowing of the lips in French than in English.

As for Subject 16, who was perceived to be a native speaker of neither English nor French, note that she had eight significant differences between the English ISP and the French ISP, more differences than two of the bilinguals perceived as native speakers of both languages had. None of these eight are in the same direction as the monolingual group differences though, and one is in the opposite direction, as mentioned above. The other seven are all at components of ISP where no significant differences were found across monolingual groups in Section 3.1.1. However, out of these seven, three (i.e. TDht, ULlo, and Lvap) are significant in the opposite direction to *tendencies*, but not significant differences, in the monolingual group data.

4.1.2. Results: Bilingual Mode Versus Monolingual Mode

In order to test Hypothesis 4, ISP during bilingual mode was compared to ISP during monolingual mode for the subjects who were perceived as native speakers of both English and French (i.e. Subjects 21, 22, and 19), as well as for Subject 23 who was perceived to be a native speaker by two listeners. Recall that in bilingual mode the subjects had no way of knowing what language the next sentence to read would be in, whereas in monolingual mode the language of the stimuli was kept constant and the subject was aware of this. Hypothesis 4 proposed that bilingual speakers who are perceived as native speakers of each of their two languages have a unique bilingual-mode ISP that differs in all significant respects from both monolingual-mode ISPs (where "significant respects" are those respects in which differences obtain between the two monolingual modes). The results in Section 4.1.1 indicate that "significant respects" here means ULpr and LLpr for all four subjects, as well as TTht for Subjects 21 and 23, and Lnar for Subject 19.

Prior to conducting a test of Hypothesis 4, it was necessary to contend with the problem, mentioned in Section 2.3.2 and illustrated in Table 2.5, of having a small number of tokens available for each mode-language pairing (i.e. bilingual-mode English, bilingual-mode French, monolingual-mode English, monolingual-mode French). With such a small number of tokens per subject in each of these four categories, it was likely that some statistical differences between modes might not have been discovered. Thus, in order to prepare the data such that statistical power was increased, it was desirable to combine categories where possible. Since monolingual-mode English ISP was shown to be significantly different from monolingual-mode French ISP in Experiment Section 4.1.1, these two monolingual-mode categories could not be combined. However, the two bilingual-mode categories (i.e. bilingual-mode English and bilingual-mode French) had not been compared to see whether they could be combined in order to increase statistical power for the test of Hypothesis 4 across modes. Thus, bilingual-mode English ISP was compared to bilingual-mode French ISP by performing 15 t tests (assuming unequal variances) where the dependent variable was the individual mean measurement of the ISP position of a given ISP component (i.e. TTht, ULpr, LLpr, or Lnar) for a given subject (i.e. Subjects 21, 22, 19, and 23). The independent variable was the language (English or French) of the sentence preceding the ISP. Results of the *t* tests indicated no significant differences at a level of $p < .05$. Thus, the two categories of bilingual-mode data were combined for each subject and then a test of Hypothesis 4 was carried out.

The combined bilingual-mode dataset for each subject was compared to that subject's set of monolingual English data and the set of monolingual French data, in turn. Table 4.2 shows a summary of the outcome of 30 *t* tests (assuming unequal variances) comparing the combined ISP for bilingual mode with the ISP for each language's monolingual mode. There were 30 tests because there were 2 monolingual-mode data sets (one English and one French) for each of the 16 subject-measurement pairings (4 subjects X 4 components of ISP), minus 2 because Lnar data (in both languages) was unavailable for Subject 22. The dependent variable for these *t* tests was the mean ISP position of a given component of ISP for a given speaker for a given monolingual-mode language. The independent variable was the stimuli-presentation mode (monolingual versus bilingual).

Table 4.2. For each bilingual who was perceived as native in both languages, a comparison of bilingual-mode ISP ("Bil") to each of the monolingual-mode ISPs ("MonoEng" and "MonoFre") for 4 components of ISP. ["=" means no significant difference between the two; "<" and ">" indicate significant differences ($p < .05$); "n/a" means data not available]

Subject	Tongue tip height (TTht)	Upper lip protrusion (ULpr)	Lower lip protrusion (LLpr)	Horizontal lip narrowing (Lnar)
21	MonoEng = Bil MonoFre < Bil	MonoEng > Bil MonoFre = Bil	MonoEng > Bil MonoFre = Bil	MonoEng = Bil MonoFre < Bil
22	MonoEng = Bil MonoFre = Bil	MonoEng > Bil MonoFre = Bil	MonoEng > Bil MonoFre = Bil	n/a
19	MonoEng = Bil MonoFre = Bil	MonoEng = Bil MonoFre < Bil	MonoEng = Bil MonoFre < Bil	MonoEng < Bil MonoFre = Bil
23	MonoEng = Bil MonoFre < Bil	MonoEng = Bil MonoFre < Bil	MonoEng = Bil MonoFre < Bil	MonoEng > Bil MonoFre = Bil

In Table 4.2, note that for every pairing of a subject and a component of ISP, the bilingual-mode ISP was always equivalent to at least one of the monolingual-mode ISPs. It was never different from *both* language's monolingual-mode ISPs.

For the TTht measurement, note that Subjects 21 and 23 showed identical results, with the bilingual-mode ISP being equivalent to the monolingual-mode *English* ISP but greater than (i.e. having a higher tongue tip than) the monolingual-mode *French* ISP. Subjects 22 and 19 showed identical results to each other, with no significant differences between the bilingual mode and either of the monolingual modes. These two subjects had one ISP for the tongue tip, whether they were speaking French, English, or in bilingual mode. For lip protrusion, note that the upper lip's results match the lower lip's results for all four subjects. Subjects 21 and 22 pattern together in having a bilingual-mode ISP equivalent to the monolingual-mode *French* ISP, and Subjects 19 and 23 pattern together in having a bilingual-mode ISP equivalent to the monolingual-mode *English* ISP.

4.2. Discussion

In Experiment 2, ISP was measured in nine bilingual speakers of Canadian English and Québécois French in order to test Hypotheses 3 and 4. The results in Section 4.1 support Hypothesis 3, showing that bilinguals who are perceived as native in two languages have two ISPs and that the differences between these two ISPs mirror the differences between monolingual groups' ISPs. Results also show that bilinguals who are not perceived as native in at least one language do not have the same significant differences in ISPs. The results in Section 4.1 do not support Hypothesis 4, showing that bilinguals perceived as native in two languages do not have a unique bilingual-mode ISP that differs from both monolingual-mode ISPs in significant respects.

As mentioned above, from Figures 4.1 to 4.3, it is evident that there was no clear pattern as to how the monolingual groups' mean ISPs compared to the ISPs of the different types of bilinguals. For example, it is not necessarily the case that bilinguals perceived as native speakers of both languages have ISPs that fall between the two monolingual group means. Nor is it necessarily the case that bilinguals who are only perceived as native speakers of French or English have ISPs that are closer to the French or English monolingual groups, respectively. In addition, Figures 4.1 to 4.3 illustrate the anomalous results for Subject 16, perceived as a native speaker of neither English nor French. In Figure 4.1, the ISP for the tongue tip in both her languages is very different (much higher) than the tongue tip for all the other subjects. Although not shown in Section 4.1 in figures, the same is true for the other three of her tongue components of ISP (i.e. TBht, TDht, and TRrn). Her tongue's ISP is closer to the opposing vocal tract surface for all four of these tongue components of ISP. In Figure 4.3, for all subjects *except Subject 16*, lower lip protrusion is more variable in French than in English. Although not illustrated with a figure, the same is true for upper lip protrusion - it is more variable in French than in English for all subjects *except Subject 16*. It is possible that these factors could contribute to her not being perceived as a native speaker of either of her languages.

4.2.1. Discussion Regarding Test of Hypothesis 3

In Table 4.1, note that all three bilingual subjects who were perceived as native in two languages, and for whom data was available, showed a greater upper and lower lip protrusion in English than in French. These match two of the four significant differences between the two monolingual groups. Subject 23 also shows these differences and, although she was not perceived to be a native speaker of English, the native listener judgements of her English speech were very mixed. She was perceived to be a native speaker by 2 out of 10 judges, a near-native speaker by 5 out of 10 judges, and adequate, but not near-native by 3 out of 10 judges (see Appendix V). Since reasons for the judgements were not collected, it was impossible to determine if there was an anomalous reason for them such as a slightly different intonation pattern or one sound that was slightly mispronounced, but it is clear from her language background (see Appendix III) that she was exposed to a balance of both French and English from an early age at home. Thus, her results were also included with the results of the bilinguals perceived as native speakers of both languages in Section 4.1 and they will be included in the discussion here.

Hypothesis 3 stated that a bilingual who is perceived as a native speaker of both languages has a different ISP for each language and will show the same types of crosslinguistic ISP differences that monolingual groups show; conversely, a bilingual who is perceived as *not* being a native speaker of at least one language will have fewer, if any, of the crosslinguistic ISP differences that monolingual groups show. The results in Table 4.1 fully support this hypothesis. All subjects who were perceived to be native speakers of both of their languages had at least two, and at most three of the four crosslinguistic differences that the monolingual groups showed in Experiment 1. Of the other four subjects who were perceived not to be a native speaker of one or both of their languages, only one subject (24) showed a difference that matched the monolingual group differences found in Experiment 1. That difference was for the ISP of Lnar, the degree of lip narrowing from a fully spread position. In addition, three of the four subjects who were perceived to be non-native in at least one language had at least one crosslinguistic difference that was opposite to the monolingual group differences. This only happened once with one of the bilinguals who was perceived as native in both languages, and this was for the ISP of Lnar.

All subjects except Subject 22 showed at least one and at most two differences across languages in tongue components of ISP. However, the type and direction of the differences was not systematic, especially within each of the four groups of bilinguals.

Overall, the one common thread between all bilinguals who were perceived as native speakers of both of their languages was a greater upper and lower lip protrusion for the English ISP than for the French ISP. It appears that in bilinguals who are native in both languages, this component of ISP must mirror crosslinguistic differences in monolingual speakers. As two of the four bilinguals perceived as native in both languages had a higher tongue tip in English, just like the monolinguals in Experiment 1, it seems that this is a salient measure of proficiency, but one of secondary importance compared to lip protrusion. Subject 20, perceived as a native speaker of French only, had a higher tongue tip in French, the opposite of the monolinguals in Experiment 1. Although it is not possible to determine with certainty the reason she was not perceived as a native English speaker, it is possibly due to her opposite tongue tip setting, but certainly also is due to her lack of a difference in lip protrusion across languages. For lip protrusion, this same reason can be used with all the bilinguals who were not perceived to be native in one or more of their languages. As for Lnar, the degree of lip narrowing from a fully spread position, results were very mixed and thus it can be concluded that this component of ISP is probably not an important factor in whether a bilingual is perceived as a native speaker of a given language or not.

4.2.2. Discussion Regarding Test of Hypothesis 4

Hypothesis 4 was tested and the results presented in Section 4.1.2. This hypothesis was not supported by the data. In Table 4.2, for every cell in the table (i.e. every subject-component pairing), bilingual-mode ISP was the same as at least one of the monolingual-mode ISPs. It was never different from *both* language's monolingual-mode ISPs. This is a clear refutation of Hypothesis 4 because Hypothesis 4 predicts that there should exist a unique bilingual-mode ISP for TTht for Subjects 21 and 23, for ULpr and LLpr for all four subjects, and for Lnar for Subject 19.

As mentioned in Section 4.1.2, Subjects 21 and 22 pattern together in having a bilingual-mode ISP equivalent to the monolingual-mode *French* ISP, and Subjects 19 and 23 pattern together in having a bilingual-mode ISP equivalent to the monolingual-mode *English* ISP. It is interesting to note that for all four of these subjects, the ISP for lip protrusion for bilingual mode resembled the monolingual-mode language that was dominant in the subject's daily use at the time of the experiment. For subjects 21 and 22, French was the dominantly used language. Subject 21 was living in Vancouver but used exclusively French at home with her children and husband. She only used English at her part-time job and with some friends outside of the home. Subject 22 was living in Montreal and was working in French. For Subjects 19 and 23, English was the dominantly used language. Both subjects were living in Vancouver at the time of the experiment. Subject 19 judged his typical week to be 90% English - school and work were both entirely in English. The only chances he had to speak French were with his parents and siblings. Subject 23 judged her typical week to be 70% English. Thus, for the most salient components of ISP (ULpr and LLpr), all four subjects have bilingual-mode ISPs that are equivalent to the ISP of their dominantly used language at the time of the experiment. Perhaps this was because the bilingual-mode task was more complex than the monolingual-mode task, and so these subjects simply chose the ISP they were most habituated to using at the time. Notice that there was no relationship between these subjects' L1 and the language their bilingual mode resembled. The L1 of Subject 21 was English, and that of Subjects 22, 19, and 23 was French.

Lnar showed mixed results, but note that its importance for the bilinguals is negligible. In Table 4.1, it was clear that the bilinguals followed the monolingual group differences in their lip protrusion and for some subjects in their tongue tip height, but not in their degree of lip narrowing. Thus, it is not surprising to see no clear pattern emerging from the Lnar results for these bilinguals.

4.3. Summary of Chapter IV

In Chapter IV, the results were presented of Experiment 2, an investigation of (1) whether or not a bilingual's ISP is language dependent (in a balanced phonetic context in monolingual-mode speech), and (2) whether or not a bilingual speaker's ISP is mode dependent (i.e. different for monolingual-mode speech versus bilingual-mode speech). Hypotheses 3 and 4 were tested, and results strongly support Hypothesis 3, but do not support Hypothesis 4. Specifically, upper and lower lip protrusion were greater for the English ISP than for the French ISP, in all bilinguals who were perceived as native speakers of both of their languages (and Subject 23), but in none of the other bilinguals. Tongue tip height was also a salient component of ISP for bilinguals perceived as native in both languages, but it was of secondary importance compared to lip protrusion. As for the degree of lip narrowing from a fully spread position, this component of ISP was concluded not to be an important factor related to a bilingual's proficiency in Canadian English and Québécois French.

As for bilingual mode versus monolingual mode, Hypothesis 4 was not supported, meaning that bilingual-mode ISP was not uniquely different from both monolingual-mode ISPs. However, an interesting finding was that for the most salient ISP components (ULpr and LLpr), all four subjects have bilingual-mode ISPs that are equivalent to the ISP of their dominantly used language at the time of the experiment.

CHAPTER V General Discussion and Conclusions

5.1. General Discussion

Results of Experiment 1 showed that, for monolinguals, ISP is sensitive to the language being spoken, as well as being sensitive to the phonetic context preceding the ISP. The four components of ISP that show language-specific differences are tongue tip height, upper and lower lip protrusion, and the degree of horizontal lip narrowing compared to a fully spread position. The components of ISP that show sensitivity to phonetic context are the amount of jaw lowering in English (in three of seven subjects), the height of the lower lip and the vertical lip aperture in French (in five of eight speakers), and the horizontal lip aperture and the degree of lip narrowing, also in French (in three of eight speakers).

Results of Experiment 2 showed that, for bilinguals, ISP is once again sensitive to the language being spoken, and also that it is sensitive to speaking mode, in that bilingual-mode ISP is identical to the monolingual-mode ISP of the speaker's dominantly used language at the time. For bilinguals who are perceived as native speakers of both of their languages, their two ISPs differ from each other in three of the four ways that the monolingual groups differed in Experiment 1. In addition to confirming Hypothesis 3, these within-speaker bilingual results validate the method and normalization used across speakers in Experiment 1. Mirroring the two monolingual groups, upper and lower lip protrusion for all 4 of these bilinguals were greater in English than in French. However, none of the bilinguals who had an accent in one or both languages showed this lip protrusion difference between languages. Tongue tip height differences between languages also had a tendency to mirror the two monolingual groups, with the tongue tip being higher in English ISP than in French ISP for two of the four bilinguals perceived as native in both languages. Again, none of the bilinguals who had an accent in one or both languages showed this tongue tip height difference between languages, and in fact one showed a difference in the opposite direction. The degree of horizontal lip narrowing compared to a fully spread position is not a salient difference across languages in order to be perceived as a native speaker of both languages - none of the four bilinguals perceived as a native speaker of both languages had this difference, and in fact one had the opposite difference from the monolingual groups.

In Experiment 1, it was shown that upper and lower lip protrusion are the components of ISP that are least affected by phonetic context. It is interesting to note that these are the two strongest differences in ISP across monolingual language groups and they are also the two differences that are shared in common among every bilingual speaker perceived to be native in both languages. As mentioned in Chapter 1, Laver (1980) suggested that a language's AS can be overridden by the requirements of a particular sound segment in a language. Since upper and lower lip protrusion are least affected by phonetic context and the most salient differences across Canadian English and Québécois French, it appears that lip protrusion is a component of AS that is *less* apt to be overridden by the articulatory requirements of individual sound segments. On the other hand, based on the effects of context on ISP observed in Experiment 1, degree of lip narrowing from a maximally spread position is *more* apt to be overridden by the demands of individual segments, at least in French.

With the tongue only coming to rest in about half of the pauses between sentences (55% for English subjects, 43% for French subjects, and 57% for bilingual subjects), one may argue that the ISP is not a target configuration, contrary to what Gick et al. (2004) found for English and French. However, there are at least two factors to be considered before jumping to this conclusion. First, many of the tokens where the tongue failed to reach a speech rest position did so because of non-linguistic events such as swallowing. Second, because of the speed and automaticity of the stimuli presentation style in Experiments 1 and 2, it was often the case that a subject did not finish saying a previous sentence before the next one was presented (leaving no time to put the system into a rest posture). The consequences of this second factor were also seen when a speaker made a speech error that he or she decided to correct, leaving no time to pause between sentences. In an initial pilot study, a 2-second pause was used but it was found that some subjects had too much time and were bracing their tongues against their palates, possibly indicative of an absolute rest position, or a swallow, instead of a speech rest position. A 1-second pause was chosen for the present study to reduce this type of occurrence. If, contrary to the findings in the second experiment of Gick et al. (2004), ISP does *not* behave like a speech target, the phonetic context should have a *very* noticeable effect on ISP as there would be no reason to move one's articulators between stimuli, other than simply to relax one's muscles. Since, especially in English, phonetic context does *not* have a clear effect on ISP (except for a weak effect on jaw posture), this is consistent with the view that ISP behaves like a speech target in English. To further test this question, in future studies, velocity profiles of the articulators can be examined to determine whether or not movement into ISP is systematically similar in velocity to movement into a speech target.

In Experiment 1, the components of ISP with the greatest crosslinguistic *similarities* were the position of the tongue root (p = .9848 across the two monolingual groups) and the jaw (p = .9254 across the two monolingual groups). Note that these two articulators somewhat determine the position of some of the other articulators. Specifically, the tongue is resting on the jaw and hence jaw height will have a strong effect on tongue height. Also, because of the hydrostatic nature of the tongue, the degree of tongue root retraction can have a great effect on the height of the tongue body. Perhaps then, the jaw and tongue root are grossly positioned (and English and French have similar gross positions for these) and then the finer adjustments are made by the rest of the components of the tongue and the lips. Note that since jaw height was not significantly different across the two languages in Experiment 1, the difference found in tongue tip height had nothing to do with the jaw.

5.1.1. Implications of this Research

One important implication of these results is for the field of L2 acquisition, especially pronunciation teaching and learning. In the last 50 years, the methods and status of pronunciation teaching have fluctuated greatly (see Morley, 1991, and Celce-Murcia et al., 1996, for thorough reviews), but recently there have been an increasing number of calls for the inclusion of AS in second language teaching curricula (Brown, 1995; Celce-Murcia et al., 1996; Collins & Mees, 1995, 2003; Esling, 1987; Esling & Wong, 1983; Jenkins, 1998; Jones & Evans, 1995; Kerr, 2000; Mompeán-González, 2003; Pennington, 1996; Pennington & Richards, 1986; Rich, 2003; Thornbury, 1993). These calls and the methods that are used to teach AS exist in spite of the fact that there has been no empirical evidence for language-specific ASs. Studies of LTAS have demonstrated similarities and differences in the acoustics of two different languages, but as mentioned previously, LTAS does not necessarily directly relate to AS, and this acoustic information provided by LTAS is often very difficult if not impossible to map onto articulatory parameters for L2 learners. The results of this dissertation have shown that AS is indeed language specific, and have shown exactly where the relevant differences in AS occur between Canadian English and Québécois French. These results, along with those of Gick et al. (2004), provide much-needed quantitative evidence to support the teaching of AS.

Another implication of the present results is for studies that have used the ISP as a baseline from which to compare and measure components of the postures of various speech sounds. Examples of this type of study include Adler-Bock (2004), who used the default rest position for correcting her before-treatment versus after-treatment ultrasound images of the tongue, McDowell (2004), who also used the rest position across her ultrasound data as a reference for comparing tongue shapes, and Oh (2004), who used the average ISP in her ultrasound images of the tongue and made measurements relative to that one position. The fact that in Experiment 1 none of the components of the tongue ISP were systematically influenced by phonetic context is encouraging for the above studies, as none of them had systematically controlled for phonetic context around the ISP.

This research also has implications for the claims of some researchers who equate a language's schwa with that language's AS. This position has been taken despite the fact that Gick (2002) has shown that, contrary to traditional belief, American English schwa has an articulatory target - retraction of the tongue root relative to pre-speech posture. For example, Kühnert & Fougeron (2004) state that "Broadly speaking, the neutral vowel schwa can be considered as a kind of homebase to which the tongue returns frequently in the course of speech. As such, it can be considered as an indicator of the overall articulatory setting of a language." The fact that European-French schwa is phonetically rounded (Price, 1991) and impressions of Parisian-French AS described in Section 1.2.1 have the lips rounded supports Kühnert & Fougeron's position. More support comes from

Barnes and Kavitskaya (2002), who found significant visible lip rounding remaining on "deleted" inaudible schwas spoken by one speaker of (presumably European) French. If Kühnert & Fougeron's claim is true, then the results of Experiments 1 and 2 make specific predictions for the differences in articulation of Canadian-English schwa versus Québécois-French schwa: Canadian-English schwa should have greater lip protrusion and a higher tongue tip than Québécois-French schwa and should not have the retracted tongue root position Gick (2002) found for American English. A test of these predictions is left for future research.

The results from Chapter IV showing that there is no unique ISP for bilingual speech mode (i.e. one that is different from each monolingual-mode ISP) suggest that differences between monolingual mode and bilingual mode (Grosjean, 1998) do not hold at the phonetic level. It is possible that bilingual mode is the norm for a bilingual's AS, and hence their bilingual-mode ISP defaults to the same ISP as the dominant language of their present life. For a bilingual, speaking in the non-dominant monolingual mode is not the norm and perhaps the ISP for this mode must be actively set. Evidence showing that bilinguals reset the phonetic parameters of their languages, depending on the conversational setting and on their proficiency in each language, has come from various studies, e.g., see Flege, Schirru, and MacKay (2003), Sancier and Fowler (1997), and Watson (1990, 1991).

5.2. Limitations and Future Directions

There are a number of limitations to be considered in this study, such as the relative accuracy of the measurement systems used, the method of normalizing the data, the criteria for distinguishing between a bilingual and a monolingual, and other issues. These limitations, as well as directions for future studies are now considered below.

One limitation of the present study was the relative degrees of accuracy of the Optotrak and ultrasound measurement systems. The spatial resolution of Optotrak is much higher than that of ultrasound. Very small differences (1 mm or less) in lip position can be detected with Optotrak, but these same differences in tongue position may be missed with ultrasound. This difference in spatial resolution may have been a factor in (1) the finding of more crosslinguistic differences in lip ISP than in tongue ISP, and (2) the finding of many more phonetic context effects on the lips than on the tongue. As for the accuracy of the ultrasound system, there have been conflicting reports. Beasley, Stefansic, Herline, Guttierez, and Galloway (1999, p. 132), in an Optotrak calibration study of an ultrasound probe, show that "it is possible to track and (sic) ultrasound probe in space, with errors on the order of 1.0 mm" and that "it is possible to register ultrasound images with physical space, with average target errors on the order of 3.0 mm." On the other hand, Schreiner, Galloway, Lewis, Bass, and Muratore (1998, p. 640) had results that showed ultrasound to be much more accurate: "the ultrasonic system differed from the [Optotrak] pointing system by a mean of 0.5 mm with a 95% confidence interval of +/- 0.1 mm when localizing the same point in space." As cited by Kaburagi & Honda (1994, p. 2270): "Honda (1985) showed that the tracing error of the tongue contours from the [B-mode] ultrasonic images was 1.1 mm on average by comparison with x-ray pictures taken at the same time as the ultrasonic scanning." It should be pointed out though that x-ray images are not true slices of the vocal tract. They contain shadows that potentially make small measurements unreliable.

A major challenge of any phonetic study where group means are calculated based on results from a number of different speakers is how to normalize the data. Honda, Maeda, Hashi, Dembowski, and Westbury (1996, p. 784) point out that the shape of "the space within which articulation takes place [...] is not the same among individuals or races". Although this study has serendipitously controlled for race, individual differences in vocal tract morphology undoubtedly added noise to the results, possibly masking some differences between the AS of each language. However, the normalizing of the data that was done attempted to minimize across-subject differences. In future studies, an MRI or CT scan of each subject's vocal tract could be taken and used for scaling purposes. However, because of the lack of agreement on what anatomical distances are best to use for scaling data, even that method may not provide the best answer.

Another limitation of the present research has been the ability to make a systematic statement about the relationship between ISP and the various proficiencies of bilinguals who are *not* perceived as native in both languages. Because of the multitude of factors that influence the success of a bilingual's acquisition of more than one language (Marinova-Todd, 2003), it is very difficult to control for the background of the subjects such that all factors are balanced. In the present study, because of the difficulty of finding, in Vancouver, relatively balanced bilinguals who are perceived as native speakers of both English and French, sacrifices had to be made as to the degree of similarity between bilinguals in this study.

For degree of jaw lowering, the chin marker is attached to the skin on the chin and not to the mandible directly, and it is highly likely that the skin, and therefore the marker, can move (stretch) while the mandible remains stationary. However, this is probably the case mostly when the lower lip is raised to make a labial constriction during speech. It is expected that during ISP, assuming the lips are not closed, the chin marker would represent a reasonably accurate indication of the position of the mandible. Zerling (1992, p. 3) stated that "behind the apparent simplicity of the binary phonological feature [+/-round] there lies a complex pattern of activity for the lips". There are a number of measurements one could make to calculate lip aperture. The most salient measurement is probably the area of the opening between the lips, but this is impossible to measure using Optotrak, and even with video it is difficult to determine the correct coronal cross-section at which to measure this area. Using Optotrak, the best possible measurements to make are the width of the opening (very roughly approximated in this case by the distance between the markers at each corner of the mouth) and the height of the opening (very roughly approximated here by the distance between the upper lip marker and the lower lip marker).

Takano, Honda, and Dang (2002) give evidence suggesting that lateral tongue shape is much different for different vowels. As the present study has only focused on midsagittal tongue shape, there is the potential that other crosslinguistic differences in ISP may exist in the coronal view of the tongue - something that is, in fact, predicted by the results of Section 3.1.1 showing greater English tongue measures for all components of the tongue ISP. Crosslinguistic differences in *coronal* tongue shape would most certainly interact with crosslinguistic differences in *midsagittal* tongue shape. A multivariate analysis to see which components of ISP correlate could be done in future work. Since the tongue is a hydrostat, it would not be surprising to discover a causal relationship among different components of ISP, both within the midsagittal plane and between the coronal and midsagittal planes.

Another possible limitation of the present study is the fact that the English stimuli all contained some low frequency and/or nonsense words, whereas none of the French stimuli contained such types of words. Thus, the task was technically not exactly the same across languages, and was probably more complex in English. An attempt was made to compensate for this by allowing a practice trial in English, but it is not known whether there was still a task effect present in the results. Another difference between the English stimuli and the French stimuli is the length of the sentences. As can be seen in Appendix VI, the English sentences range in length from 6 to 11 syllables. However, the French sentences, which can be seen in Appendix VII, range in length from 9 to 16 syllables. With the average sentence to read being longer in French, if the English and French speakers read at the same rate (syllables per second), then there was less time between sentences to return to ISP in French[8], and if the lips have more inertia than the tongue, then they will lag behind in the return to the ISP. This may be one reason why phonetic context played a greater role for the French speakers, at least for the lips.

A difficult question for any study that attempts to define certain phonetic properties of a group of speakers of a language is how narrowly to define that language. I have used the terms "Canadian English" and "Québécois French" in this dissertation, but there certainly could be great variation in ISP among the English dialects present in Canada, and the French dialects present in Quebec. Each of these dialects could actually have its own ISP, and so the results of this study necessarily contain added noise from the variability of ISPs within Canadian English speakers and Québécois French speakers. In future instrumental studies, tighter control of the origin of each group of speakers might help to reduce such noise and show dialectal differences in ISP. Such studies would synergize with non-instrumental data from a wider range of dialects and languages than have been studied to date.

Although *carry-over* effects of phonetic context were analyzed in Chapter 3, *anticipatory* effects were assumed not to exist because of the method of stimuli

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[8] However, with the complex codas and diphthongs in English, it would not be surprising if the syllable rate in French were higher than in English.

presentation. However, it would have been prudent to do an analysis of anticipatory effects of phonetic context because if anticipatory effects were found, it would call into question the carry-over coarticulation results.

In future studies, the origin of AS and its possible relation to the frequency of occurrence of a language's sounds should be investigated. Gick et al. (2004, p. 222) pointed out that it is possible that language-specific ASs are "specified parts of a language's inventory (and hence learned from other speakers) or functionally derived properties of speech motor production". In the latter case, if AS is functional, it probably arises out of motor efficiency requirements and is directly related to the frequency of the sounds of a language. This idea was suggested as long ago as Wilkins (1668, p. 381), cited in Laver (1978, p. 3): "Another different mode of Pronunciation betwixt several Nations may be in regard of strength and *distinctness* of pronouncing, which will specially appear in those kind of Letters which do most abound in a Language." Laver (2000, p. 39) pointed out that AS could be "an emergent property of segmental performance". This is exactly what Honikman (1964, p. 76) proposed when she stated that "the internal articulatory setting of a language is determined, to a great extent, by the most frequently occurring sounds and sound combinations in that language." Honikman (1964) predicted that based on the greater frequency of [a] in French, the jaw AS would be lower in French than in English. This prediction was not upheld by the results of the present research, which showed no difference in jaw ISP between English and French.

5.3. Conclusions

This research has shown that articulatory setting (AS), observed through the window of inter-speech posture (ISP) of the articulators, is significantly different between Canadian English and Québécois French, both across monolingual groups and within individual bilingual speakers. The components of ISP that differ across these languages between monolingual groups are upper and lower lip protrusion, tongue tip height, and the degree to which the corners of the mouth are drawn towards the midsagittal plane from a maximally-spread position. In Canadian English, the upper and lower lips are significantly more protruded, the tongue tip is higher, and the corners of the mouth are drawn farther toward the midsagittal plane.

It was also shown that ISP is significantly affected by carry-over coarticulation of phonetic context, but in different ways in different languages and for different speakers. In English, only the ISP of the jaw is systematically affected by phonetic context, and this in only three of seven subjects. In French, only the ISP of the lips is affected by phonetic context - specifically the height of the lower lip and the vertical lip aperture for five of eight speakers, and the horizontal lip aperture and the degree of lip narrowing for three speakers.

Within individual bilingual speakers who are perceived to be native speakers of both Canadian English and Québécois French, all speakers show the same upper and lower lip protrusion differences (i.e. English more protruded than French) as the monolingual groups, and half of the speakers show the same tongue tip differences (i.e. English higher than French) as the monolingual groups. These are the only relevant crosslinguistic differences between ISPs for bilinguals who are perceived as native in both languages. Finally, it was shown that bilinguals who are perceived as native speakers of both Canadian English and Québécois French do not have a unique ISP for bilingual speech mode (i.e. when the bilingual is ready to speak in either language). Instead, the ISP for each of these speakers in bilingual speech mode is equivalent to the monolingual-mode ISP of that speaker's dominantly-used language.

Thus, in summary, this research shows that ISP (and hence AS) is language specific between monolingual subjects and within bilingual subjects. It is also phonetic context specific, but is not mode specific.

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Appendix III Detailed background on subjects

Monolingual English subjects

Subject	Gender	Age	Place of Origin	Notes
1	Female	28	Winnipeg, MB	"dabbled" in Hebrew, French, Japanese & Spanish, but not fluent in any of them; had been living in Vancouver for over a year.
2	Female	25	Kelowna, BC (about 250 km east of Vancouver)	French Immersion from Grades 1-7 (all day French, but in Grades 4-7 she had 1 hr per day in English); high school - half French, half English; parents & siblings monolingual English.
3	Male	25	Vancouver, BC	studied French in high school; very slow, deliberate speech; slight facial twitch, but didn't seem to affect lips; was not so comfortable during data collection.
4	Female	22	Vancouver, BC	studied French in high school.
5	Female	36	Southern ON (ages 0-11); various U.S. states (ages 12-20); Fraser Valley, BC (ages 21-36)	studied French from Grade 7 to college; parents spoke Frisian & Dutch together, but the home language was always English.
6	Male	27	Richmond, BC (part of Greater Vancouver)	studied a little bit of Japanese in high school. His mother is Japanese, but she apparently speaks English with no accent.
7	Male	24	Sudbury, ON	had been living in Vancouver for 1 year at time of data collection.

Monolingual French subjects

Subject	Gender	Age	Place of origin	Notes
8	F	18	St-Jean-Chrysostôme, QC (across the St. Lawrence R. south of Quebec City)	ended every stimuli sentence with a rising intonation. Noticeably thin lips. Seemed to slur words at times - possibly due to fast speech.
9	F	21	Sherbrooke, QC (equidistant - about 150 km - east of Montreal & south of Quebec City)	spoke loudly and clearly. Wore the experiment glasses over her own glasses.
10	F	51	Montreal, QC	spoke some English, but with difficulty & heavy accent. Started learning in high school. Very thin lips - especially upper lip. Wore experiment glasses over her own.
11	M	18	Lévis, QC (across the St. Lawrence R. south of Quebec City)	spoke some English, but with a heavy accent. Had been in Vancouver for 1 week. Said his jaw was a bit sore from speaking English this week and that his friend (Subject 13) felt the same way!
12	F	19	St-Adolphe d'Howard, QC (about 70 km northwest of Montreal)	Trials 1 & 2 were done with only the experiment glasses. Trials 3-6 were done with the experiment glasses over top of her own glasses (her eyes were getting tired).
13	M	18	St. Henri de Lévis, QC (across the St. Lawrence R. south of Quebec City)	spoke English with a heavy accent. Had been in Vancouver for 1 week. Basic English vocabulary missing.
14	F	22	Mont Tremblant (about 100 km northwest of Montreal)	Studied English in college (compulsory) and spoke it with a noticeable but not too heavy accent. Has been living in Vancouver for 1 year but 60% of her time in French. Before coming to Vancouver, 90% of her time in Quebec was spent in French.
15	F	22	Jonquiére, QC (near Chicoutimi, about 175 km north of Quebec City)	clear voice.

Bilingual English-French subjects

Sub-ject	Age & gender	Places lived	Notes
16	33 - F	St. Jérôme, QC (ages 0-22); Vancouver, BC (ages 22-33)	L1=Fre; Age of exposure to Eng = 12; Parents both monolingual Fre; Typical week now 90% Eng, 10% Fre.
17	23 - F	Ottawa, ON (ages 0-23); Vancouver, BC (last 1.5 mths)	L1=Eng; Age of exposure to Fre = 5; Only Fre from kindergarten to 3rd year university; Spoke to Mom in both Eng and Fre; Typical week now 95% Eng, 5% Fre; In Ottawa, typical week was 65% Eng, 35% Fre.
18	23 - F	Quebec City, QC (ages 0-4); Ottawa, ON (ages 5-23)	L1=Swiss German - spoke it with parents; Age of exposure to Fre = 3 (spoke Fre with sister); Age of exposure to Eng = 5 (but she said her Eng was not so good until university in Ottawa.) Typical week now 80% Eng, 20% Fre.
19	19 - M	Greenwood, NS (ages 0-4); Montreal, QC (ages 5-9); Vancouver, BC (ages 10-19)	L1=Fre; Age of exposure to Eng = 9; Typical week now 90% Eng, 10% Fre; Monolingual Fre parents. Has always spoken to siblings in Fre. Not particularly used to reading in Fre.
20	25 - F	Montreal, QC (ages 0-25, except for 1 year in Japan teaching Eng)	L1=Fre; Age of exposure to Eng = 3; Typical week now 60% Fre, 40% Eng; attended Eng pre-school, then Fre kindergarten & above (but 1 hr/wk Eng lesson & Eng with friends on her street) until Eng full-time in university.
21	37 - F	ON (ages 0-10); Quebec City, QC (ages 11-22); Vancouver, BC (ages 24-37)	L1=Eng; Age of exposure to Fre = 3; Mother's L1=Fre; Father's L1=Italian, but not spoken at home; Fre only from ages 11-22 (home, school, peers); Eng only from ages 24-34; From 34-37, Fre only at home with husband & kids, Eng only at work. (Typical week now: "Home days" = 66% Fre; "Work days" = 66% Eng.)
22	23 - M	Montreal, QC (ages 0-23)	L1=Fre; Age of exposure to Eng = 13, but exposed to Eng TV at age 6; Both parents & brother monoling Fre.
23	38 - F	Montreal, QC; Vancouver, BC	L1=Fre; Age of exposure to Eng < 5; spoke Fre with mother, Eng with father, but parents spoke Eng to each other; schooled in Fre only (including CGEP); Typical week now 70% Eng, 30% Fre; Phonetically trained, speech-language pathologist.
24	46 - F	Australia (ages 0-6); Montreal, QC (ages 7-28); Quebec City, QC (ages 29-45); Vancouver, BC (age 46)	L1=both Eng & Slovene; Age of exposure to Fre = 7; At age 4.5, Eng was dominant and parents switched to Slovene-only at home. From ages 4.5 to 7.5, Slovene was dominant. Eng schooling in Montreal, but worked in Fre; 100% Fre for 16yrs in Quebec City; Typical week now 30% Fre, 70% Eng. Hardly any Slovene spoken since age 8.

Appendix IV Definition of ratings in foreign accent rating task

Native French listeners were given the following guidelines and asked to rate speakers on the following scale. Although not shown here, there was space for Speakers A to N.

5	=	**Le Français est sa langue maternelle.**
4	=	**Le Français est son deuxième langage étudié, mais il est très bien maîtrisé.**
3	=	**Le Français est son deuxième langage étudié, et elle/il le parle convenablement.**
2	=	**Le Français est son deuxième langage étudié, mais s'exprime avec difficulté.**
1	=	**Le Français est son deuxième langage étudié, mais franchement médiocre.**

la personne A: ____________________

la personne B: ____________________

la personne C: ____________________

Native English listeners were given the following guidelines and asked to rate speakers on the following scale. Although not shown here, there was space for Speakers A to M.

5	=	**English is her/his mother tongue.**
4	=	**English is her/his 2nd language, but s/he has mastered it very well.**
3	=	**English is her/his 2nd language, and s/he speaks it adequately.**
2	=	**English is her/his 2nd language, and s/he speaks it with difficulty.**
1	=	**English is her/his 2nd language, and s/he speaks it very poorly.**

Person A: ____________________

Person B: ____________________

Person C: ____________________

Appendix V Detailed results of foreign accent rating task

Table 3.2. French native listener judgements of subjects' French utterances on a scale from 1 to 5 where only 5 signifies a native speaker

Subject number	Rater number										
	8	9	10	11	12	13	14	15	A	B	avg.
2 (mono E)	2	2	2	3	3	3	3	2	3	3	2.6
16	3	3	3	4	4	4	4	4	4	4	3.7
17	4	4	4	5	5	5	5	5	5	5	4.7
18	4	5	5	5	5	5	5	5	5	5	4.9
other (mono F)	5	4	5	5	5	5	5	5	5	5	4.9
19	2	4	4	4	4	4	5	5	5	5	4.2
5 (mono E)	1	2	2	2	2	2	2	1	2	3	1.9
20	4	4	5	4	4	5	5	4	5	4	4.4
other (mono F)	4	5	4	4	5	5	5	5	4	5	4.6
21	5	4	5	5	4	5	5	4	5	4	4.6
other (E-dom)	2	3	3	2	2	3	3	2	3	3	2.6
22	5	4	5	5	5	5	5	5	5	5	4.9
23	4	4	5	5	5	5	5	5	4	5	4.7
24	3	3	-	-	4	-	4	4	4	4	3.7
avg.	3.4	3.6	4.0	4.1	4.1	4.3	4.4	4.0	4.2	4.3	4.0

Table 3.3. English native listener judgements of subjects' English utterances on a scale from 1 to 5 where only 5 signifies a native speaker

Subject number	Rater identification										
	PB	CX	KK	RW	MC	RK	KL	BS	DQ	HM	avg.
2 (mono E)	5	5	5	5	5	5	5	5	5	5	5.0
16	4	3	3	4	3	4	2	3	4	3	3.3
17	5	4	5	5	4*	5	5	5	5	4	4.7
18	4	4	4	4	4	3	4	4	4	4	3.9
19	4	5	5	5	5	5	4	4*	5	4	4.6
5 (mono E)	5	5	5	5	5	5	5	4	5	5	4.9
6 (mono E)	5	4	5	5	5	5	4	5	5	5	4.8
20	4	3	4	4	4	4	3	4	4	4	3.8
21	5	5	5	5	5	5	4	5	5	5	4.9
other (E-dom)	5	4	5	5	5	4	5	5	5	4	4.7
22	5	4	5	5	5	2	3	4*	5	5	4.3
23	4	3	4	5	4	4	3	4	5	3	3.9
24	-	-	-	5	4	5	4	5	5	4	4.6
avg.	4.6	4.1	4.6	4.8	4.5	4.3	3.9	4.4	4.8	4.2	4.4

4* means that the rater wrote "4/5" or "5/4" for this speaker.

Appendix VI English stimuli used

Block 1

Gavin said "hear ee" each spring.
Dave said "hear hee" each June.
Vance said "hair hay" each time again.
Danny said "hoar owe" each minute.
Joanna said "who roo" each holiday.
Edwin said "hair A" each time again.
Whitney said "hoar hoe" each day with Sue.
Casey said "hear ee" each scenario.
Mike said "hee wee" each fall.
Seth said "hear ee" each week.
Ann said "har awe" each turn in Thai.
Betty said "har haw" each April.
Heidi said "hee ree" each week.
Judy said "hear ee" each April.
Joyce said "hay ray" each holiday.
Jamie said "hay ray" each month.
Ben said "hee wee" each month.
Tanya said "hoe roe" each job.
Otto said "har haw" each lunch.
Cindy said "har haw" each show.
Jenny said "hee ree" each scenario.
Becky said "har haw" each autumn.
Mason said "hoar hoe" each term.
Matt said "hee wee" each time through.
Chuck said "haw yaw" each job.
Nate said "hair A" each show.
Jon said "hoar owe" each semester.
Nick said "hee ree" each time through.
Sandy said "who roo" each fall.
Stan said "har awe" each time again.

Block 2

Anne said "who're hoo" each minute.
Sam said "hoar hoe" each day.
Cathy said "hair A" each day.
Hannah said "haw raw" each July.
Evan said "hee wee" each summer.
Simon said "haw yaw" each month.
Fabian said "who roo" each evening with joy.
Tina said "hay ray" each spring.
Jacob said "who're oo" each time through.
Dan said "who're hoo" each April.
Denise said "hee ree" each sailing regatta.
Matt said "who're oo" each weekend.
Joey said "who're hoo" each show.
Hank said "hee wee" each minute.
Maggie said "har awe" each semester.
Ken said "who roo" each show.
Tony said "hair A" each January.
Ben said "hoar hoe" each day.
Tom said "who're hoo" each job.
Joseph said "har haw" each semester.
Noah said "haw raw" each sailing regatta.
Eva said "who're oo" each January.
Jody said "who roo" each autumn.
Bonnie said "har haw" each term.
Dean said "who're oo" each holiday.
Ivan said "hair hay" each evening with joy.
Guy said "hair hay" each turn in Thai.
Donna said "hoar owe" each day with Sue.
Jim said "hair hay" each turn in Thai.
Steve said "har awe" each month.

Block 3

Gina said “hay ray” each scenario.
Toby said "hoar owe" each week.
Joan said “hear ee” each scenario.
Ned said “har awe” each year.
Mitch said “who’re hoo” each year.
Kevin said “hoe roe” each weekend.
Suzie said “hay ray” each minute.
Joe said “hear ee” each minute.
Anna said “hay ray” each evening with joy.
Vicky said “hear hee” each April.
Jan said “hair hay” each time through.
Vanessa said “hay ray” each time again.
Diane said “hear ee” each June.
Tommy said “who’re oo” each show.
Dustin said “har awe” each fall.
Hank said "hee wee" each month.
Janice said “haw raw” each job.
Beth said “hee ree” each time through.
Vickie said “hoe roe” each time through.
Kate said “hoe roe” each spring.
Mike said “hoe roe” each evening with joy.
Beth said "haw yaw" each job.
Zack said “hear ee” each spring.
Josie said “har awe” each semester.
Scott said “hair hay” each weekend.
Wendy said “hair hay” each lunch.
Wanda said “who’re hoo” each time again.
Kenny said “haw raw” each January.
Pat said “hear hee” each sailing regatta.
Katie said "haw yaw" each summer.

Block 4

Ethan said “hair A” each job.
John said “har haw” each weekend.
Jean said “hoar hoe” each week.
Tom said "haw yaw" each fall.
Justin said “hear hee” each holiday.
Wayne said “hear hee” each time again.
Jane said “har haw” each year.
Teddy said “haw raw” each time again.
Jessie said “hay ray” each autumn.
Zane said “har haw” each June.
Pete said “haw raw” each term.
Simon said "haw yaw" each autumn.
June said “hee ree” each scenario.
Evan said “hoe roe” each summer.
Bob said “hair hay” each class.
Tammy said “hear hee” each afternoon.
Jasmine said “haw raw” each autumn.
Ike said “haw raw” each turn in Thai.
Ted said “hoe roe” each year.
Tim said “hear hee” each job.
Dennis said “hair A” each sailing regatta.
Jody said “hoar hoe” each weekend.
Ken said "haw yaw" each time again.
Don said “who’re oo” each fall.
Jason said “hoar hoe” each semester.
Max said “hoar owe” each July.
Vince said “haw raw” each month.
Keith said “who roo” each afternoon.
Jed said “hair A” each term.
Mindy said “hair A” each day.

Block 5

Peggy said "hair A" each afternoon.
Hugh said "hair hay" each month.
Josh said "hear hee" each minute.
Patty said "who roo" each time again.
Missy said "who're hoo" each lunch.
Fay said "who're oo" each June.
Evan said "hee wee" each summer.
Bob said "hee wee" each autumn.
Chuck said "haw yaw" each job.
James said "who're oo" each fall.
Jackie said "har haw" each class.
Kim said "hear hee" each January.
Steven said "who roo" each day.
Todd said "hear ee" each afternoon.
Janet said "hee ree" each sailing regatta.
Joanne said "har awe" each class.
Ian said "hoe roe" each July.
Shane said "who're oo" each time again.
Nancy said "hoar owe" each summer.
Jay said "hee ree" each lunch.
Dana said "hee ree" each week.
Mandy said "hear hee" each holiday.
Megan said "haw raw" each June.
Hank said "hoar hoe" each day with Sue.
Nathan said "har awe" each April.
Finn said "hear ee" each month.
Kay said "hoar hoe" each summer.
Jimmy said "who're oo" each class.
Susan said "who roo" each January.
Sean said "hoar hoe" each afternoon.

Block 6

Missy said "who're hoo" each lunch.
Gavin said "hear ee" each spring.
Katie said "hoar owe" each lunch.
Anne said "who're hoo" each minute.
Jessica said "hoar owe" each fall.
Gina said "hay ray" each scenario.
Shawn said "hee ree" each evening with joy.
Ethan said "hair A" each job.
Dominic said "who're hoo" each time again.
Peggy said "hair A" each afternoon.
Stacy said "har awe" each year.
Dave said "hear hee" each June.
Vance said "hair hay" each time again.
Danny said "hoar owe" each minute.
Joanna said "who roo" each holiday.
Jake said "hoar owe" each July.
Bobby said "who're hoo" each autumn.
Diana said "who're hoo" each day with Sue.
Scott said "haw yaw" each month.
Sam said "haw yaw" each time again.
Gina said "hee wee" each spring.
Katie said "hee wee" each fall.
Doug said "hay ray" each term.
Chuck said "hoe roe" each class.
Dawn said "hoar owe" each July.
Eddie said "hair hay" each spring.
Simon said "who roo" each turn in Thai.
Monty said "hair A" each summer.
Debbie said "hay ray" each day with Sue.
Gene said "hoe roe" each summer.

Appendix VII French stimuli used

There are 6 blocks, each consisting of 30 sentences and lasting 131 seconds.

- There are 60 names randomized throughout Blocks 1&2, Blocks 3&4, and Blocks 5&6
- There are 60 predicates randomized throughout Blocks 1&2, Blocks 3&4, and Blocks 5&6
- Within the 60 predicates, there are 20 keywords with i/I, 20 with y/Y, and 20 with u/U. Within each of these groups of 20, there are 9 keywords with the tense vowel and 11 keywords with the lax vowel.

Block 1

Vincent, il a vu une ville dans la vallée.
Alexandre, il a vu une nuque dans le dessin.
Catherine, elle a vu une loupe dans le pupitre.
Frédéric, il a vu un loup dans la forêt.
Véronique, elle a vu une russe dans le ballet.
Simon, il a vu un loup dans la forêt.
Arianne, elle a vu une pousse dans le jardin.
Gabrielle, elle a fait un vide dans la maison.
Sophie, elle a vu une pipe dans la bouche du monsieur.
Juliette, elle a vu un cube dans la boîte à jouets.
Philippe, il a vu du riz dans le chaudron.
Thomas, il a mis de la vie dans la maison.
Audrey, elle a vu une ruche dans le champ.
Gabriel, il a vu le cul de la chèvre.
Alicia, elle a vu un pouce dans la radiographie.
Claudia, elle a vu une rue dans la vieille ville.
Jérôme, il a vu une pie dans l'arbre.
Marie Ève, elle a vu un lit dans la clinique.
Étienne, il a vu une cuve dans la salle de bain.
Nicolas, il a vu un tube dans le trou.
Zachary, il a vu un nu dans le musée.
Chloé, elle a vu un bouc dans le champ.
Samuel, il a vu une pie dans l'arbre.
Benoît, il a vu une lime dans la sacoche.
Xavier, il a vu un tutu dans le vestiaire.
Sébastien, il a vu une tuque dans le linge sale.
Annabelle, elle a vu un lys dans l'étang.
Valérie, elle a vu un pou dans les poils du rat.
Amélie, elle a vu de la boue dans l'entrée de la maison.
Alexandra, elle a vu une frite dans l'assiette.

Block 2

Raphael, il a vu la lune dans le ciel.
Daphnée, elle a vu une soupe dans le livre de recettes.
Béatrice, elle a vu du pus dans la plaie.
Marc-Olivier, il a vu une trousse dans les objets perdus.
Rosalie, elle a vu un jus dans le frigidaire.
Louis, il a vu une troupe dans la parade.
Isabelle, elle a vu un trou dans l'ail.
Félix, il a vu une jupe dans la vitrine.
Hugo, il a entendu un cri dans la nuit.
Maxime, il a vu une coupe dans le salon de coiffure.
Émilie, elle a vu un trou dans la roche.
Antoine, il a vu une puce dans la perruque.
Elizabeth, elle a vu une lutte dans le bar.
Justine, elle a vu une luge dans la neige.
Julien, il a vu une cruche dans les ruines grecques.
Alexia, elle a vu un grand cru dans la cave à vin.
Guillaume, il a vu une niche dans la cour.
Christophe, il a vu un cou dans le dessin.
Adam, il a vu un saoûl dans le bar.
Mégan, elle a entendu un cri dans la nuit.
Florence, elle a vu une crique dans la forêt.
Tristan, il a vu un nid dans l'arbre.
Olivier, il a vu un cric dans la valise de l'auto.
Mélodie, elle a vu un site dans le terrain de camping.
Cédric, il a reçu un coup dans la face.
Geneviève, elle a vu une niche dans la cour.
François, il a vu une trousse dans les objets perdus.
Éric, il a vu une scie dans la boîte à outils.
Camille, elle a vu une coupe dans le salon de coiffure.
Mathieu, il a vu une troupe dans la parade.

Block 3

Alexia, elle a vu un loup dans la forêt.
Louis, il a vu de la boue dans l'entrée de la maison.
Éric, il a vu un tube dans le trou.
Béatrice, elle a vu une pie dans l'arbre.
Olivier, il a vu une pipe dans la bouche du monsieur.
Camille, elle a mis de la vie dans la maison.
Mathieu, il a vu un lys dans l'étang.
Sébastien, il a vu une frite dans l'assiette.
Justine, elle a fait un vide dans la maison.
Christophe, il a vu une cuve dans la salle de bain.
Sophie, elle a vu une ville dans la vallée.
Félix, il a vu un loup dans la forêt.
Audrey, elle a vu un bouc dans le champ.
Alicia, elle a vu un pouce dans la radiographie.
Gabriel, il a vu une russe dans le ballet.
Frédéric, il a vu une nuque dans le dessin.
Tristan, il a vu un lit dans la clinique.
Benoît, il a vu un nu dans le musée.
Juliette, elle a vu une tuque dans le linge sale.
Véronique, elle a vu une lime dans la sacoche.
Émilie, elle a vu le cul de la chèvre.
Florence, elle a vu un tutu dans le vestiaire.
Nicolas, il a vu une pie dans l'arbre.
Marie Ève, elle a vu une ruche dans le champ.
Annabelle, elle a vu un cube dans la boîte à jouets.
Maxime, il a vu du riz dans le chaudron.
Xavier, il a vu un pou dans les poils du rat.
Geneviève, elle a vu une loupe dans le pupitre.
Chloé, elle a vu une rue dans la vieille ville.
Simon, il a vu une pousse dans le jardin.

Block 4

Zachary, il a vu une troupe dans la parade.
Thomas, il a vu une lutte dans le bar.
Elizabeth, elle a vu un trou dans la roche.
Adam, il a vu un trou dans l'ail.
Amélie, elle a entendu un cri dans la nuit.
Hugo, il a vu un cou dans le dessin.
Philippe, il a vu un site dans le terrain de camping.
Samuel, il a vu une soupe dans le livre de recettes.
Vincent, il a vu un nid dans l'arbre.
Étienne, il a vu une trousse dans les objets perdus.
Daphnée, elle a vu la lune dans le ciel.
Guillaume, il a vu une crique dans la forêt.
Mégan, elle a entendu un cri dans la nuit.
Rosalie, elle a vu une trousse dans les objets perdus.
Arianne, elle a vu un jus dans le frigidaire.
Raphael, il a vu une jupe dans la vitrine.
Isabelle, elle a vu un grand cru dans la cave à vin.
Antoine, il a vu un saoûl dans le bar.
Cédric, il a vu une luge dans la neige.
Gabrielle, elle a vu une puce dans la perruque.
François, il a vu un cric dans la valise de l'auto.
Jérôme, il a vu du pus dans la plaie.
Claudia, elle a vu une coupe dans le salon de coiffure.
Valérie, elle a vu une niche dans la cour.
Catherine, elle a vu une coupe dans le salon de coiffure.
Alexandra, elle a reçu un coup dans la face.
Alexandre, il a vu une scie dans la boîte à outils.
Marc-Olivier, il a vu une cruche dans les ruines grecques.
Julien, il a vu une troupe dans la parade.
Mélodie, elle a vu une niche dans la cour.

Block 5

Tristan, il a vu un nu dans le musée.
Louis, il a vu une loupe dans le pupitre.
Audrey, elle a vu une pousse dans le jardin.
Marie Ève, elle a vu un pou dans les poils du rat.
François, il a vu un lit dans la clinique.
Benoît, il a mis de la vie dans la maison.
Justine, elle a vu un bouc dans le champ.
Samuel, il a vu un loup dans la forêt.
Gabriel, il a vu une lime dans la sacoche.
Amélie, elle a vu une cuve dans la salle de bain.
Alexandre, il a vu le cul de la chèvre.
Maxime, il a vu une pie dans l'arbre.
Arianne, elle a vu un pouce dans la radiographie.
Marc-Olivier, il a vu une ville dans la vallée.
Béatrice, elle a vu une pie dans l'arbre.
Chloé, elle a vu une rue dans la vieille ville.
Nicolas, il a vu de la boue dans l'entrée de la maison.
Isabelle, elle a vu une tuque dans le linge sale.
Sébastien, il a vu une ruche dans le champ.
Cédric, il a fait un vide dans la maison.
Geneviève, elle a vu un tube dans le trou.
Camille, elle a vu une frite dans l'assiette.
Florence, elle a vu une pipe dans la bouche du monsieur.
Alexandra, elle a vu un lys dans l'étang.
Christophe, il a vu du riz dans le chaudron.
Hugo, il a vu un tutu dans le vestiaire.
Elizabeth, elle a vu un cube dans la boîte à jouets.
Thomas, il a vu un loup dans la forêt.
Frédéric, il a vu une nuque dans le dessin.
Rosalie, elle a vu une russe dans le ballet.

Block 6

Mélodie, elle a vu une niche dans la cour.
Félix, il a vu un grand cru dans la cave à vin.
Antoine, il a vu un saoûl dans le bar.
Alicia, elle a vu une cruche dans les ruines grecques.
Julien, il a vu une jupe dans la vitrine.
Guillaume, il a entendu un cri dans la nuit.
Valérie, elle a vu une scie dans la boîte à outils.
Catherine, elle a vu une troupe dans la parade.
Véronique, elle a vu du pus dans la plaie.
Jérôme, il a vu un nid dans l'arbre.
Claudia, elle a vu une trousse dans les objets perdus.
Gabrielle, elle a vu une crique dans la forêt.
Simon, il a vu une coupe dans le salon de coiffure.
Émilie, elle a vu un trou dans la roche.
Juliette, elle a vu un trou dans l'ail.
Mégan, elle a vu la lune dans le ciel.
Olivier, il a vu un cou dans le dessin.
Éric, il a vu une lutte dans le bar.
Mathieu, il a vu une coupe dans le salon de coiffure.
Raphael, il a vu une niche dans la cour.
Annabelle, elle a entendu un cri dans la nuit.
Vincent, il a vu une troupe dans la parade.
Zachary, il a vu une trousse dans les objets perdus.
Xavier, il a vu un jus dans le frigidaire.
Daphnée, elle a reçu un coup dans la face.
Étienne, il a vu une soupe dans le livre de recettes.
Philippe, il a vu une luge dans la neige.
Sophie, elle a vu une puce dans la perruque.
Alexia, elle a vu un cric dans la valise de l'auto.
Adam, il a vu un site dans le terrain de camping.

Appendix VIII Sentences used in foreign accent rating task

English:

		English sentences used for each subject	
		Stimuli block used	First word of sentences used (see Appendix VI for full sentences)
Subject number	2 (mono E)	Block 2	Hank, Maggie, Ken, Tony, Ben
	16	Block 2	Hank, Maggie, Tony, Ben, Tom
	17	Block 1	Dave, Vance, Danny, Joanna, Edwin
	18	Block 2	Hank, Maggie, Ken, Tony, Ben
	19	Block 2	Hank, Maggie, Ken, Tony, Ben
	5 (mono E)	Block 2	Hank, Maggie, Ken, Tony, Ben
	6 (mono E)	Block 2	Hank, Maggie, Ken, Tony, Ben
	20	Block 2	Hank, Tony, Ben, Joseph, Dean
	21	Block 2	Hank, Maggie, Ken, Tony, Ben
	other (E-dom)	Block 2	Hank, Maggie, Ken, Tony, Ben
	22	Block 2	Hank, Tony, Ben, Tom, Joseph
	23	Block 2	Hank, Maggie, Ken, Tony, Ben
	24	Block 2	Hank, Maggie, Ken, Tony, Ben

French:

		French sentences used for each subject	
		Stimuli block used	First word of sentences used (see Appendix VII for full sentences)
Subject number	2 (mono E)	Block 1	Chloé, Samuel, Benoît, Xavier, Sébastien
	16	Block 1	Chloé, Samuel, Benoît, Xavier, Sébastien
	17	Block 1	Zachary, Chloé, Samuel, Benoît, Xavier
	18	Block 1	Chloé, Samuel, Benoît, Xavier, Sébastien
	other (mono F)	Block 1	Chloé, Samuel, Benoît, Xavier, Sébastien
	19	Block 1	Samuel, Benoît, Xavier, Sébastien, Annabelle
	5 (mono E)	Block 1	Chloé, Samuel, Benoît, Xavier, Sébastien
	20	Block 1	Chloé, Samuel, Benoît, Xavier, Sébastien
	other (mono F)	Block 1	Samuel, Benoît, Xavier, Sébastien, Annabelle
	21	Block 1	Chloé, Samuel, Benoît, Xavier, Sébastien
	other (E-dom)	Block 1	Nicolas, Zachary, Chloé, Samuel, Benoît
	22	Block 1	Chloé, Samuel, Benoît, Xavier, Sébastien
	23	Block 2	Raphael, Daphnée, Béatrice, Marc-Olivier, Rosalie
	24	Block 1	Samuel, Benoît, Xavier, Annabelle, Valérie

Appendix IX Bilingual-mode stimuli used

Block 1 contains the first 15 sentences from Fr. Block 1 & the first 15 from Eng. Block 1.
Block 2 contains the last 15 sentences from Fr. Block 1 & the last 15 from Eng. Block 1.

The order of language that comes next is different between blocks and was decided randomly.

Block 1

Gavin said "hear ee" each spring.
Vincent, il a vu une ville dans la vallée.
Alexandre, il a vu une nuque dans le dessin.
Dave said "hear hee" each June.
Vance said "hair hay" each time again.
Danny said "hoar owe" each minute.
Catherine, elle a vu une loupe dans le pupitre.
Joanna said "who roo" each holiday.
Edwin said "hair A" each time again.
Whitney said "hoar hoe" each day with Sue.
Frédéric, il a vu un loup dans la forêt.
Casey said "hear ee" each scenario.
Véronique, elle a vu une russe dans le ballet.
Simon, il a vu un loup dans la forêt.
Arianne, elle a vu une pousse dans le jardin.
Gabrielle, elle a fait un vide dans la maison.
Mike said "hee wee" each fall.
Seth said "hear ee" each week.
Sophie, elle a vu une pipe dans la bouche du monsieur.
Juliette, elle a vu un cube dans la boîte à jouets.
Ann said "har awe" each turn in Thai.
Betty said "har haw" each April.
Philippe, il a vu du riz dans le chaudron.
Heidi said "hee ree" each week.
Judy said "hear ee" each April.
Thomas, il a mis de la vie dans la maison.
Audrey, elle a vu une ruche dans le champ.
Gabriel, il a vu le cul de la chèvre.
Alicia, elle a vu un pouce dans la radiographie.
Joyce said "hay ray" each holiday.

Block 2

Jamie said "hay ray" each month.
Claudia, elle a vu une rue dans la vieille ville.
Ben said "hee wee" each month.
Tanya said "hoe roe" each job.
Jérôme, il a vu une pie dans l'arbre.
Otto said "har haw" each lunch.
Marie Ève, elle a vu un lit dans la clinique.
Étienne, il a vu une cuve dans la salle de bain.
Cindy said "har haw" each show.
Jenny said "hee ree" each scenario.
Becky said "har haw" each autumn.
Nicolas, il a vu un tube dans le trou.
Zachary, il a vu un nu dans le musée.
Mason said "hoar hoe" each term.
Matt said "hee wee" each time through.
Chloé, elle a vu un bouc dans le champ.
Samuel, il a vu une pie dans l'arbre.
Benoît, il a vu une lime dans la sacoche.
Chuck said "haw yaw" each job.
Xavier, il a vu un tutu dans le vestiaire.
Nate said "hair A" each show.
Sébastien, il a vu une tuque dans le linge sale.
Annabelle, elle a vu un lys dans l'étang.
Jon said "hoar owe" each semester.
Valérie, elle a vu un pou dans les poils du rat.
Nick said "hee ree" each time through.
Sandy said "who roo" each fall.
Amélie, elle a vu de la boue dans l'entrée de la maison.
Stan said "har awe" each time again.
Alexandra, elle a vu une frite dans l'assiette.

Appendix X Geometrical formulas used in the MATLAB code

LINGUISTIC PROJECT

MACIEJ MIZERSKI FOR IAN WILSON

1. Bone point moves with the head

Let m_1, m_2 and m_3 be the vectors in the lab coordinates of 3 markers at any time t where take m_1 be the marker behind the head (these are functions of t). Define

$$v_1(t) := m_2(t) - m_1(t)$$
$$v_2(t) := m_3(t) - m_1(t)$$
$$v_3(t) := v_1(t) \times v_2(t)$$

This will be the basis for the new coordinate system centered at m_1: the coordinate system of the head. For better results choose m_2 and m_3 to be the coordinates of the extreme points on the glasses. Recall the vector product formula:

$$(a_1, a_2, a_3) \times (c_1, c_2, c_3) = (a_2c_3 - a_3c_2, a_3c_1 - a_1c_3, a_1c_2 - a_2c_1)$$

We need to express $b(t) - m_1(t)$ in the coordinates $v_1(t)$, $v_2(t)$ and $v_3(t)$:

$$b(t) - m_1(t) = c_1v_1(t) + c_2v_2(t) + c_3v_3(t) \tag{1}$$

and so

$$b(t) = m_1(t) + c_1v_1(t) + c_2v_2(t) + c_3v_3(t). \tag{2}$$

where c_1, c_2 and c_3 are constants that do not change with time as $b(t)$ is a fixed point on the head. To find these let $M(t)$ be the matrix whose columns are $v_1(t)$, $v_2(t)$ and $v_3(t)$:

$$M(t) = (v_1(t)|v_2(t)|v_3(t))$$

then

$$b(t) - m_1(t) = M(t) \cdot \begin{pmatrix} c_1 \\ c_2 \\ c_3 \end{pmatrix}.$$

Hence we express c_1, c_2 and c_3 by inverting $M(t)$:

$$\begin{pmatrix} c_1 \\ c_2 \\ c_3 \end{pmatrix} = M(t)^{-1} \cdot (b(t) - m_1(t))$$

At some time $t = 0$, measure the coordinates of the bone $b(0)$ in the coordinates of the lab, so we can find

$$\begin{pmatrix} c_1 \\ c_2 \\ c_3 \end{pmatrix} = M(0)^{-1} \cdot (b(0) - m_1(0)) \tag{3}$$

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Then at any other time t, $b(t)$ is given by the equation 2:

$$b(t) = m_1(t) + c_1v_1(t) + c_2v_2(t) + c_3v_3(t) = m_1(t) + M(t) \cdot c$$

where

$$c := \begin{pmatrix} c_1 \\ c_2 \\ c_3 \end{pmatrix}.$$

Thus the problem is reduced to inverting the matrix $M(0)$ which is a 3 by 3 matrix, you will find formulas for this in linear algebra books.

There is an alternate method for finding c's. Use the fact that v_3 is orthogonal to v_1 and v_2 (that is $v_1 \cdot v_3 = v_2 \cdot v_3 = 0$). Taking the scalar product of 1 with v_1, v_2 and v_3, get

$$\begin{aligned}
(b(0) - m_1(0)) \cdot v_1(0) &= c_1(v_1(0) \cdot v_1(0)) + c_2(v_2(0) \cdot v_1(0)) \\
(b(0) - m_1(0)) \cdot v_2(0) &= c_1(v_1(0) \cdot v_2(0)) + c_2(v_2(0) \cdot v_2(0)) \\
(b(0) - m_1(0)) \cdot v_3(0) &= c_3(v_3(0) \cdot v_3(0))
\end{aligned}$$

Thus

$$\begin{aligned}
\begin{pmatrix} c_1 \\ c_2 \end{pmatrix} &= \begin{pmatrix} v_{11}(0) & v_{12}(0) \\ v_{12}(0) & v_{22}(0) \end{pmatrix}^{-1} \cdot \begin{pmatrix} v_{b1}(0) \\ v_{b2}(0) \end{pmatrix} \\
&= \frac{1}{v_{11}(0)v_{22}(0) - v_{12}(0)^2} \cdot \\
&\begin{pmatrix} v_{22}(0) & -v_{12}(0) \\ -v_{12}(0) & v_{11}(0) \end{pmatrix} \cdot \begin{pmatrix} v_{b1}(0) \\ v_{b2}(0) \end{pmatrix}
\end{aligned}$$

and

$$c_3 = \frac{v_{b3}(0)}{v_{33}(0)}$$

where define

$$\begin{aligned}
v_{11}(0) &:= v_1(0) \cdot v_1(0) \\
v_{12}(0) &:= v_1(0) \cdot v_2(0) \\
v_{22}(0) &:= v_2(0) \cdot v_2(0) \\
v_{33}(0) &:= v_3(0) \cdot v_3(0) \\
v_{bi}(0) &:= (b(0) - m_1(0)) \cdot v_i(0)
\end{aligned}$$

for i = 1,2 and 3.

2. From probe coordinates to lab coordinates

It is the same idea for the coordinate transformation. Instead of the 3 markings on the head we use: p (resp. m_5 and m_6) the vectors in lab coordinates of the probe center (resp. marking #5 and

#6). Define

$$v_1 := m_5 - p$$
$$v_2 := m_6 - p$$
$$v_3 := v_1 \times v_2$$

So the position of the bone b is given by

$$b - p = a_1 v_1 + a_2 v_2 + a_3 v_3$$

but $a_3 = 0$ as we assume that the bone is on the cross section (i.e. the plane spaned by v_1 and v_2):

$$b - p = a_1 v_1 + a_2 v_2$$

Take the measuremenet of $b - p$ in the probe coordinates. Express v_1 and v_2 in probe coordinates. Take the scalar products:

$$(b-p) \cdot v_1 = a_1(v_1 \cdot v_1) + a_2(v_2 \cdot v_1)$$
$$(b-p) \cdot v_2 = a_1(v_1 \cdot v_2) + a_2(v_2 \cdot v_2)$$

And we can isolate a_1 and a_2 as follows:

$$\begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} v_1 \cdot v_1 & v_2 \cdot v_1 \\ v_1 \cdot v_2 & v_2 \cdot v_2 \end{pmatrix}^{-1} \cdot \begin{pmatrix} (b-p) \cdot v_1 \\ (b-p) \cdot v_2 \end{pmatrix} \tag{4}$$

$$= \frac{1}{(v_1 \cdot v_1)(v_2 \cdot v_2) - (v_2 \cdot v_1)^2} \cdot \begin{pmatrix} v_2 \cdot v_2 & -v_2 \cdot v_1 \\ -v_1 \cdot v_2 & v_1 \cdot v_1 \end{pmatrix} \cdot \begin{pmatrix} (b-p) \cdot v_1 \\ (b-p) \cdot v_2 \end{pmatrix} \tag{5}$$

Now b in lab coordinates is given by

$$b = p + a_1 v_1 + a_2 v_2$$

where all vectors are expressed in lab coordinates.

3. From lab coordinates to probe coordinates

Have m_5, m_6, p and b in lab coordinates. Define v_1, v_2 as above. Compute

$$v_1 \cdot v_1,\ v_1 \cdot v_2,\ (b-p) \cdot v_1,\ (b-p) \cdot v_2$$

and compute a_1 and a_2 using 4. Then after expressing v_1, v_2 and p in probe coordinates ($p = 0$ as it is the origin of this coordinate system), get

$$b = a_1 v_1 + a_2 v_2$$

the position of the bone in probe coordinates.

University of British Columbia, Department of Mathematics
E-mail address: mizerski@math.ubc.ca

Appendix XI Means and standard deviations for all 24 subjects

In the following tables, individual means and within-subject standard deviations are given for each component of ISP for each subject. Note that for each monolingual subject, these means and standard deviations are based on a number of tokens approximately equal to the number shown in the rightmost column of Table 2.2 in Section 2.1.3.2. For each bilingual subject, these means and standard deviations are based on a number of tokens approximately equal to the number shown in the third and fourth columns of Table 3.5 in Section 3.1.3.2. If there were cases where the tongue line was not visible on the ultrasound image, the number of tokens may be slightly fewer than the numbers shown in those tables. The numbers given here for the bilingual subjects are for monolingual mode only.

Tongue and jaw

	Subject	TTht	TBht	TDht	TRrn	JAWl
Monolingual	1 - Eng	62.97 (1.72)	61.99 (2.87)	53.93 (3.63)	45.23 (3.90)	8.26 (0.96)
	2 - Eng	64.68 (2.33)	61.72 (3.02)	56.11 (2.92)	43.64 (4.37)	14.35 (1.98)
	3 - Eng	58.02 (1.68)	67.26 (2.24)	61.10 (2.59)	51.42 (2.25)	2.29 (0.70)
	4 - Eng	64.94 (1.17)	67.94 (1.41)	58.20 (2.29)	44.85 (1.80)	3.65 (0.96)
	5 - Eng	72.88 (2.46)	71.98 (1.91)	64.98 (2.11)	58.25 (2.00)	5.30 (0.73)
	6 - Eng	58.33 (1.41)	62.08 (2.24)	42.62 (3.43)	34.26 (3.22)	7.45 (1.14)
	7 - Eng	65.35 (1.06)	71.88 (1.68)	70.38 (1.66)	62.57 (2.14)	3.20 (0.63)
Monolingual	8 - Fre	55.46 (1.23)	60.96 (1.20)	55.78 (2.61)	47.21 (3.03)	4.85 (0.96)
	9 - Fre	56.56 (2.09)	61.44 (1.77)	54.11 (2.59)	43.54 (2.80)	4.68 (1.22)
	10 - Fre	61.30 (2.42)	63.31 (2.43)	61.94 (2.30)	59.40 (3.55)	9.96 (1.63)
	11 - Fre	64.50 (1.54)	72.19 (1.54)	61.12 (2.89)	54.68 (2.24)	6.22 (1.14)
	12 - Fre	53.96 (1.93)	53.50 (1.84)	44.97 (1.73)	38.34 (1.77)	5.30 (2.86)
	13 - Fre	61.12 (1.82)	68.23 (2.05)	62.40 (2.69)	51.15 (3.80)	11.59 (1.44)
	14 - Fre	57.24 (1.82)	63.44 (1.65)	53.66 (3.42)	44.91 (3.10)	4.20 (1.36)
	15 - Fre	56.66 (1.46)	63.55 (1.63)	57.18 (2.59)	50.27 (2.45)	5.48 (0.91)
Bilingual (NS of both)	21 - Eng	68.92 (1.73)	69.41 (1.27)	61.86 (1.68)	46.86 (3.79)	5.45 (1.35)
	- Fre	67.55 (2.24)	68.98 (1.33)	62.05 (2.16)	49.21 (1.89)	3.97 (0.60)
	17 - Eng	n/a	n/a	n/a	n/a	n/a
	- Fre	60.83 (1.33)	62.81 (1.91)	56.64 (1.80)	55.98 (2.23)	5.79 (0.49)
	22 - Eng	55.50 (2.42)	57.94 (3.62)	56.53 (2.32)	44.90 (2.64)	2.28 (0.65)
	- Fre	55.86 (1.75)	57.37 (2.71)	55.50 (2.02)	44.87 (2.19)	2.30 (0.17)
	19 - Eng	61.00 (1.77)	70.14 (1.42)	67.03 (1.49)	48.19 (3.84)	3.40 (0.36)
	- Fre	60.60 (2.52)	68.56 (2.21)	65.49 (1.80)	49.34 (2.95)	3.92 (0.35)
Bilingual (NS of Fre only)	18 - Eng	63.19 (1.72)	68.48 (1.45)	63.89 (1.70)	56.61 (3.20)	2.05 (0.69)
	- Fre	64.65 (1.23)	65.86 (2.21)	61.92 (1.96)	54.28 (2.73)	3.61 (1.22)
	23 - Eng	64.16 (1.04)	75.14 (1.56)	66.19 (1.90)	57.09 (2.92)	14.63 (0.93)
	- Fre	62.63 (0.99)	71.95 (2.29)	64.88 (1.14)	56.13 (1.32)	13.82 (1.03)
	20 - Eng	63.00 (1.85)	66.56 (1.43)	55.88 (1.79)	45.92 (3.37)	11.07 (1.44)
	- Fre	66.43 (1.71)	67.53 (1.92)	54.66 (2.98)	44.57 (3.34)	10.27 (1.59)
Bilingual (NS of Eng only)	24 - Eng	65.86 (1.44)	64.24 (1.85)	55.65 (2.72)	43.25 (3.08)	8.82 (0.98)
	- Fre	65.23 (1.44)	62.18 (3.08)	56.26 (2.60)	45.62 (1.62)	7.80 (1.11)
Bilingual (NS of neither)	16 - Eng	72.40 (0.92)	79.92 (2.67)	77.07 (4.00)	70.09 (2.45)	10.03 (0.56)
	- Fre	72.98 (2.01)	79.76 (1.61)	80.29 (2.92)	72.89 (1.50)	8.81 (0.63)

Lip height and protrusion

	Subject	ULlo	LLlo	ULpr	LLpr
Monolingual	1 - Eng	78.99 (0.59)	99.45 (1.13)	44.71 (3.82)	48.93 (5.48)
	2 - Eng	70.83 (0.70)	98.63 (2.25)	24.72 (2.05)	30.55 (2.95)
	3 - Eng	75.67 (0.44)	91.11 (0.67)	23.84 (1.90)	28.10 (2.45)
	4 - Eng	76.70 (0.33)	98.19 (1.05)	32.96 (1.39)	39.06 (2.08)
	5 - Eng	74.80 (0.68)	96.06 (1.87)	32.75 (4.15)	37.13 (5.90)
	6 - Eng	74.64 (1.22)	95.02 (2.56)	29.79 (2.70)	32.09 (3.52)
	7 - Eng	76.14 (0.26)	101.52 (0.88)	33.82 (1.32)	36.14 (1.90)
Monolingual	8 - Fre	74.70 (0.55)	95.83 (1.42)	18.37 (1.57)	20.11 (2.06)
	9 - Fre	65.34 (0.96)	83.47 (2.04)	17.38 (3.38)	19.50 (4.99)
	10 - Fre	80.97 (0.62)	105.16 (2.05)	27.21 (2.96)	30.34 (3.79)
	11 - Fre	70.98 (0.59)	102.53 (1.45)	27.73 (1.35)	30.62 (2.14)
	12 - Fre	66.47 (2.82)	90.22 (3.86)	21.32 (1.33)	27.76 (1.81)
	13 - Fre	71.92 (0.19)	100.00 (1.00)	24.90 (1.28)	27.28 (1.82)
	14 - Fre	76.13 (0.92)	96.63 (2.36)	30.39 (2.06)	34.47 (2.75)
	15 - Fre	72.52 (0.21)	95.44 (0.76)	21.49 (1.62)	25.96 (2.45)
Bilingual (NS of both)	21 - Eng	78.17 (0.80)	99.56 (1.16)	27.04 (1.10)	28.53 (1.31)
	- Fre	77.96 (0.72)	98.61 (0.55)	26.05 (1.53)	27.31 (1.83)
	17 - Eng	n/a	n/a	n/a	n/a
	- Fre	66.59 (0.44)	96.63 (0.74)	26.01 (0.88)	30.93 (1.59)
	22 - Eng	71.11 (0.57)	96.38 (2.58)	27.90 (0.63)	28.38 (0.77)
	- Fre	72.17 (0.37)	94.80 (0.89)	25.64 (1.42)	24.45 (2.14)
	19 - Eng	68.84 (0.28)	94.33 (0.61)	26.02 (1.00)	29.51 (0.98)
	- Fre	68.77 (0.28)	95.00 (0.83)	25.22 (0.97)	27.98 (1.44)
Bilingual (NS of Fre only)	18 - Eng	75.74 (0.59)	94.56 (0.62)	24.09 (1.72)	27.12 (2.17)
	- Fre	76.36 (0.34)	95.41 (0.48)	28.41 (3.34)	32.53 (4.37)
	23 - Eng	71.21 (0.26)	90.34 (1.10)	31.42 (0.83)	39.44 (1.52)
	- Fre	70.86 (0.56)	89.40 (0.96)	28.05 (1.04)	34.86 (1.68)
	20 - Eng	73.73 (1.27)	102.25 (2.05)	23.91 (3.61)	26.57 (5.67)
	- Fre	73.37 (1.79)	101.26 (2.27)	21.72 (4.66)	23.31 (6.26)
Bilingual (NS of Eng only)	24 - Eng	71.29 (0.32)	98.88 (1.99)	21.46 (0.97)	26.95 (1.70)
	- Fre	71.45 (0.59)	98.23 (1.85)	21.93 (4.47)	28.01 (6.23)
Bilingual (NS of neither)	16 - Eng	75.23 (0.62)	100.21 (0.56)	29.72 (1.73)	35.48 (2.26)
	- Fre	76.57 (0.44)	97.87 (0.58)	29.78 (2.03)	34.55 (2.44)

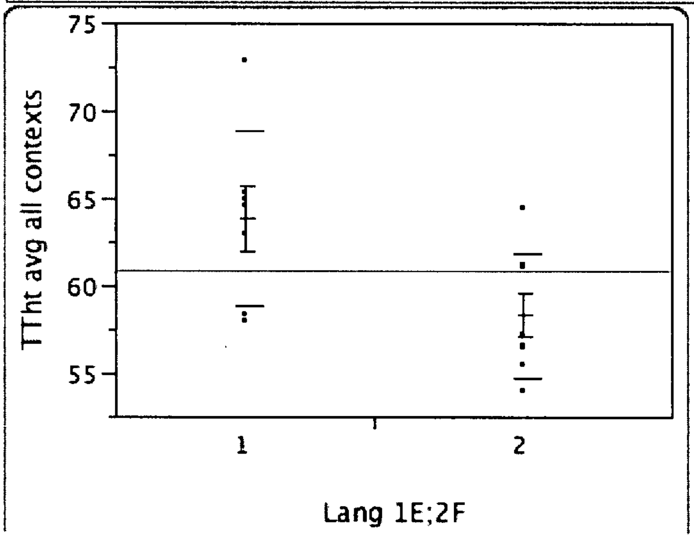
Lip aperture and narrowing

	Subject	Lvap	Lhap	Lnar
Monolingual	1 - Eng	21.31 (1.35)	58.63 (0.80)	20.28 (0.80)
	2 - Eng	27.70 (2.45)	69.16 (0.89)	19.26 (0.89)
	3 - Eng	15.99 (0.80)	59.71 (0.46)	14.93 (0.46)
	4 - Eng	21.62 (1.19)	59.64 (0.30)	16.94 (0.30)
	5 - Eng	21.41 (2.28)	60.93 (0.68)	15.46 (0.68)
	6 - Eng	20.82 (3.39)	58.94 (0.36)	4.13 (0.36)
	7 - Eng	26.06 (1.00)	66.73 (0.37)	7.76 (0.37)
Monolingual	8 - Fre	21.13 (1.83)	55.99 (0.28)	5.21 (0.28)
	9 - Fre	18.16 (2.67)	59.53 (0.40)	1.95 (0.40)
	10 - Fre	24.53 (1.77)	72.43 (0.81)	13.65 (0.81)
	11 - Fre	31.81 (1.94)	58.10 (0.47)	5.50 (0.47)
	12 - Fre	23.54 (2.67)	55.84 (0.45)	9.11 (0.45)
	13 - Fre	28.52 (1.01)	65.21 (0.40)	8.77 (0.40)
	14 - Fre	20.71 (3.03)	57.76 (0.61)	9.34 (0.61)
	15 - Fre	22.75 (0.91)	61.62 (0.34)	5.52 (0.34)
Bilingual (NS of both)	21 - Eng	21.69 (1.22)	65.34 (1.35)	15.81 (1.35)
	- Fre	20.99 (0.67)	65.96 (0.73)	15.19 (0.73)
	17 - Eng	n/a	n/a	n/a
	- Fre	30.31 (0.84)	59.49 (0.38)	n/a
	22 - Eng	25.81 (3.06)	55.70 (0.20)	n/a
	- Fre	23.32 (1.12)	55.55 (0.30)	n/a
	19 - Eng	26.00 (0.71)	60.89 (0.26)	9.46 (0.26)
	- Fre	26.81 (1.02)	60.70 (0.18)	9.64 (0.18)
Bilingual (NS of Fre only)	18 - Eng	18.88 (0.35)	68.57 (0.29)	7.78 (0.29)
	- Fre	19.11 (0.43)	68.36 (0.63)	7.99 (0.62)
	23 - Eng	19.12 (1.12)	69.92 (0.59)	13.90 (0.59)
	- Fre	18.53 (0.95)	70.64 (1.11)	13.18 (1.11)
	20 - Eng	28.75 (2.41)	60.05 (1.58)	13.49 (1.58)
	- Fre	28.14 (2.16)	61.21 (2.34)	12.33 (2.34)
Bilingual (NS of Eng only)	24 - Eng	27.59 (2.00)	66.65 (0.34)	15.79 (0.34)
	- Fre	26.80 (1.53)	67.67 (0.66)	14.77 (0.66)
Bilingual (NS of neither)	16 - Eng	25.19 (0.88)	62.89 (1.12)	13.47 (1.12)
	- Fre	21.47 (0.77)	61.73 (0.63)	14.63 (0.63)

Appendix XII Detailed statistics for Table 3.2

The following graphs and tables are extracted directly from JMP statistical analysis software. They show the results of *t* tests (assuming unequal variances) comparing the 7 individual English means to the 8 individual French means for each component of ISP. On the horizontal axis, "1" means *English* and "2" means *French*.

Oneway Analysis of TTht avg all contexts By Lang 1E;2F



Means and Std Deviations

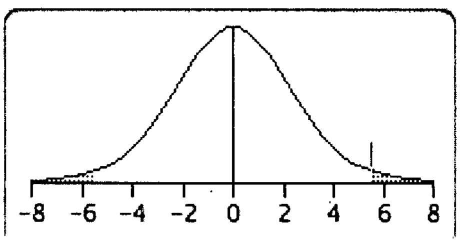
Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	7	63.8834	5.01672	1.8961	59.244	68.523
2	8	58.3507	3.56825	1.2616	55.368	61.334

t Test

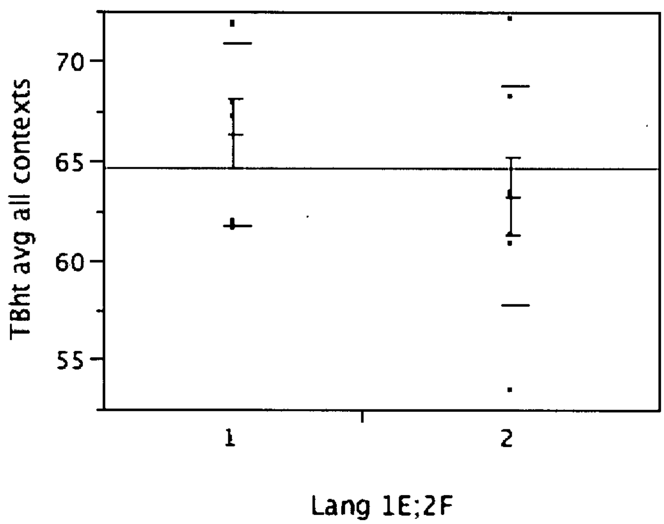
1-2

Assuming unequal variances

Difference	5.5327	t Ratio	2.429313
Std Err Dif	2.2775	DF	10.69191
Upper CL Dif	10.5631	Prob > |t|	0.0340
Lower CL Dif	0.5023	Prob > t	0.0170
Confidence	0.95	Prob < t	0.9830



Oneway Analysis of TBht avg all contexts By Lang 1E;2F



Means and Std Deviations

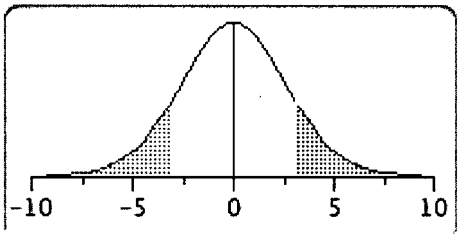
Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	7	66.4098	4.54969	1.7196	62.202	70.618
2	8	63.3265	5.45679	1.9293	58.765	67.888

t Test

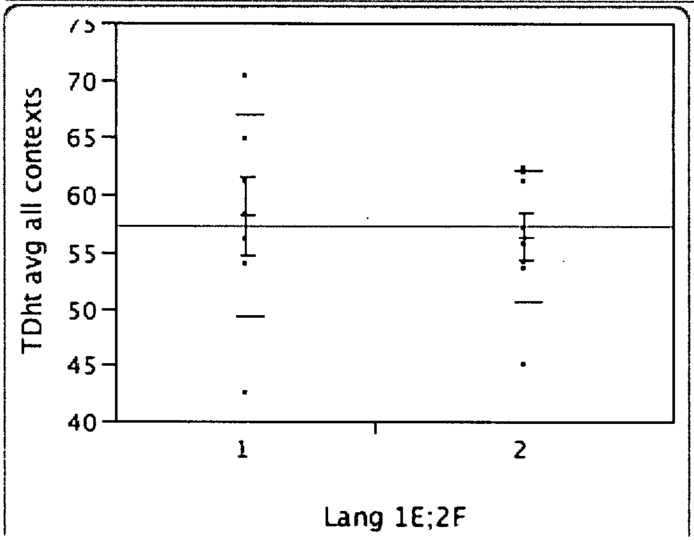
1-2

Assuming unequal variances

Difference	3.0833	t Ratio	1.193024
Std Err Dif	2.5844	DF	12.98153
Upper CL Dif	8.6673	Prob > |t|	0.2542
Lower CL Dif	-2.5008	Prob > t	0.1271
Confidence	0.95	Prob < t	0.8729



Oneway Analysis of TDht avg all contexts By Lang 1E;2F



Means and Std Deviations

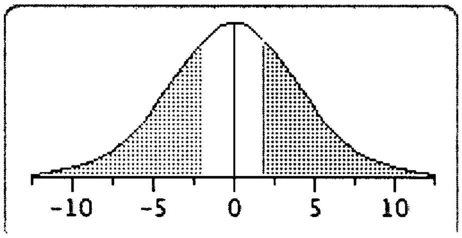
Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	7	58.1892	8.83149	3.3380	50.021	66.357
2	8	56.3939	5.77336	2.0412	51.567	61.221

t Test

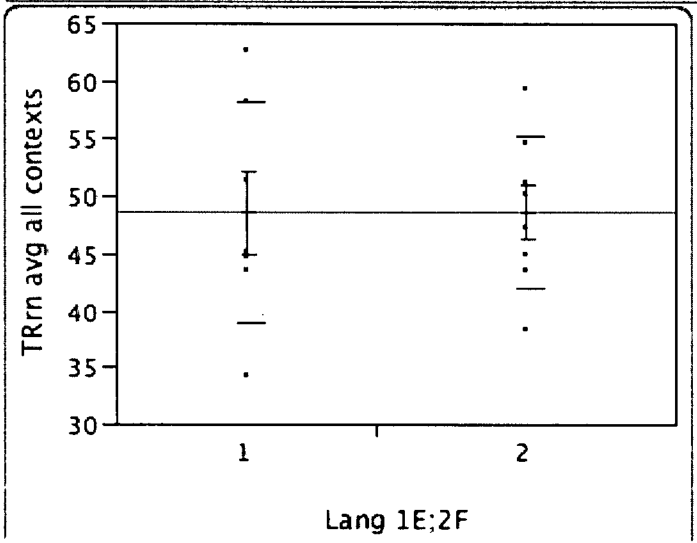
1-2

Assuming unequal variances

Difference	1.795	t Ratio	0.458856
Std Err Dif	3.913	DF	10.11401
Upper CL Dif	10.500	Prob > |t|	0.6560
Lower CL Dif	-6.909	Prob > t	0.3280
Confidence	0.95	Prob < t	0.6720



Oneway Analysis of TRrn avg all contexts By Lang 1E;2F



Means and Std Deviations

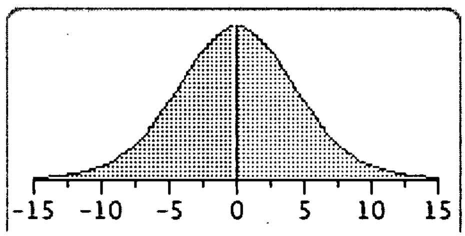
Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	7	48.6031	9.59189	3.6254	39.732	57.474
2	8	48.6875	6.64656	2.3499	43.131	54.244

t Test

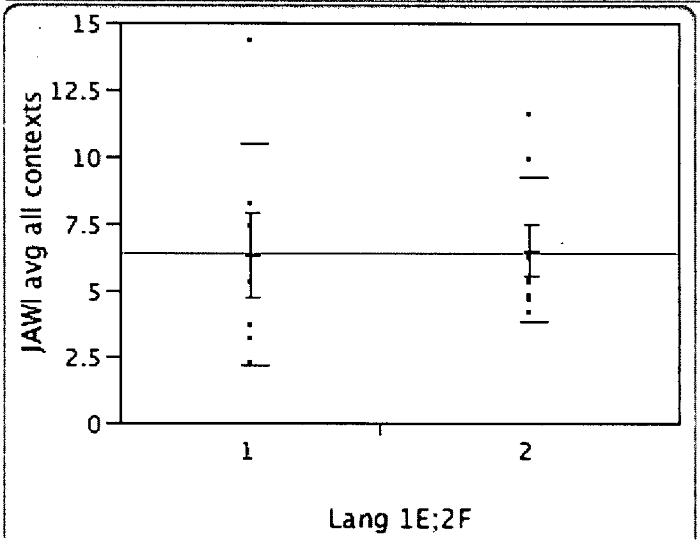
1-2

Assuming unequal variances

Difference	-0.0844	t Ratio	-0.01954
Std Err Dif	4.3204	DF	10.51052
Upper CL Dif	9.4790	Prob > |t|	0.9848
Lower CL Dif	-9.6478	Prob > t	0.5076
Confidence	0.95	Prob < t	0.4924



Oneway Analysis of JAWI avg all contexts By Lang 1E;2F



Means and Std Deviations

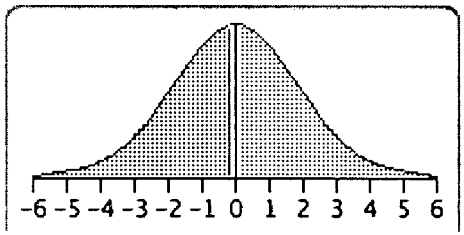
Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	7	6.35707	4.15665	1.5711	2.5128	10.201
2	8	6.53374	2.71762	0.9608	4.2617	8.806

t Test

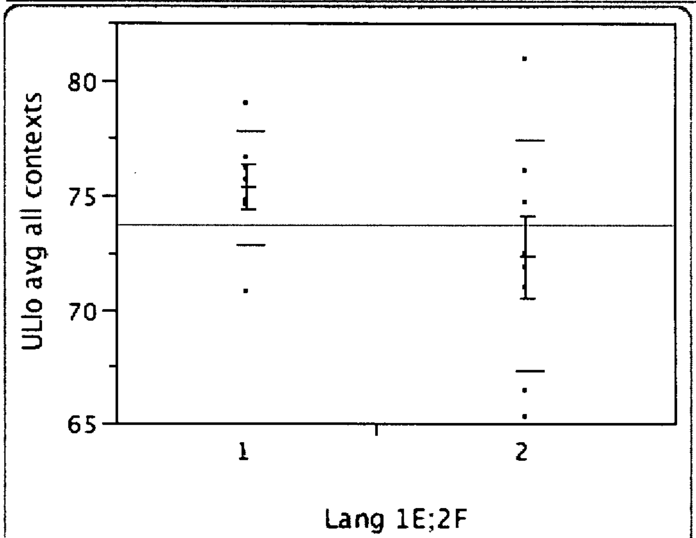
1-2

Assuming unequal variances

Difference	-0.1767	t Ratio	-0.09593
Std Err Dif	1.8416	DF	10.11479
Upper CL Dif	3.9203	Prob > |t|	0.9254
Lower CL Dif	-4.2737	Prob > t	0.5373
Confidence	0.95	Prob < t	0.4627



Oneway Analysis of ULlo avg all contexts By Lang 1E;2F



Means and Std Deviations

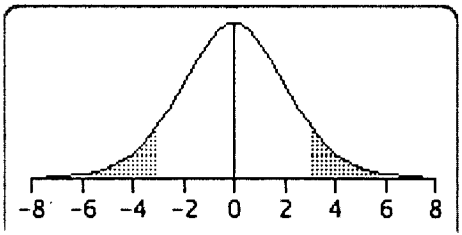
Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	7	75.3947	2.48669	0.9399	73.095	77.695
2	8	72.3779	5.07040	1.7927	68.139	76.617

t Test

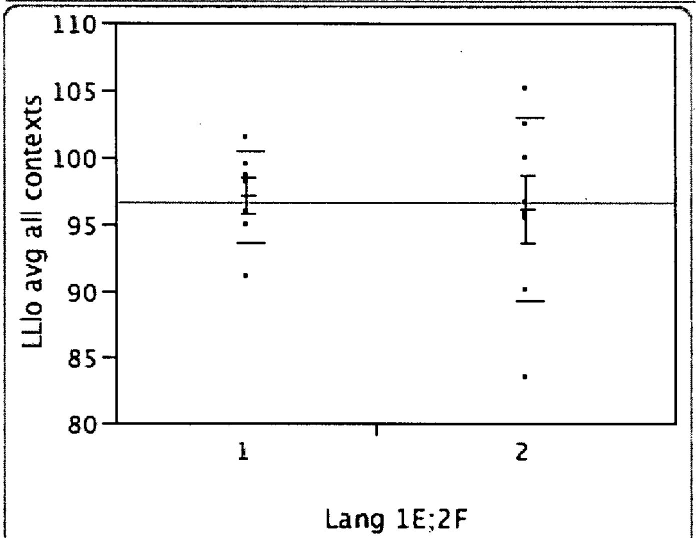
1-2

Assuming unequal variances

Difference	3.0168	t Ratio	1.49044
Std Err Dif	2.0241	DF	10.4556
Upper CL Dif	7.5003	Prob > |t|	0.1656
Lower CL Dif	-1.4667	Prob > t	0.0828
Confidence	0.95	Prob < t	0.9172



Oneway Analysis of LLlo avg all contexts By Lang 1E;2F



Means and Std Deviations

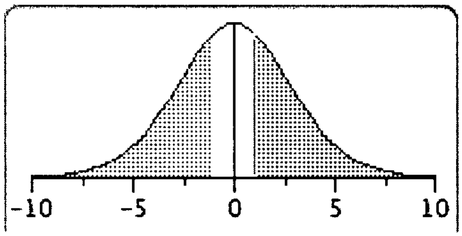
Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	7	97.1414	3.41264	1.2899	93.985	100.30
2	8	96.1594	6.90319	2.4406	90.388	101.93

t Test

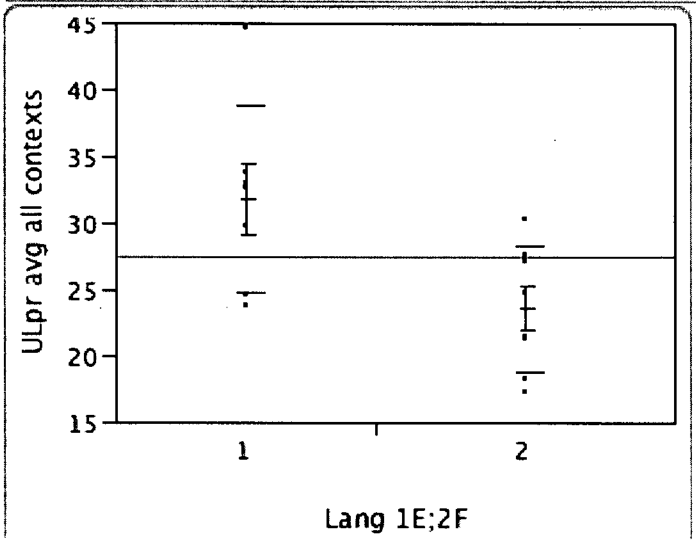
1-2

Assuming unequal variances

Difference	0.9820	t Ratio	0.355712
Std Err Dif	2.7605	DF	10.50062
Upper CL Dif	7.0933	Prob > |t|	0.7291
Lower CL Dif	-5.1294	Prob > t	0.3645
Confidence	0.95	Prob < t	0.6355



Oneway Analysis of ULpr avg all contexts By Lang 1E;2F



Means and Std Deviations

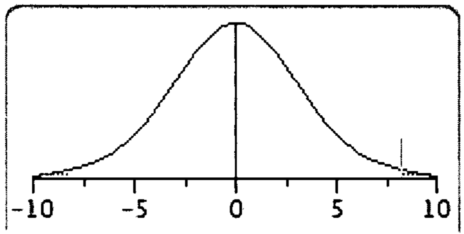
Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	7	31.7995	6.95836	2.6300	25.364	38.235
2	8	23.5994	4.68467	1.6563	19.683	27.516

t Test

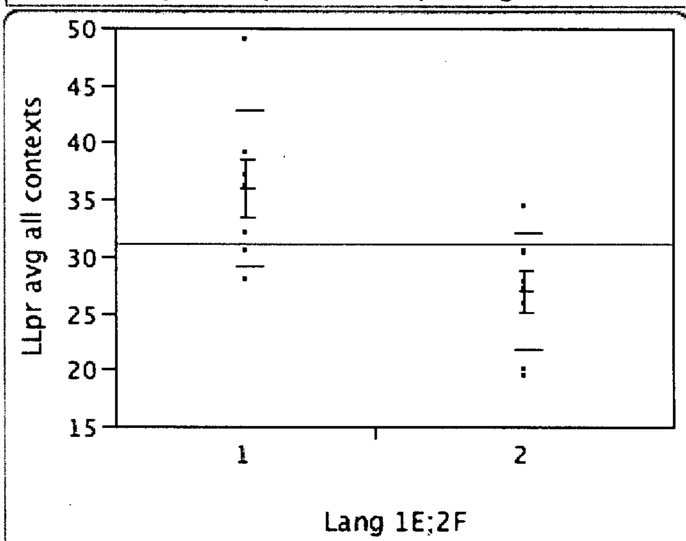
1-2

Assuming unequal variances

Difference	8.2000	t Ratio	2.638283
Std Err Dif	3.1081	DF	10.31259
Upper CL Dif	15.0969	Prob > |t|	0.0242
Lower CL Dif	1.3031	Prob > t	0.0121
Confidence	0.95	Prob < t	0.9879



Oneway Analysis of LLpr avg all contexts By Lang 1E;2F



Means and Std Deviations

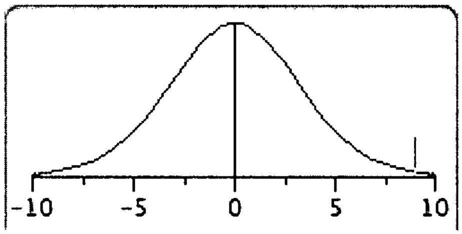
Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	7	36.0015	6.89646	2.6066	29.623	42.380
2	8	27.0052	5.14720	1.8198	22.702	31.308

t Test

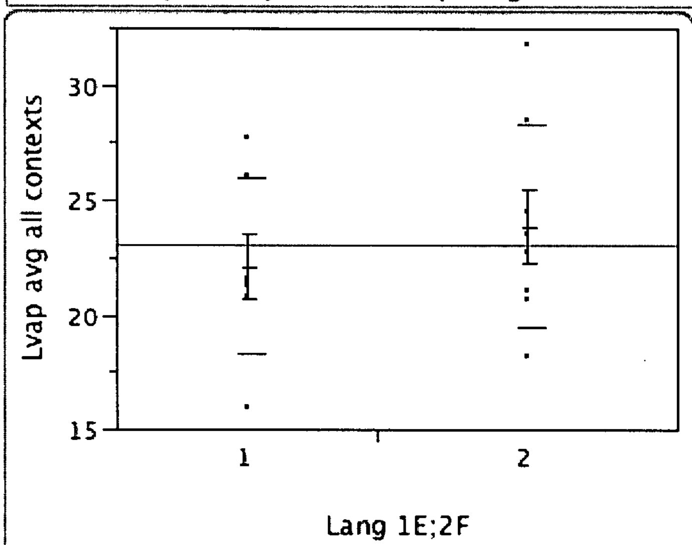
1-2

Assuming unequal variances

Difference	8.9963	t Ratio	2.829912
Std Err Dif	3.1790	DF	11.02861
Upper CL Dif	15.9911	Prob > |t|	0.0163
Lower CL Dif	2.0016	Prob > t	0.0082
Confidence	0.95	Prob < t	0.9918



Oneway Analysis of Lvap avg all contexts By Lang 1E;2F



Means and Std Deviations

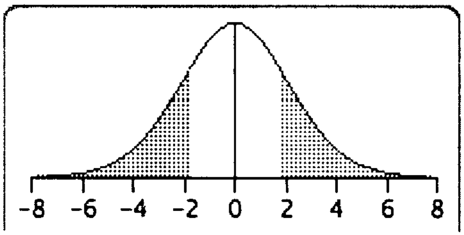
Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	7	22.1306	3.81637	1.4425	18.601	25.660
2	8	23.8946	4.41818	1.5621	20.201	27.588

t Test

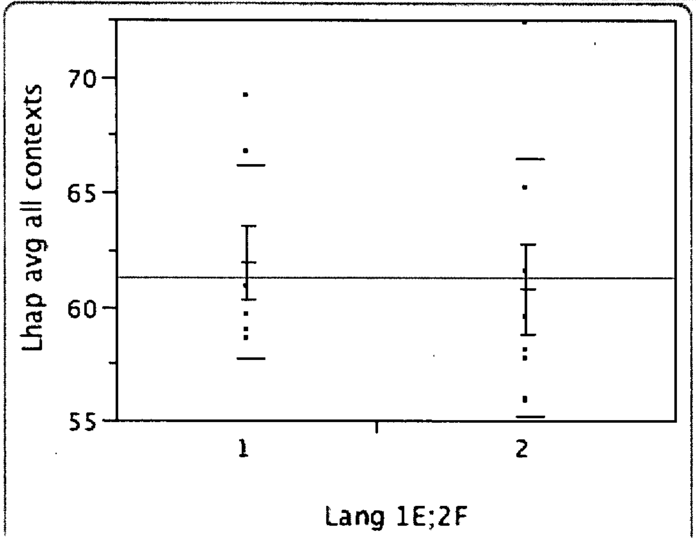
1-2

Assuming unequal variances

Difference	-1.7640	t Ratio	-0.82967
Std Err Dif	2.1262	DF	12.99991
Upper CL Dif	2.8293	Prob > |t|	0.4217
Lower CL Dif	-6.3574	Prob > t	0.7891
Confidence	0.95	Prob < t	0.2109



Oneway Analysis of Lhap avg all contexts By Lang 1E;2F



Means and Std Deviations

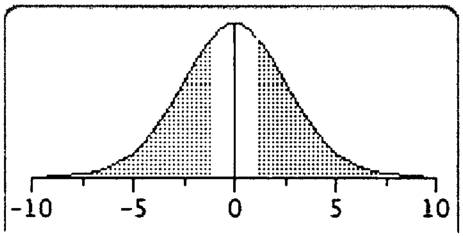
Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	7	61.9613	4.20848	1.5907	58.069	65.854
2	8	60.8110	5.62271	1.9879	56.110	65.512

t Test

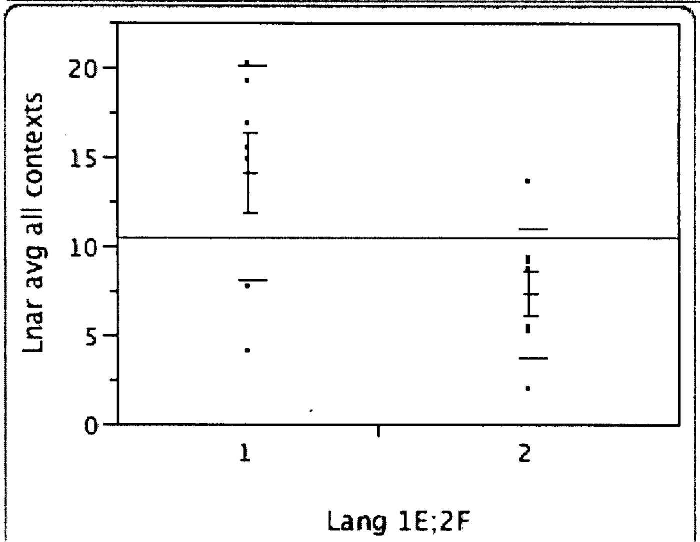
1-2

Assuming unequal variances

Difference	1.1504	t Ratio	0.451842
Std Err Dif	2.5460	DF	12.74012
Upper CL Dif	6.6621	Prob > |t|	0.6590
Lower CL Dif	-4.3613	Prob > t	0.3295
Confidence	0.95	Prob < t	0.6705



Oneway Analysis of Lnar avg all contexts By Lang 1E;2F



Means and Std Deviations

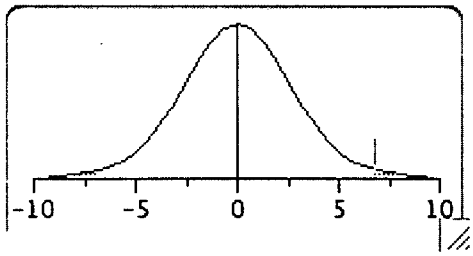
Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	7	14.1079	5.98555	2.2623	8.5722	19.644
2	8	7.3814	3.57144	1.2627	4.3956	10.367

t Test

1-2

Assuming unequal variances

Difference	6.7265	t Ratio	2.596244
Std Err Dif	2.5909	DF	9.527966
Upper CL Dif	12.5383	Prob > |t|	0.0277
Lower CL Dif	0.9147	Prob > t	0.0138
Confidence	0.95	Prob < t	0.9862



Appendix XIII Questionnaire filled out by French subjects

This page is part of a questionnaire created by Dr. Alain Desrochers (Cognitive Psychology Laboratory, University of Ottawa, 2003), and was used with his permission.

QUESTIONNAIRE SUR LA FLUIDITÉ LANGAGIÈRE DES PERSONNES BILINGUES FRANÇAIS-ANGLAIS

Section 1
Renseignements généraux

Veuillez indiquer :

Votre âge ______________________
Votre sexe ______________________
Votre pays ou province d'origine ______________________
Votre langue maternelle ______________________
Vos langues secondes ______________________
La langue maternelle de votre mère ______________________
Les langues secondes de votre mère ______________________
La langue maternelle de votre père ______________________
Les langues secondes de votre père ______________________

S'il y a lieu, à quel âge avez-vous commencé à :

	Le français	L'anglais	Autre : précisez
Parler			
Lire			
Écrire			

Dans quelle(s) langue(s) avez-vous fait vos études primaires et secondaires? Veuillez indiquer la langue d'enseignement selon les niveaux spécifiés ci-dessous.

	Mat	1	2	3	4	5	6	7 Se1	8 Se2	9 Se3	10 Se4	11 Se5	12 C1	13 C2
Français														
Anglais														
Autres														