INVESTIGATING LANGUAGE REPRESENTATIONS AND SENSORIMOTOR LEARNING IN BILINGUAL SPEAKERS

by

Sarah Bobbitt

Thesis submitted in partial fulfillment of the

requirements for the Degree of

Bachelor of Science with

Honours in Psychology

Acadia University

April, 2020

This thesis by Sarah Bobbitt

is accepted in its present form by the

Department of Psychology

as satisfying the thesis requirements for the degree of

Bachelor of Science with Honours

Approved by the Thesis Supervisor

Dr. Daniel Lametti	Date

Approved on behalf of the Head of the Department

Dr. Anne Sophie Champod	Date

Approved by the Honours Committee

Dr. Joseph Hayes	Date

I, Sarah Bobbitt, grant permission to the University Librarian at Acadia University to reproduce, loan or distribute copies of my thesis in microform, paper or electronic formats on a non-profit basis. I, however, retain the copyright in my thesis.

Signature of Author

Date

Acknowledgements

Since the beginning of my time at Acadia, I have looked forward to completing my honours thesis. At the time I didn't know how it would be done, but I knew why I wanted to do it. With the help of some really fantastic mentors, friends, and family members, I've completed a project I can feel proud of.

Dan, I am so grateful for everything you have done. Your direction, understanding, and humour made this project really rewarding and valuable to me. You were always there to help me when I needed it, and you also gave me ample room to solve and accomplish things on my own. All of those hours in the lab playing with cables honestly taught me many valuable skills, and it's hard to express the impact that this experience (and specifically, your guidance) has had on me – I have grown and learned so much, and with your help I feel so ready and excited to pursue research next year.

To the rest of the Acadia Psychology Faculty, and specifically Dr. Anne Sophie Champod – thank you so much for your feedback and advice. I have learned so much from you, both during this thesis and throughout my previous years at Acadia.

Mom, Dad, Max, Rachel, Emily, and Jacob – thank you all. You have likely listened to several hours of my ramblings and for this alone I am grateful. You were my biggest supporters, my home base, and (for a few of you) my incredibly patient pilot participants. Your love, friendship, and encouragement mean the world.

Table of Contents

List of Tables

List of Figures

Abstract

Studies of language representations in bilingual individuals thus far have produced conflicting reports; many patient/case studies suggest languages are represented independently, while imaging and behavioural studies show mixed results with age of acquisition and proficiency level differentially impacting representations. The present study employed an experimental model of sensorimotor learning in speech using altered auditory feedback to investigate the relationship between speech production and language representations in a group of 20 adult English/French bilinguals. To induce sensorimotor learning, participants produced full sentences in either English or French while altered auditory feedback was applied to their vowel sounds in real time. All participants produced English sentences in one session and French sentences in the other. Before and after learning, a transfer test involving the production of isolated words in both English and French assessed vowel production in the absence of auditory feedback (i.e., speech was heavily noise masked). The amount of speech motor learning within each language was measured as well as the degree of transfer of the adaptation from one language to another. Results indicated equal amounts of learning in English and French and equivalent transfer between and within both languages. The present study suggests that, in bilinguals, speech motor learning acquired in the context of one language is broadly applicable to a second language. The work supports the idea that the motor programs used to communicate language are shared in the bilingual brain.

Keywords: language, bilingualism, speech, sensorimotor learning

Investigating Language Representations and Sensorimotor Learning in Bilingual Speakers

Bilingualism, defined by Grosjean (1994) as the ability to use multiple languages in daily life, has been a topic of significant scientific study and debate. Recent literature continues to explore the neural mechanisms behind acquiring, maintaining, and utilizing multiple languages. One significant remaining question is the extent to which languages possessed by bilingual individuals share neural and/or cognitive representations or instead are represented independently of one another. A large body of studies examining bilinguals with brain damage suggests separate language representations, while many imaging studies show overlap in neural activity associated with first (L1) and second (L2) language use. Behavioural studies show a mixed pattern of results, with some suggesting separate representations while others provide evidence for shared representations. Both imaging and behavioural studies indicate the presence of qualifying factors such as age of acquisition and proficiency level that influence the distinctiveness of language representations. The present study aims to investigate the nature of language representations in the bilingual brain by examining the influence of language use on sensorimotor control in speech production.

Patient Studies

As case studies of bilingual aphasic patients appeared in medical literature, two main theories were used to explain different patterns of multiple language recovery: Ribot's Law (1882) and Pitres' Law (1895). Ribot's Law draws from patterns observed in cases of retrograde amnesia and thus states that languages learned early in life will be the first recovered following language loss. Pitres' Law, instead, maintains that more frequently used languages should be more resistant to damage and thus should recover more quickly following brain injury. Both Ribot's Law and

Pitres' Law operate under the assumption of independent language representations, as a shared representation would imply simultaneous or equivalent recovery of languages.

Many early patient studies support this conception of distinct, separate representations of different languages in the bilingual brain. One patient suffering from epilepsy experienced seizures that caused her to switch between her four spoken languages; in the middle of speaking English, for example, she would suddenly produce a sentence in Punjabi, having no memory of what she had said afterwards (Schwartz, 1994). This abrupt switch in language use suggests that the various languages she possessed were independently represented in her brain. Another patient had a lesion removed from language areas in her left hemisphere and experienced postoperative verbal deficits in her native language (L1) but not her second language (L2) (Gomez-Tortosa, Martin, Gaviria, Charbel, & Ausman, 1995). This differential recovery of the patient's spoken languages indicates a dissociation of the two languages in the brain. Electrocortical stimulation applied to bilingual epileptic patients has been shown to differentially disrupt performance on naming tasks in L1 and L2, depending on where the stimulation is applied—again, a result suggestive of the presence of distinct cortical language representations (Cervenka, Boatman-Reich, Ward, Franaszczuk, & Crone, 2011). Collectively, a significant body of patient/case study literature suggests that bilingual individuals possess independent neural representations for the languages they speak.

Imaging Studies

Contrary to the reviewed work on brain damaged patients, many neuroimaging studies have found evidence for shared neural representations of multiple languages in the brain. A PET study where participants performed lexical search tasks in both L1 and L2 found that similar areas of the left frontal cortex were activated regardless of which language was spoken (Klein, Milner, Zatorre, Meyer, & Evans, 1995). Similarly, Hernandez, Dapretto, Mazziotta, and Bookheimer (2001) found overlapping areas of brain activation in the left dorsolateral prefrontal cortex when bilinguals performed picture naming tasks in both English and Spanish. They also observed increased activation in the dorsolateral prefrontal cortex when participants switched from one language to another.

There is also recent evidence that the semantic context of words differentiates their representations in the brain, regardless of the language being spoken. Buchweitz, Shinkareva, Mason, Mitchell, and Just (2012) found that neural activation patterns of a noun spoken in one language (e.g., hammer) could be used to reliably predict whether the participants were thinking of the same noun in their second language, indicating similar activation areas independent of language. Correia et al. (2014) conducted a similar study and found the same results; certain brain regions appear to be involved in the semantic coding of spoken words regardless of other factors such as speaker voice or language. Evans, Price, Diedrichsen, Gutierrez-Sigut, and MacSweeney (2019) investigated these findings using individuals who were bilingual in sign and speech, two languages that differ significantly in form. Like Buchweitz et al. (2012) and Correia et al. (2014), Evans et al. (2019) found that similar semantic contexts elicited the same activation in both sign and speech. These studies strongly suggest that, at the level of meaning, multiple languages in the bilingual brain share neural substrates.

Age of Acquisition and Proficiency

The age that an individual acquires their second language, referred to in the literature as "age of acquisition", is an important qualifying factor for the nature of language representations. Kim, Relkin, Lee, and Hirsch (1997) used functional magnetic resonance imaging (fMRI) to examine language representations in two groups of bilinguals: those who learned both languages simultaneously early in development (early bilinguals) and those who learned their second language as young adults (late bilinguals). Results indicated significant language overlap in Broca's area in early bilinguals, while late bilinguals showed a dissociation of the two languages within Broca's area. In line with these findings, Pierce, Chen, Delcenserie, Genesee, and Klein (2015) investigated the impact of early language exposure on patterns of language activation during a French working memory task. They found that French monolingual children who were exposed to Chinese before the age of three but then discontinued using the language showed similar patterns of activation to French-Chinese bilinguals. This suggests that early exposure to a language, even when the language is not maintained, may significantly influence language representations.

Another important factor is the level of proficiency with which a bilingual individual uses their spoken languages. Wartenburger et al. (2003) found that age of acquisition and proficiency level differentially impact the neural substrates of L2 depending on the type of decision task being performed (i.e., grammatical or semantic). For grammatical decisions, age of acquisition was associated with differential patterns of activation in late bilinguals compared to early bilinguals, while proficiency impacted activation during both grammatical and semantic decision tasks. Abutalebi et al. (2013) also found that bilinguals showed increased activation in the left putamen (a subcortical structure important for motor sequence learning) when using L2 compared to L1, but this increase in activation was only present when individuals were less proficient in their second language. This indicates that proficiency influences patterns of activation during L2 use.

There is further evidence suggesting that acquisition age and proficiency not only impact patterns of activation in the brain but also the structural development of the brain itself. Mechelli et al. (2004) found that acquisition of a second language is linked to increased gray matter density in the left inferior parietal cortex; specifically, they reported that as the age of second language acquisition decreased and proficiency increased, gray matter density in this area increased. Similarly, Klein, Mok, Chen, and Watkins (2014) found that gray matter density in the left inferior frontal gyrus is linked to acquisition age. Both studies demonstrate that age of second language acquisition and proficiency impact neural development on a structural level, further suggesting that they play a significant role in the nature of L2 representations in bilinguals. As a whole, the neuroimaging literature suggests a shared neural representation of multiple languages in the brain when they are acquired early and spoken fluently. Second languages acquired later in life, or second languages in which the speaker is significantly less proficient, are associated with patterns of neural activation that differ from those elicited by first languages.

Behavioural Studies

Language representations can also be studied by observing behaviour. If languages share representations, a behaviour that engages one language might also engage an individual's other spoken languages, indicating an interaction between how the languages are used. If, however, the languages have distinct representations, no interaction between languages would be observed; a task involving the use of one language should not be influenced by an individual's other spoken language(s). Behavioural studies can also provide insight into aspects of speech and language use that imaging studies cannot. When studying a certain behaviour (such as language use), behavioural studies can more directly demonstrate the effects of manipulations made to the behaviour itself, while in imaging studies, neural activation in a certain area is not always indicative of a meaningful contribution to the behaviour.

Many behavioural studies seem to provide evidence for overlap between spoken languages in the mind. Several studies using lexical decision tasks—tasks in which participants judge whether displayed text constitutes a known word—have demonstrated interference between languages, indicating a shared representation of the languages (Bijeljac-babic, Biardeau, & Grainger, 1997; Lagrou, Hartsuiker, & Duyck, 2013; Spivey & Marian, 1999; Guillelmon & Grosjean, 2001; Chambers & Cooke, 2009). However, in behavioural work the role of age of acquisition and proficiency in language representations is less clear. Spivey and Marian (1999) tracked eye movements during an auditory lexical activation task in which late bilinguals were instructed to pick objects in one of their languages. Results showed that, regardless of language, participants briefly fixated on objects whose names were phonetically similar to the target object (i.e., when told to "pick up the marker", participants would briefly fixate on the cross, which is "marka" in Russian). Chambers and Cooke (2009) conducted a similar study in which participants viewed a display of various objects while listening to short sentences in French. Participants briefly fixated on distractor objects when the English translation of the distractor word sounded like the French object (i.e., when told to click on the chicken, or "poule" in French, participants briefly fixated on the pool). Interestingly, Chambers and Cooke (2009) did not find that proficiency level influenced lexical competition. While many imaging studies suggest that late bilinguals have separate language representations, these results suggest parallel activation of both languages, indicating a shared lexical representation.

Guillelmon and Grosjean (2001) investigated the role of age of acquisition in language representations by presenting recordings of French sentences to early and late English-French bilinguals. The participants were presented with both grammatically correct and incorrect phrases and were asked to repeat the phrases as quickly as possible. Late bilinguals showed no difference in time taken to repeat grammatically correct and incorrect phrases. However, early bilinguals took longer to repeat grammatically incorrect phrases than grammatically correct phrases, results which align with the behavior of French monolinguals. This suggests that phonological language representations differ between early and late bilinguals; late bilinguals do not represent French in the same way as early French bilinguals or as French monolinguals. Overall, the results of behavioural studies are divided about the role of age of acquisition and proficiency in language representations.

While many behavioural studies suggest a shared language representation, there is also behavioural evidence for the presence of distinct language representations. Paradis (2001) investigated phonological systems in bilingual two-year olds and found that bilingual infants had slightly different syllable preservation patterns compared to monolinguals. The authors concluded that the children had distinct phonological systems for their two spoken languages, but that the systems were not autonomous (i.e., they interacted with each other). In another study investigating language representations in infants, Burns, Yoshida, Hill, and Werker (2007) found that infants as young as 10-12 months possessed language-specific perceptual abilities, indicating independent phonetic representations. Finally, Pallier, Colomé, and Sebastián-Gallés (2011) found that Spanish-Catalan bilinguals whose L1 was Catalan could discriminate between two similar Catalan vowel sounds, but bilinguals whose L1 was Spanish could not. These results suggest the presence of separate phonological representations for bilinguals who learned Catalan later in life.

As a whole, the current literature from patient, imaging, and behavioural studies demonstrates that the nature of language representations is complex and depends on a multitude of factors including semantic context, age of acquisition, and proficiency level.

Speech and Language

One behavioral context in which language representations have not been thoroughly investigated is speech production—the primary means by which we use language. It is possible that the motor sequences used to produce speech may be language specific in bilinguals. If the motor sequence that produces a certain vowel sound is the same in all spoken languages, this may suggest that the languages share a representation (e.g., the motor plan to produce /ɑ/ is the same whether that /ɑ/ is placed in an English or French word). Therefore, any adaptation to an individual's motor sequence that occurs in one language should transfer to other spoken languages. Conversely, if the language representations are distinct, the pattern of speech production used to produce a certain vowel may not be the same in each language spoken by an individual. Thus, a learned alteration to speech production in one language would not be immediately observed in other languages. In the present study we specifically address this question using an experimental model of sensorimotor learning in which participants adapt to an altered auditory feedback system.

In a seminal study, Houde and Jordan (1998) established that the speech motor system rapidly adapts to altered auditory feedback. When the vowel sound that participants hear themselves producing is suddenly shifted in one direction, participants learn to produce vowel sounds in the opposite direction. This adaptation occurs to compensate for the difference between what participants perceive themselves producing and what they intend to produce. This paradigm induces changes to vowel sounds through manipulation of formants, bands of concentrated acoustic energy that represent the resonant frequencies produced during vowel production. Critically, the vowel adaptation persists for some time after the alteration has ceased and spans across different vowel sounds and words.

A small body of literature has investigated the relationship between language and speech motor learning. Mitsuya, Samson, Menard, and Munhall (2013) used altered auditory feedback to investigate differences in vowel adaptations between French and English speakers. The results indicated that French speakers alter their vowel formants differently than English speakers, and that this was not due to cognitive strategies or difference in awareness of the feedback; French speakers demonstrated greater sensitivity to altered auditory feedback and tend to compensate more than English speakers overall. The authors concluded that this suggests language-specific phonemic processes. Bourguignon, Baum, and Shiller (2014) investigated whether adaptation to altered feedback would differ depending on the lexical status of the words being produced. To do this, they induced changes to participants' vowels that would either change the words they produced from real words to pseudowords (e.g., less-liss) or from pseudowords to real words (e.g., kess-kiss). Results showed that compensation was greater when lexical status was shifted from pseudowords to real words than from real words to pseudowords, suggesting that speech motor learning favours changes in production that maintain the lexical status of words. These two studies provide support for the influence of linguistic processing in speech motor planning.

Present Study

Previous literature remains divided on the nature of language representations, and while imaging studies generally suggest that a late age of acquisition and low proficiency are associated with more distinct representations, behavioural studies do not demonstrate this same trend. The use of a sensorimotor adaption model may provide a new avenue through which this question can be investigated at the behavioural level. Based on the paradigm developed by Houde and Jordan (1998), the present study used an altered auditory feedback system to alter the vowel sounds that bilingual participants heard themselves producing in order to induce speech motor learning. In bilinguals, we then examined whether this adaptation, acquired in the context of one language, could be applied to a second language.

Previous studies employing a similar methodology have found significant effects using 10 participants or less per group (Lametti, Smith, Watkins, & Shiller, 2018; Bourguignon et al., 2014; Houde & Jordan, 1998). Therefore, 20 English-French bilinguals were used in the present study which employed a within-subjects design, resulting in 20 participants per condition. In two separate sessions, English-French bilinguals experienced altered vowel sound feedback during the fluid production of either English or French sentences. These training blocks drove a learned change in vowel sound production. The training blocks were interspersed with transfer blocks in which participants produced single words in both English and French that had identical vowel sounds. The transfer blocks measured the extent to which vowel adaptations acquired in the context of one language (e.g., English) could be transferred to identical vowels produced in a different language (e.g., French). It was hypothesized that there would be greater transfer of speech motor learning from English sentences to English words than English sentences to French words, and vice versa. That is, speech motor learning would be constrained to the linguistic context in which it was acquired. In a secondary analysis, the amount of vowel adaptation (i.e., learning) in each language was measured to investigate whether speech motor learning was related to proficiency. Therefore, it was also hypothesized that the amount of within-language learning would be greater in participants' first language (English) than in their second language (French).

Method

Participants

Twenty bilinguals between the ages of 18 and 55 took part in the study. Participants were native English speakers with varying degrees of second language fluency in French; all participants considered themselves to be fluent enough to read French aloud. Participants were recruited via emails sent through Acadia University's email system (AcadiaFYI), the University's research participation system (SONA), and through emailing local French teachers. The experimental procedure was approved by the Acadia University Research Ethics Board and participants gave informed consent. Participants received $35 in compensation at the end of the study or course credit, or a combination of credits and money. An additional $10 was provided to cover travel costs if necessary.

Materials

Participants wore a microphone (Shure, SM35-XLR), through which their voices were recorded, and headphones (Sennheiser, HD 280 Pro), from which they heard (in real-time) the sound of their own voice whenever they spoke. An LED dB meter (American Audio, DB Display MKII) was placed in front of participants to aid in monitoring the volume of their speech. Audapter, software based in Matlab, was used to record speech and alter feedback of speech on some trials. Praat was used for speech analysis. A laptop (Dell XPS) was used by the experimenter for stimulus presentation and a computer monitor displayed sentences to participants.

Language Experience Questionnaire. Participants completed a Language Experience Questionnaire that was adapted from a modified version of the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld, & Kaushanskaya, 2007). The LEAP-Q was developed to provide a comprehensive evaluation of a multilingual individual's language proficiencies. However, the questionnaire provides descriptive data and does not produce a numerical proficiency score. In addition, age of acquisition is broken into multiple components, including age when participants began acquiring the language, age when they became fluent in the language, time spent in a country or household in which the language was spoken, etc. This provides comprehensive information about the participant's history but does not produce a numerical age of acquisition with which correlations may be conducted. Thus, in the present study, select questions from the LEAP-Q were retained (e.g., age of language acquisition, number of years spoken, etc.) while in addition participants were asked to indicate, on a scale from 1 to 10, their proficiency in writing, speaking, and reading in English and French. The average of these three numbers was calculated for each participant to produce a composite self-report proficiency score for each participant.

Stimuli. Participants read sentences that were taken from a corpus of phonetically balanced phrases known as the Harvard Sentences (e.g., "The birch canoe slide on the smooth planks") (https://www.cs.columbia.edu/~hgs/audio/harvard.html). For the purposes of this study, 250 of these sentences were translated from English to French. Fifty of the translated sentences, which matched the original sentences for number of words, syllables, morphemes, and vowel structure, were selected for use in the study (e.g., "De nos jours, le poulet est un plat rare" and "These days, a chicken leg is a rare dish").

Monosyllabic transfer words were presented during two vowel blocks. The 16 words were: pis, patte, pâte, toute, sept, pote, eux, eau (French) and pea, pat, pot, toot, set, putt, hood, bid (English). The vowel blocks consisted of 8 French and 8 English words with similar vowels (e.g., 'pea' in English and 'pis' in French) that spanned the English-French vowel space.

Procedures

The experimenter verbally explained the experiment and provided the participant with the consent form and LEAP-Q. If the participant agreed to take part in the study and understood the task, they were fitted with the microphone and headphones and sat comfortably facing the computer monitor. They faced an LED dB meter which indicated the volume of their voice as registered by the microphone; they were told to try to keep their voice within the indicated range. Participants were instructed to read the sentences/words that appeared on the screen in a clear, natural speaking voice, and to refrain from speaking other than to read the stimuli. They were warned that they may hear a static sound through the headphones and that this sound may increase on some trials, preventing them from being able to hear themselves speak. They were told to ignore this and continue to speak clearly and normally.

Before the experiment began, participants were shown a list of eight English and French monosyllabic words which served as the experimental stimuli on some trials. As French was not their native language, an audio recording of a female speaker producing the French words was played for the participant to confirm that the participant knew how to properly produce the words in French. Participants then completed a demo block in which they produced the eight English and eight French words.

Participants produced each of the 50 sentences seven times over the course of the experiment (Figure 1). The experiment was divided into seven blocks in which each sentence was produced once, resulting in a total of 350 sentence productions. During the first two sentence blocks (S1 and S2) participants experienced normal auditory feedback. During the following four sentence blocks (S3-S6) participants experienced altered auditory feedback (see Altered Auditory

Feedback). The final sentence block (S7) was completed with normal auditory feedback and served to wash out changes in speech production related to altered feedback.

Participants also produced isolated words during two vowel blocks (V1 and V2) that occurred before and after altered auditory feedback associated with sentence production. Each of the 16 words (8 French, 8 English) were presented in a random order five times each for a total of 80 word productions per vowel block. Speech-shaped masking noise was played during the two vowel blocks such that participants could not hear the sound of their own voice. The aim of these vowel blocks was to assess whether changes in vowel production acquired during the sentence blocks (because of altered auditory feedback) could be applied to the production of words, some of which were in the speakers second language. Auditory feedback was masked during these trials to prevent unlearning of any adaptation acquired during sentence production. The vowel production blocks thus directly measure the extent to which a change in vowel production acquired in one language could be applied to the same vowels in a second language.

During data collection, stimuli were presented in nine blocks: two baseline sentence blocks followed by a vowel block, four sentence blocks with altered auditory feedback, a second vowel block, and a final sentence block to wash out changes in speech associated with altered feedback (Figure 1). In the participant's first session, the sentences were presented in one language and in the second session the sentences were presented in the other language (e.g., English in Session 1 and French in Session 2); the order of language presentation was counterbalanced across participants. At the end of the second session, participants were debriefed on the purpose of the study and provided compensation (money and/or course credits) for their participation.

Altered Auditory Feedback. Changes to vowel sounds were induced through the manipulation of formants. Formants are resonant frequencies of the vocal tract that can be manipulated using articulators. The first and second formants, F1 and F2, define the vowel space, and changes to these formants result in changes to the vowel sound being produced. Using the software package Audapter (https://github.com/shanqing-cai/audapter_matlab) first and second formant frequencies were altered and played back to participants in near-real-time to promote sensorimotor adaptation. To do this, we applied a 49.5 mel decrease to F1 and a 49.5 mel increase to F2 for a total change of 70 mels in F1/F2 space. Mels were used rather than hertz because numeric changes in pitch on the mel scale are perceived by listeners to be equal (a property that is not true of the Hz scale). The transformation from Hz to mel was:

$$\text{mel} = 1127.01048 \times \log(1 + \text{Hz}/700)$$

This alteration was increased linearly over the first 25 trials of altered feedback (S3) and was then held constant until the end of altered feedback in S6.

Acoustic Analysis. The procedure for acoustic analysis was adapted from Lametti et al. (2018). Matlab was used to record speech at 48000 Hz and the software package Praat (http://www.fon.hum.uva.nl/praat/) was used for speech analysis. Through Praat's autocorrelation method, pauses and unvoiced consonants were removed from the acoustic signal, leaving only the vocalized portions of speech (which largely consist of vowels). Linear Predictive Coding (LPC)—a method for representing acoustical spectra—was used to compute F1 and F2 from these segments. For the transfer blocks, the voiced segment of each word was isolated and LPC was used to compute F1 and F2 values; the most appropriate LPC order for each sentence and word, within each participant, was determined through visual inspection. Average F1 and F2 values were found for each of the sixteen transfer words.

Statistical Analysis. To assess compensation related to altered auditory feedback, changes in F1 and F2 frequency associated with sensorimotor adaptation and transfer of adaptation were projected onto a vector in F1-F2 space that perfectly opposed the direction of the applied change in the sound of the voice. Thus, compensation in response to altered auditory feedback was defined as sensorimotor adaptation that was exactly opposite the direction of the alteration. To do this, the angular difference between the inverse of the vector representing the feedback shift and the vector representing production change in F1-F2 space was found. The cosine of this difference was then multiplied by the magnitude of production change. This made it possible to quantify the degree to which the observed change in formants exactly countered the alteration. This value was then represented as a percentage (e.g., a 70 mel change in produced formants in opposition to the 70 mel change in perceived formants equals 100% compensation).

Two tests were conducted: one within-subjects t-test was used to measure the degree of learning in L1 compared to learning in L2, and a 2-way repeated measures ANOVA assessed transfer of the adaptation from L1 to L2 versus transfer from L2 to L1. To test the degree of learning within each language across sentences, the average change in F1 and F2 was calculated between S6 and S2 (i.e., the last sentence block of altered feedback was compared to the sentence block just before altered feedback was applied). This change was calculated for each participant, within L1 and L2. Learning related change in F1 and F2 production were compared between languages using within-subjects t-tests. To assess the degree of transfer from one language to another, the change in F1 and F2 associated with experiencing altered feedback during sentence production was calculated for the words produced in the vowel blocks. Specifically, changes in formant production between V2 and V1 (i.e., just after altered feedback and just before altered feedback) were calculated for each participant, in both L1 and L2. These changes reflect the amount of learning-related transfer from sentence production to word production. A 2-way repeated measures ANOVA was then performed on the data to examine the amount of transfer from learning associated with English sentences to the production of English words and French words, and learning associated with French sentences to the production of English words and French words.

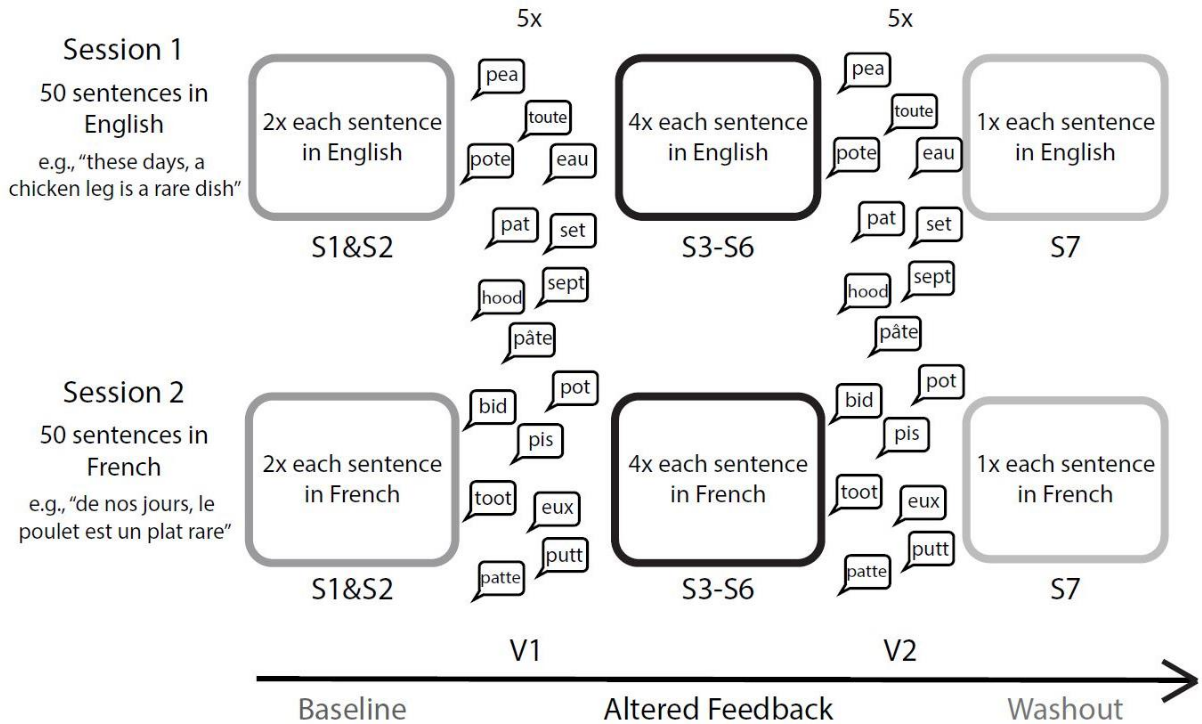

Figure 1. Experimental procedure. Session 1 and Session 2 occurred 7-10 days apart. Half of the participants performed Session 1 in French and Session 2 in English. Participants produced seven blocks of 50 sentences in each session. Transfer blocks (represented by the word bubbles) consisting of single word production with noise-masked speech occurred after the Baseline blocks and the Altered Feedback blocks.

Results

The present study sought to investigate language representations in bilingual individuals using an experimental model of sensorimotor learning. In two different sessions, participants produced sentences in either English or French while hearing their own voice played back to them with a slight alteration to their vowel formants, F1 and F2. This alteration induced an adaptation to the vowels produced by participants. The degree to which participants acquired the adaptation was measured as the difference in compensation between the final sentence block produced under altered auditory feedback and the sentence block just before altered feedback was applied. Before and after sensorimotor adaptation, participants produced single words in both English and French while their voices were heavily noise-masked. Changes in vowel production between these blocks assessed the degree to which the vocal adaptation transferred from the sentences (produced in one language) to the vowel sounds in single words (produced in both languages).

Learning

Figure 2 shows the percentage of compensation (i.e., sensorimotor learning) for altered auditory feedback associated with the production of French sentences (blue bar) and English sentences (red bar). Significant compensation was observed during the production of both French and English sentences. That is, in both cases one-sample t-tests showed that the percentage of compensation differed from zero (English sentences: $t(19) = 4.95$, $p < 0.001$; French sentences: $t(19) = 6.71$, $p < 0.001$). However, a one-tailed within-subjects t-test found no difference in the amount of sensorimotor learning between languages ($t(19) = -0.317$, $p = 0.755$). First language English, second language French bilinguals showed the same amount of compensation for altered auditory feedback regardless of whether they were producing English sentences (*Mean* *compensation* = 22.03, *SD* = 19.89) or French sentences (*Mean compensation* = 20.28, *SD* = 13.51) (Figure 2).

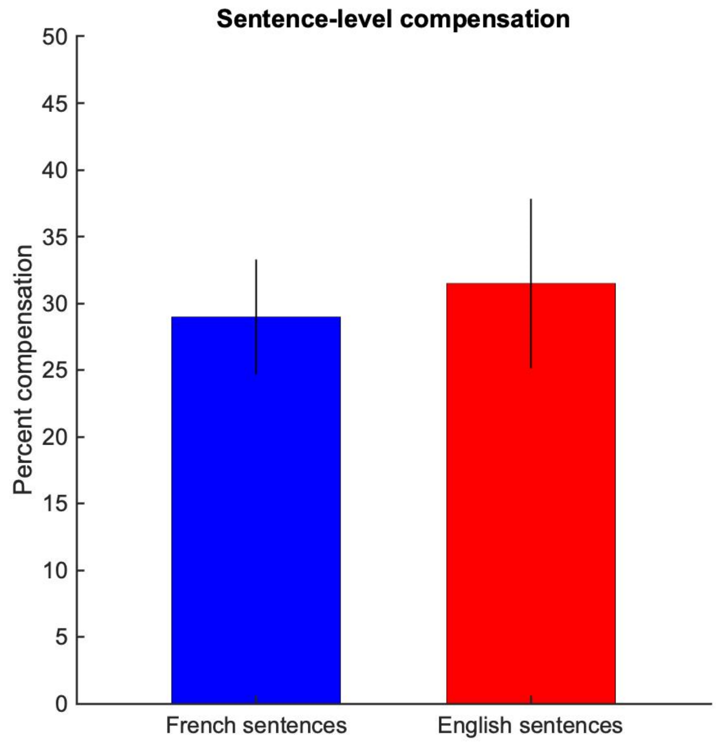

Figure 2. Percentage of compensation for altered auditory feedback between S6 and S2 (learning) when producing French sentences and English sentences. Error bars represent ±1 SE.

Transfer

Figure 3 shows the amount of transfer of learning from altered auditory feedback associated with French sentence training (left side) and English sentence training (right side) to the production of isolated words in French (blue bars) and English (red bars). In this case, transfer is represented as the percentage of compensatory change during the transfer task (i.e., word production) in relation to the change experienced during sentence production. To compare the percentage of transfer between training languages and transfer languages, a 2-way repeated measures ANOVA was conducted with training language (French or English) and transfer language (French or

English) as the independent variables and percent compensation as the dependent variable. There was no significant interaction between Training Language and Transfer Language, $F(1, 19) = 4.101$, $p = 0.057$. Training on English sentences was not associated with greater transfer to English words, and vice versa for French. The main effect of Training Language was not significant ($F(1, 19) = 2.467$, $p = 0.133$). That is, there was no difference in transfer when participants trained with sentences in English ($M = 22.53$, $SD = 27.51$) compared to when they trained on French sentences ($M = 8.85$, $SD = 17.62$) (Figure 3). Significant transfer was observed from both training languages; one sample t-tests showed significant levels of transfer when training in both English ($t(19) = 3.66$, $p = 0.002$) and French ($t(19) = 2.25$, $p = 0.037$). There was no main effect of Transfer Language ($F(1, 19) = 4.297$, $p = 0.052$); participants showed the same amount of transfer to English words ($M = 12.28$, $SD = 13.55$) as French words ($M = 19.10$, $SD = 15.29$), regardless of training language. Significant transfer was observed to both English and French words; when collapsing across Training Language, a one sample t-test indicated that participants showed significant transfer to both English ($t(19) = 4.05$, $p = 0.001$) and French ($t(19) = 5.58$, $p < 0.001$).

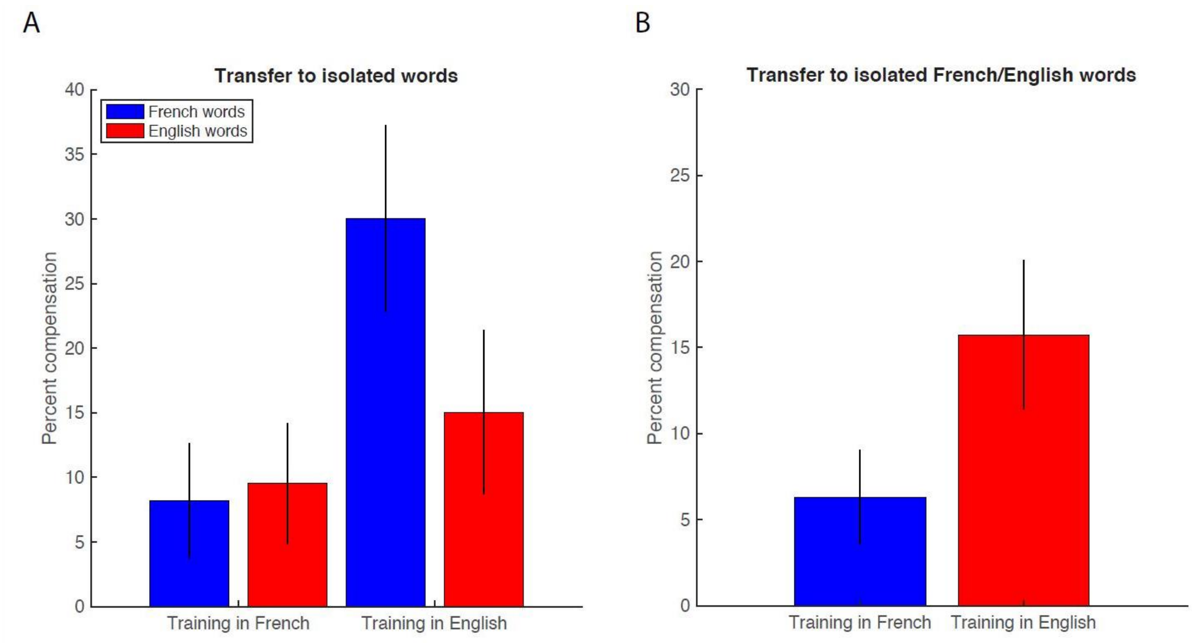

Figure 3. (A) Degree of transfer of the adaptation to altered auditory feedback when training with French and English sentences and transferring to French and English single words. Error bars represent ±1 SE. (B) Degree of transfer to both English and French single words when training with French and English sentences, collapsing across transfer words. Error bars represent ±1 SE.

Age of Acquisition and Proficiency Level

Using responses to the Language Experience Questionnaire (see Appendix A, Table 1 for details on participant data), exploratory analyses were conducted to test whether proficiency in L2 and age of acquisition of L2 were correlated with compensation or transfer of the adaptation. There was a significant negative correlation between age of acquisition and proficiency (r = -0.613, p = 0.007). Correlations between proficiency and compensation in French (r = -0.166, p = 0.484) and age of acquisition and compensation in French (r = -0.010, p = 0.968) were not significant. Likewise, there were no significant correlations between age of acquisition and the amount of transfer associated with training in French (r = 0.359, p = 0.143), or training in English (r = -0.102,

$p = 0.686$). There were also no significant correlations between proficiency and amount of transfer associated with training in French ($r = -0.043$, $p = 0.856$), or training in English ($r = -0.182$, $p = 0.444$).

Discussion

The present study aimed to investigate the nature of language representations in the bilingual brain using an experimental model of sensorimotor learning in speech. In two separate sessions, English-French bilinguals produced either English or French sentences while their vowel sounds were altered in real-time. In these training blocks, participants learned to adapt the sound of the vowels they produced. Transfer blocks interspersed throughout the training blocks consisted of single word production in both English and French. These transfer blocks measured the extent to which vowel adaptations acquired in the context of one language (e.g., English) could be transferred to identical vowels produced in a different language (e.g., French). It was hypothesized that the amount of learning (i.e., the difference in compensation between S6 and S2) would be greater in English than in French, as the study was conducted using native English speakers. It was also hypothesized that we would observe greater transfer of the vowel adaptation within languages than between languages (i.e., there would be greater transfer from English sentences to English words than from English sentences to French words, and vice versa).

Learning took place in both English and French, indicating that participants responded to altered auditory feedback by adapting their vowels in both languages. However, though both groups showed learning, in this sample of L1 English, L2 French bilinguals we found no difference in the amount of learning associated with English or French sentences. These results do not support our hypotheses, suggesting that bilinguals demonstrate sensorimotor learning in both their native and second languages, and that this learning does not differ depending on the language in which the adaptation is required. Participants demonstrated equal amounts of learning regardless of whether they acquired the adaptation in the native or second language, indicating that sensorimotor adaptation is not constrained by linguistic context or by proficiency.

Significant transfer of the adaptation was observed when training in English and French (collapsing across transfer words) and when transferring to English and French (collapsing across training words); significant amounts of transfer were observed in all conditions. However, this transfer did not differ between groups; participants transferred the adaptation equally to French and English words regardless of which language they trained in, and the total amount of transfer when training in English did not differ from the total amount of transfer when training in French. These results do not support our hypothesis; we expected to observe greater transfer to English than to French when training in English, and greater transfer to French than to English when training in French, as this would suggest that the adaptation was largely restricted to the language in which it was acquired. The results of the present study, instead, suggest that representations of the sensorimotor plans used to produce vowels do not differ between English and French. Bilingual participants appear to acquire and apply sensorimotor adaptations to speech equally in both their languages, and then can apply these adaptations to the other language they speak.

While the difference in adaptation between training in English and training in French was not significant, there does appear to be a trend toward greater transfer of learning when participants trained in English (see Figure 3B). Subsequent studies with a greater number of participants are needed to further investigate this potential difference. If this were to be the case, this might suggest that bilinguals demonstrate greater transfer of sensorimotor learning when they train in their native language (in this case, English). Thus, acquisition of the adaptation may be equivalent in both English and French, but the adaptation can be transferred to a different linguistic context more easily if acquired in one's native language.

While a significant body of background literature indicated that age of acquisition and proficiency level significantly impact language representations, no correlations between these measures and learning or transfer of the adaptation were found in the present study. The only significant correlation between age of acquisition and proficiency level was between the two variables themselves; as would be expected, the younger an individual was when they learned their spoken language, the more proficient they were in speaking that language. This finding supports the validity of the questionnaire and suggests that the variables of interest were being accurately measured. While no specific hypotheses were made regarding age of acquisition and proficiency, the lack of any correlations in the data does not align with much of the literature, especially that which investigated language representations using neuroimaging studies. While we did find a correlation between age of acquisition and proficiency level, the lack of correlations between other variables may be due in part to the small sample size limiting our statistical power. Conversely, the results of the present study align with several behavioural studies that have indicated that age of acquisition and proficiency level may not impact representations (Spivey & Marian, 1999; Chambers & Cooke, 2009). This finding suggests that age of acquisition and proficiency level may impact how languages are represented in the brain without impacting performance on various behavioural measures.

The results of the present study somewhat conflict with other studies that investigated how language interacts with sensorimotor learning in speech. Mitsuya et al. (2013) found that English and French speakers differentially adapted their speech to altered feedback, a result which suggests language-specific phonemic processes. The present study, in contrast, did not find a difference in sensorimotor learning between English and French. However, this difference may be driven by the fact that Mitsuya et al. (2013) used a sample of native English and native French speakers, rather than English-French bilinguals.

While there were no differences in transfer or learning between English and French found in the present study, nor between amount of learning in English and French, it should be noted that this does not necessarily indicate that the two languages share a representation at a “higher” linguistic level. It is important to interpret these results within the context of the mechanism through which we induced and measured adaptation: sensorimotor learning. One interpretation of these results may be that the motor plans needed to produce speech are the same across languages, i.e., that bilingual individuals do not possess separate paths for motor sequences used in production of English and French speech. However, motor planning is just one dimension at which we can describe language representations. Therefore, while the results of the present study may not indicate entirely separate language representations across every dimension, they do suggest that, in the context of speech production, bilinguals appear to share motor plans across their separate languages.

While the present study provides support for overlapping motor plans during production of French and English speech, there are potential limitations of the study that limit its generalizability. Firstly, there were some issues with obtaining high-quality audio recordings from participants, particularly during the single-word transfer task. The masking noise played to participants had to be loud enough so that they could not hear themselves speaking and this may have caused some participants to speak outside the optimal volume range for audio recording. Because of this, several of the audio recordings from the transfer task contained a significant degree of extraneous noise which may have impacted the ability of the program (Praat) to accurately detect formants in the speech signal.

There are also some limitations of the participant pool used. The bilinguals that took part in this study were drawn from a primarily English-speaking region. An ideal sample might consist of more “active” bilinguals – i.e., those living in a bilingual region who frequently speak in both languages during their daily lives. Many of the bilinguals used in the present study likely do not frequently speak French at home, work, or school, which may have impacted their ability to transition between speech production in English and French. Further, there is a relatively small range of ages at which participants acquired their second language; no participants acquired their second language over the age of 13, and the mean age of acquisition is relatively young at 5.67 years of age (Table 1). As previously discussed, many studies have indicated that bilinguals who learn their second language later in life have distinct language representations and early bilinguals possess shared representations. In the present study, it is possible that the sample, which primarily learned their second language before adolescence, does not possess a wide enough range of acquisition ages to show a correlation between age of acquisition and compensation or transfer. There is also a limited range of proficiency level in our participant pool. The scale for proficiency ranged from 1-10, while responses ranged only from 5-10, with a mean of 7.96 (Table 1), indicating that present study lacked individuals with low proficiency in French. This might similarly have reduced our ability to observe a significant impact of proficiency level on compensation or transfer. As it may be difficult for participants to make an accurate judgment regarding their own proficiency levels, future studies might attempt to use a more objective measure of proficiency, perhaps through a language proficiency task that would produce an objective proficiency score.

The transfer task used in the present study also presents some potential limitations. Central to this study is the notion that we can observe language representations by having speakers switch from speaking in one language to speaking in the other. This assumption lays the foundation for the conclusions drawn and is crucial to our ability to obtain and interpret results. As such, it is essential that the task used accurately captures this transition between languages; speakers must "code switch" (i.e., genuinely engage each of their spoken languages during transfer trials). The training task used in the present study involves natural speech, as participants rapidly produced complex sentences. However, the transfer task used only single, monosyllabic words, as this is the typical methodology employed to study sensorimotor learning in speech (as developed by Houde & Jordan, 1998). Given the simplicity of the transfer task from a production standpoint, participants may not have been able to properly engage the desired linguistic context of the word being spoken. That is, after training on complete English sentences they may have produced the simple French transfer words with an English accent, and vice versa. If this is true, it is possible that participants were not engaging the same neural and/or cognitive systems normally used to produce speech in either language. This is an important issue that could be addressed in future studies by using a more ecologically valid transfer task.

Future studies might further investigate the relationship between motor plans and language representations. The present study was conducted upon the assumption that motor plans might reflect the nature of language representations. Specifically, it was thought that distinct representations would require separate motor plans when producing speech in each of an individual's spoken languages, while in the case of overlapping representations, a shared motor plan would be employed regardless of which language was being spoken. It is important to investigate the precise nature of this relationship to determine whether these patterns of representation would indeed engage these types of motor plans. Future work might employ similar models of sensorimotor learning to investigate language in a variety of different contexts (e.g., whether an accent or lisp in one language is observed in the individual's other spoken language(s)).

Deeper investigation of this relationship will permit further work in this area and allow for more specific conclusions to be drawn.

A "language representation" has, for the sake of simplicity and brevity, been treated in the present study largely as one cohesive construct, comprised of various aspects of language; a language representation might be reflected in the physical structure and patterns of activation of the brain, in phonetic, lexical, or semantic representations, or, as in the present study, in speech and the motor plans used to execute speech. These constructs might all interact differentially with language, and indeed may point to different patterns of representation; perhaps two languages share one type of representation but not another. In such a case, and in the case of the present study, it is important to acknowledge the vast and varied elements of language and speech, and to consider that the concept of a "language representation" may itself consist of many different types of representations.

The present study was conducted to investigate the nature of language representations through a model of sensorimotor learning in speech. Contrary to our hypotheses, participants demonstrated equal amounts of learning within English and French and transferred the vowel adaptation equally within and between both languages. These results may suggest shared linguistic representations in bilingual speakers; they also indicate an overlap in the motor plans that bilinguals use to produce speech in English and French. This research provides a meaningful foundation upon which future studies might build a greater understanding of the relationship between language representations and motor plans in the bilingual brain.

References

Abutalebi, J., Rosa, P. A. D., Castro Gonzaga, A. K., Keim, R., Costa, A., & Perani, D. (2013). The role of the left putamen in multilingual language production. *Brain and Language*, *125*(3), 307–315. doi:10.1016/j.bandl.2012.03.009

Bijeljac-babic, R., Biardeau, A., & Grainger, J. (1997). Masked orthographic priming in bilingual word recognition. *Memory & Cognition*, *25*(4), 447–457. doi:10.3758/BF03201121

Bourguignon, N. J., Baum, S. R., & Shiller, D. M. (2014). Lexical-perceptual integration influences sensorimotor adaptation in speech. *Frontiers in Human Neuroscience*, *8*. doi:10.3389/fnhum.2014.00208

Buchweitz, A., Shinkareva, S. V., Mason, R. A., Mitchell, T. M., & Just, M. A. (2012). Identifying bilingual semantic neural representations across languages. *Brain and Language*, *120(3)*, 282–289. doi:10.1016/j.bandl.2011.09.003

Burns, T. C., Yoshida, K. A., Hill, K., & Werker, J. F. (2007). The development of phonetic representation in bilingual and monolingual infants. *Applied Psycholinguistics*, *28*(3), 455–474. doi:10.1017/S0142716407070257

Cervenka, M. C., Boatman-Reich, D. F., Ward, J., Franaszczuk, P. J., & Crone, N. E. (2011). Language mapping in multilingual patients: Electrocorticography and cortical stimulation during naming. *Frontiers in Human Neuroscience*, *5*, 13. doi:10.3389/fnhum.2011.00013

Chambers, C. G., & Cooke, H. (2009). Lexical competition during second-language listening: Sentence context, but not proficiency, constrains interference from the native lexicon. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*(4), 1029–1040. doi:10.1037/a0015901

Correia, J., Formisano, E., Valente, G., Hausfeld, L., Jansma, B., & Bonte, M. (2014). Brain-based translation: FMRI decoding of spoken words in bilinguals reveals language-independent semantic representations in anterior temporal lobe. *Journal of Neuroscience, 34(1)*, 332–338. doi:10.1523/JNEUROSCI.1302-13.2014

Evans, S., Price, C. J., Diedrichsen, J., Gutierrez-Sigut, E., & MacSweeney, M. (2019). Sign and speech share partially overlapping conceptual representations. *Current Biology*, *29(21)*, 3739-3747.e5. doi:10.1016/j.cub.2019.08.075

Gomez-Tortosa, E., Martin, E. M., Gaviria, M., Charbel, F., & Ausman, J. I. (1995). Selective deficit of one language in a bilingual patient following surgery in the left perisylvian area. *Brain and Language*, *48*(3), 320–325. doi:10.1006/brln.1995.1014

Grosjean, F. (1994). The bilingual individual. In R. E. Asher (Ed), *The encyclopaedia of language and linguistics* (p. 1656-1660). Oxford, UK: Pergamon Press.

Guillelmon, D., & Grosjean, F. (2001). The gender marking effect in spoken word recognition: The case of bilinguals. *Memory & Cognition*, *29*(3), 503–511. doi:10.3758/BF03196401

Hermans, D., Ormel, E., van Besselaar, R., & van Hell, J. (2011). Lexical activation in bilinguals' speech production is dynamic: How language ambiguous words can affect cross-language activation. *Language and Cognitive Processes*, *26*(10), 1687–1709. doi:10.1080/01690965.2010.530411

Hernandez, A. E., Dapretto, M., Mazziotta, J., & Bookheimer, S. (2001). Language switching and language representation in Spanish-English bilinguals: An fMRI study. *NeuroImage*, *14*(2), 510–520. doi:10.1006/nimg.2001.0810

Houde, J. F., & Jordan, M. I. (1998). Sensorimotor adaptation in speech production. *Science*, *279*(5354), 1213–1216. doi:10.1126/science.279.5354.1213

Kim, K. H. S., Relkin, N. R., Lee, K.-M., & Hirsch, J. (1997). Distinct cortical areas associated with native and second languages. *Nature*, *388*(6638), 171–174. doi:10.1038/40623

Klein, D., Milner, B., Zatorre, R. J., Meyer, E., & Evans, A. C. (1995). The neural substrates underlying word generation: A bilingual functional-imaging study. *Proceedings of the National Academy of Sciences*, *92*(7), 2899–2903. doi:10.1073/pnas.92.7.2899

Klein, D., Mok, K., Chen, J.-K., & Watkins, K. E. (2014). Age of language learning shapes brain structure: A cortical thickness study of bilingual and monolingual individuals. *Brain and Language*, *131*, 20–24. doi:10.1016/j.bandl.2013.05.014

Lagrou, E., Hartsuiker, R. J., & Duyck, W. (2013). Interlingual lexical competition in a spoken sentence context: Evidence from the visual world paradigm. *Psychonomic Bulletin & Review*, *20*(5), 963–972. doi:10.3758/s13423-013-0405-4

Lametti, D. R., Smith, H. J., Watkins, K. E., & Shiller, D. M. (2018). Robust sensorimotor learning during variable sentence-level speech. *Current Biology*, *28*(19), 3106-3113.e2. doi:10.1016/j.cub.2018.07.030

Marian, V., Blumenfeld, H. K., & Kaushanskaya, M. (2007). The Language Experience and Proficiency Questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech, Language, and Hearing Research: JSLHR*, *50*(4), 940–967. doi:10.1044/1092-4388(2007/067)

Mechelli, A., Crinion, J. T., Noppeney, U., O'Doherty, J., Ashburner, J., Frackowiak, R. S., & Price, C. J. (2004). Structural plasticity in the bilingual brain. *Nature*, *431*(7010), 757. doi:10.1038/431757a

Mitsuya, T., Samson, F., Ménard, L., & Munhall, K. G. (2013). Language dependent vowel representation in speech production. *The Journal of the Acoustical Society of America*, *133*(5), 2993–3003. doi:10.1121/1.4795786

Pallier, C., Colomé, A., & Sebastián-Gallés, N. (2001). The influence of native-language phonology on lexical access: Exemplar-based versus abstract lexical entries. *Psychological Science*, *12*(6), 445–449. doi:10.1111/1467-9280.00383

Paradis, J. (2001). Do bilingual two-year-olds have separate phonological systems? *International Journal of Bilingualism*, *5*(1), 19–38. doi:10.1177/13670069010050010201

Pierce, L. J., Chen, J.-K., Delcenserie, A., Genesee, F., & Klein, D. (2015). Past experience shapes ongoing neural patterns for language. *Nature Communications*, *6*. doi:10.1038/ncomms10073

Pitres, A. (1895). Aphasia in polyglots. In M. Paradis (Ed.) (1983), *Readings on aphasia in bilinguals and polyglots* (p. 26-49). Montreal: Marcel-Dieder.

Ribot, T. A. (1882). *Diseases of memory: An essay in the positive psychology*. New York: Appleton.

Schwartz, M. S. (1994). Ictal language shift in a polyglot. *Journal of Neurology, Neurosurgery, and Psychiatry*, *57*(1), 121.

Spivey, M. J., & Marian, V. (1999). Cross talk between native and second languages: Partial activation of an irrelevant lexicon. *Psychological Science*, *10*(3), 281–284. doi:10.1111/1467-9280.00151

Wartenburger, I., Heekeren, H. R., Abutalebi, J., Cappa, S. F., Villringer, A., & Perani, D. (2003). Early setting of grammatical processing in the bilingual brain. *Neuron*, *37*(1), 159–170. doi:10.1016/S0896-6273(02)01150-9

Appendix A

Table 1

Participant Demographics and Responses to the Language Experience Questionnaire

Code	Gender	Language Order	AoA French	Proficiency Score
p01	g1	English/French	Na	8.67
p02	g1	French/English	0	10
p03	g2	English/French	12	9
p04	g2	English/French	5	8.67
p05	g1	French/English	5	8.67
p06	g2	French/English	7	6.67
p07	g2	English/French	6	6
p08	g2	French/English	5	7.33
p09	g1	English/French	13	6
p10	g2	French/English	6	7.33
p11	g2	English/French	6	7.67
p12	g1	French/English	4	9
p13	g1	English/French	6	6.67
p14	g1	French/English	11	6.33
p15	g1	English/French	5	8.67
p16	g1	French/English	0	9.67
p17	g1	English/French	5	9.33
p18	g1	French/English	6	7.67
P19	g1	English/French	0	8.67
p20	g1	French/English	Na	5.5
Mean			5.67	7.96

Note. NaN indicates that these data points were not collected from participants. AoA refers to age of acquisition. g1 indicates female and g2 indicates male.

Appendix B

Language Experience Questionnaire

Subject Code: Age:	Date:

List the languages you speak.

At what age did you begin learning French?

At what age did you begin learning English?

What languages did you speak at home when you were a child? Specify any regional accent (e.g., Quebecer).

In which languages have you studied?

On a scale of 1 to 10, rate your proficiency level for each of the languages spoken.

1 = beginner, 5 = functional, 10 = native language.

Language	Score (1 to 10)

(Scale: 1 = beginner, 5 = functional, 10 = native language.)

On a scale of 1 to 10, indicate your proficiency level in speaking, understanding, and reading FRENCH:

a) Speaking:

b) Understanding spoken language:

c) Reading:

On a scale of 1 to 10, indicate your proficiency level in speaking, understanding, and reading ENGLISH:

a) Speaking:

b) Understanding spoken language:

c) Reading:

On a scale of 1 to 10, indicate your proficiency level in speaking, understanding, and reading Spanish (indicate another language, if applicable):

a) Speaking:

b) Understanding spoken language:

c) Reading: